Knowledge infrastructures for just urban futures

A case of water governance in Lima, Peru

Fenna Imara Hoefsloot

Knowledge infrastructures for just urban futures: a case of water governance in Lima, Peru

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Table of Contents

Information on publications and co-authorship i

Acknowledgements iii

List of figures ix

List of tables xi

Chapter 1: Introduction 1

1.1 Discontent in Lima’s water distribution 2

1.2 Urban infrastructure: a relational view 7

1.3 Water governance and the Peruvian city 19

1.4 Research methodology...25

1.5 Positionality 35

1.6 Structure of the thesis 42

Chapter 2: The datafication of water infrastructure and its implications for (il)legible water consumers 45

2.1 Introduction 46

2.2 Conceptual approach 49

2.3 Methodology...54

2.4 Results: Practices of legibility-making...56

2.5 Interpretation: Degrees of (il)legibility and their effects on water provision and consumers 70

2.6 Conclusion 74

Chapter 3: Expert-amateurs and smart citizens: how digitalisation reconfigures Lima’s water infrastructure.. 77

3.1 Transitioning from fragmented towards integrated infrastructure 78

3.2 Methodology...83

3.3 Results..87

3.4 Agency and self-determination within digitised infrastructure 99

3.5 The peripheralisation of the non-digital 102

Chapter 4: An emerging knowledge system for future water governance: sowing water for Lima 104

4.1 Introduction 105

4.2 Theoretical Framework 106

4.3 Context, methods and positionality 112

4.4 The encounter between modern-scientific and indigenous knowledge 116

4.5 (A)Symmetric hybridisation of knowledge systems 130

4.6 Conclusions 136

Chapter 5: Eliciting design principles using a data justice framework for participatory urban water governance observatories 138

5.1 Introduction 139

5.2 Datafication of the water sector 141

5.3 Data justice and the participatory urban observatory 143

5.4 Methodology 151

5.5 Review of literature on participatory urban observatories 154

5.6 Analysis of participatory urban observatories used in practice 163

5.7 Towards design principles for just participatory urban observatories for water governance 171

5.8 Conclusions 175

Chapter 6: The *Observatorio Metropolitano de Agua para Lima-Callao*: a digital platform for water and data justice 177

6.1 Introduction 178

6.2 Developing citizens' observatories 181

6.3 Methodology 184

6.4 The design of the Observatorio Metropolitano de Agua 191

6.5 Concluding remarks and next steps 199

Chapter 7: Conclusions **204**
7.1 Knowledge infrastructures for just urban water governance 205
7.2 Main contributions to theory 218
7.3 Recommendations for practice 226
7.4 Opportunities for future research 229
Bibliography **232**
Appendix 1: Data overview **271**
Appendix 2: Interview Guides **279**
Appendix 3: Focus group guides **283**
Appendix 4: Code books **291**
Appendix 5: Methods structured literature review **297**
Summary **309**
Samenvatting **316**
Resumen **323**
Author biography **331**

List of figures

Figure 1.1 Aerial image of Lima........ 18

Figure 1.2 Map of fieldwork locations........ 31

Figure 1.3 Overview of four key fieldwork sites in Lima........ 32

Figure 1.4 Relationship between the three sub-projects within this thesis........ 42

Figure 2.1 Newly urbanised area in José Carlos Mariátegui........ 58

Figure 2.2 The SCADA control room at the La Atarjea water treatment plant........ 63

Figure 2.3 Truck with water tank (camión cisterna)........ 69

Figure 3.1 Aerial and street views of the three research areas........ 84

Figure 3.2...... Poster on the communal wall in quinta, keeping track of the payments for the water bills........ 91

Figure 4.1 Conceptual framework for the encounter between the Andean knowledge systems (AKS) and modern-scientific knowledge systems (MSKS) in water governance........ 111

Figure 4.2 A restored amuna........ 113

Figure 4.3 Map of the research region........ 115

Figure 5.1 Applied data justice framework for participatory urban observatories. Based on the three pillars of the data framework........ 151

Figure 5.2 Overview of the publication years, case study locations, initiators, and thematic focus in the structural review of the academic literature and the observatories in the field of water........ 154

Figure 5.3 Analysis of urban water observatories from practice........ 170

Figure 6.1 Workflow and methods followed in the development of the MWO **187**

Figure 6.2 Schematic representation of the ‘noise’ added to the data coordinates to protect residents’ location privacy via geo-indistinguishability **198**

Figure 6.3 Screenshot of the MWO prototype **200**

List of tables

Table 1.1 Overview of the different actors and perspectives covered throughout the first three empirical chapters. Drawing on conceptualisations of Jasanoff (2017) and Bijker (2010). **27**

Table 2.1 Conceptual overview of commonalities and differences between legibility-making in the high-modernist city (Scott, 1999) and legibility-making in the smart city. **53**

Table 2.2 Summary of the identified types of water consumers that emerge from the datafication of the water infrastructure. **72**

Table 4.1 Elements of the Andean knowledge systems (AKS) and modern-scientific knowledge systems (MSKS). **131**

Table 5.1 Categorisation of participatory urban observatories (POU) resulting from the review of cases in academic literature **164**

Table 5.2 Data justice informed principles for designing participatory urban observatories (PUO). **172**

Table 6.1 Summary of the requirements for the functionalities for the MWO, drawing from the online focus groups with residents. Table adapted from Jimenez, Hoefsloot, et al. (2022). **193**

Table 6.2 Implementation of data justice design principles (as formulated by Hoefsloot, Jimenez, et al., (2022) based on Taylor's (2017) data justice framework) in the *Observatorio Metropolitano de Agua*. **194**

Chapter 1:

Introduction

1.1 Discontent in Lima's water distribution

Every day, engineers work for Lima's drinking water and sewage service (*Servicio de Agua Potable y Alcantarillado de Lima*, SEDAPAL) to capture, treat, and distribute water to the city's residents and industry. On average, 24m^3 of water flows from Lima's water treatment plants to its consumers every second (SEDAPAL, 2022). Through an intricate system of larger and smaller pipes, valves, and pumps, Lima and Callao's 50 districts and 473 hydraulic sectors are serviced. At parts, this network still follows the trajectory of the water distribution system as constructed by the Spanish colonisers in the 16th century (Bell, 2015). The exact numbers of how much water enters each hydraulic sector, which valve is open or closed, how high the water pressure is, and if domestic or commercial consumers have paid their bills are all monitored in the digital dashboard installed in La Atarjea, Lima's main water treatment plant and the head office of SEDAPAL. The work SEDAPAL's engineers do in operating this complex system is absolutely crucial in supplying the metropolitan area of Lima-Callao with water.

Yet, despite this impressively engineered system and continuous labour, up to 2019, it took SEDAPAL, on average, 10.4 years to install water and sewerage services in unplanned neighbourhoods and almost one million people residing in Lima and Callao are not connected to SEDAPAL's water distribution system (SEDAPAL, 2022). An even higher number of people only receive water for limited hours per day, only a couple of days per week.

In public opinion, SEDAPAL is seen as unwilling or incapable of improving. In 2012, 2016, and 2019 residents took to the streets to protest plans to privatise the water service provision and express their dissatisfaction with the current water policy (El Comercio, 2016, 2019; Jiménez, 2012). More recently, in October 2021, a group of residents of San Juan de Lurigancho, Lima's most populous and poorest district, marched in protest of the lack of maintenance on the water pipes in the area. The direct trigger was that residents had received a higher water bill than usual, while the water supply had been cut or limited for 11 days during September and the first weeks of October 2021 (El Comercio, 2021), but these protests have to be understood in relation to the broader sense of injustice felt by significant parts of Lima’s population due to the unequal water distribution in the city. The water infrastructure is full of discontent and controversy.

Traditionally, SEDAPAL has responded to these protests by emphasising its efforts to become more efficient. Through large-scale maintenance and repair projects funded by multi- or bilateral organisations such as the World Bank and the Japan International Cooperation Agency (JICA) and the implementation of digital infrastructure to monitor the water distribution system, SEDAPAL aims to respond faster to breakdowns and reduce leakages in the system. In this thesis, I zoom into the digital infrastructure implemented and its contribution toward just urban water governance.

Datafication - the transformation of something, for instance, social activities, objects and their characteristics, or natural phenomena, into quantitative data through diverse actors, methods, and technologies which allows it to be recorded, analysed, and reorganised (Mayer-Schönberger & Cuckier, 2013) - is frequently attributed a key role in urban change and resource management. The datafication of the water infrastructure through the supervisory control and data acquisition (SCADA) and the implementation of sensors in the water distribution system and recording water as data, it is possible to monitor the flow and pressure of the water without physically being present in different locations. Whereas SEDAPAL was previously dependent on valve operators to monitor, control, and regulate a specific segment of the water infrastructure, the introduction of the SCADA system allows these processes to be carried out remotely from a central location. As a result of these developments in digital infrastructure and datafication, SEDAPAL has significantly reduced the percentage of 'non-revenue water' - the primary indicator of the economic efficiency of the water distribution system - from 44% in 2000 to 28% of the water produced in 2021 (SEDAPAL, 2022). This is no small feat.

Within the context of discontent between SEDAPAL and urban water consumers, there are at least three promises of modernity (Harvey & Knox, 2012) that the digital infrastructure (i.e., the SCADA system) seems to instantiate: the promises of seeing, control, and economic efficiency. These promises, at first glance, engage with problems that Lima's residents face. The promise of seeing makes it more transparent where water flows within the city and whom it reaches. The promise of control engages with the issue of continuity and reliability in service provision. Finally, the promise of economic efficiency speaks to the continuous critique that the water authority, as a public institution, is excessively bureaucratic.

However, as I will analyse in the following chapters of this thesis, while the digital infrastructure improves seeing, control, and efficiency for SEDAPAL, this does not automatically lead to improvements in the water distribution system for all residents. In effect, it introduces new differences between consumers, excludes labour and knowledge, and prioritises operational efficiency over justice.

The unequal distribution of water, where some have plenty while others lack access to sufficient, safe, and affordable water, generates a powerful sense of injustice amongst Lima's marginalised communities. For the communities awaiting water connections, or the people taking to the streets to protest, the urgency for expanding the distribution system and providing adequate public water infrastructure is related to the wish for social and urban transformation. A few voices occasionally call for alternative approaches to improving the water distribution system, such as decentralising the water distribution system into more small-scale autonomous systems, more nature-based solutions, or switching sources from surface and groundwater to desalinated ocean water (Criqui, 2020; SEDAPAL, 2022). Nevertheless, all voices depart from the incontestable recognition shared across districts and socioeconomic classes that water access is a necessary and fundamental good. And, despite the context of discontent and prolonged struggle, Lima's urban and rural residents ultimately cultivate hope through their strategies for expanding, diversifying, restructuring, maintaining, or resisting the water and digital infrastructure.

Therefore, this dissertation aims to understand how knowledge infrastructures – understood here as a sociotechnical system for generating, distributing, mobilising, and contesting knowledge - may play an important role in stabilising or rearranging unjust orders within the city. Luque-Ayala and Marvin (2015, p. 2108) state that, in critically researching digital transformation and smart urbanism, one of the main challenges is 'the analysis of the social and political implications of implementing smart logics – both materially and discursively – and examine how specific urban conditions enable and constrain SU [smart urbanism] transitions, and to co-produce alternative pathways.' This thesis responds to this challenge by paying attention to the active role of residents in the process of datafication and by analysing the knowledge infrastructure implemented within the context of the wider hydrosocial inequalities. This dissertation addresses these dynamics by tackling the following research question:

How can knowledge infrastructures support just urban water governance?

This question is answered using a multi-method, multi-perspective, and multi-scalar approach. While the first empirical sections of the dissertation primarily draw on the qualitative modes of inquiry at different scales, the later sections of the thesis employ review methods and collaborative design science to inform the development of a digital artefact. In doing so, it moves from conceptual analysis to design science as applied in action research to theorise about the potential of knowledge infrastructures to support more just water governance in Lima. We thereby understand just water governance as the collective of administrative, material, political, and social systems that work towards the fair allocation of water and the recognition of the social, political, and epistemological dimensions of water (Zwarteveen & Boelens, 2014). To research these dynamics, this thesis is multi-scalar and moves beyond the metropolitan level to understand the relationship between knowledge, infrastructure, and water governance on the regional and neighbourhood scale.

As this dissertation is explicitly situated in, and particular to, the context of Lima and the region and engages with the diverse expressions of smart urbanism in the Global South (e.g., Amankwaa et al., 2021; Datta, 2018; Sultana, 2020; Taylor & Broeders, 2015), it contributes to expanding the range of urban contexts within which smart urbanism is emerging. Within this research, the city is not a passive backdrop. Instead, its residents intervene, enable, resist, adapt, and transform the city in various ways.

The introductory chapter continues as follows. First, I will situate this dissertation in the broader scholarship on urban (digital) infrastructures and smart urbanism. In this theoretical framework, I describe our approach to urban infrastructure as relational and processual. It is an arrangement of, amongst others, pipes, valves, pumps, institutions, water, sensors, people, documents, data, algorithms, conventions, and knowledge shaped by contingencies and continuities. By combining insights from smart urbanism, critical geography, and science and technology studies, this research intends to analyse the social, political, and material implications of the infrastructural works. Second, I will elaborate on the overall research design and important methodological considerations. This includes a description of the three main communities in the metropolitan region of Lima with whom I collaborated in this dissertation: José Carlos Mariátegui, Barrios Altos, and Miraflores. Finally, I will detail how the empirical chapters of this thesis are structured and relate to each other.

1.2 Urban infrastructure: a relational view

Today, urban governance, understood as the regimes of decision-making and coordination between state and non-state actors for the planning, development, and management of urban space and life (Gupta, Pfeffer, Ros-Tonen & Verrest, 2015), is increasingly reliant on the production of digital data for decision-making, and the urban society, materiality, and economy are intertwined with coded algorithms (Shaw & Graham, 2017; Datta, 2018). Urban operational processes such as water distribution and traffic control are digitised with the expectation of making their measurement and monitoring more efficient and equitable (Amankwaa et al., 2021). Specifically, with regard to urban infrastructures, supervisory control and data acquisition (SCADA) systems have been extensively rolled out in cities globally to monitor and control flows in water, traffic, and electricity grids (Kitchin & Dodge, 2017). Essentially, current SCADA systems entail the implementation of sensors in non-digital technologies, which are connected through software that allows the registration and monitoring of measurements. The sensors applied to the infrastructure measure the volume of the water at any single time and at multiple locations within the system. Together, these single measurements produce large data sets that record the water volume in the complete system in near real-time. Like other 'smart city' technologies, these SCADA systems have become increasingly autonomous in that they currently allow for automated interventions to change settings in the system.

To understand the implications of these changes for the city and the just distribution of urban resources, we must look at the transformation of the infrastructure through the introduction of digital elements.

Smart city technologies and approaches are characterised by a strong belief in technology as inherently good (Verrest & Pfeffer, 2018). It is argued that new opportunities for big data and crowdsourced information may create possibilities for more open, complete, and democratic data collection (Elwood, 2008; McFarlane & Söderström, 2017). Moreover, the developments in computing and measurement technologies that have allowed for the generation and analysis of big data have spawned the idea that, with sophisticated and reliable technologies, it would be possible to reduce human idiosyncrasies in the management and governance of urban flows (Taylor & Richter, 2017).

As will be elaborated in the following sections of this theoretical framework, drawing on scholarship in smart urbanism, critical (feminist and decolonial) geography, and science and technologies studies can help further our understanding of infrastructure and the city. In particular, approaching urban infrastructure as relational enables us to see how infrastructure mediates, is emergent from the relations between ideas, people, and materials, and how it structures daily urban life in political ways. As a first step towards understanding the complex relationship between urban resource distribution, physical infrastructure, and smart elements, I want to zoom in on the relationship between humans and technology and, precisely, the mediating roles of infrastructure.

1.2.1 The mediating roles of infrastructure

Latour (2005) makes a distinction between intermediaries and mediators, which is useful in thinking about the different roles of infrastructure in relation to society (Kathiravelu, 2021). Firstly, infrastructure can function as a tool, an intermediary, with an input and an output. For example, infrastructure can facilitate the transport of goods, information, or people. Secondly, infrastructure mediates. In connecting and disconnecting, infrastructure categorises, transforms, distorts, or modifies the network and the meanings ascribed to elements within the network (Star, 1999). For example, being incorporated in the cadastre - a spatial data infrastructure - can transform an auto-constructed dwelling into personal property or real estate (Holston, 1991).

To understand this mediating property of infrastructure, I turn to the philosophy of technology. In the philosophy of technology, there have been two main approaches to defining what technology is and how people relate to it. Verbeek (2005, p. 11) explains:

> 'the first is the instrumentalist view that technology is a neutral means to achieve human goals be they good or evil; the second is the substantivist conception that technology is not neutral but a determining and controlling influence on society and culture.'

The instrumentalist view of technology was inspired by modernism in its focus on the functionality of technology: technology, in any shape or context, is considered to be a tool that serves human action. This aligns with Latour's (2005) conceptualisation of the intermediary.

As a reaction to the instrumentalist view of technology, the substantivist view argues that technologies do not merely contain functions but also bear meanings and structure our lifeworld (Verbeek, 2005). Rather than considering technology as a neutral tool or a controlling structure, we can best view technology as a mediating presence. Verbeek (2008) draws on the work of Don Ihde (1990) to describe four types of mediation: embodiment, hermeneutical, alterity, and background. Together, these forms of mediation capture the ways we relate to technology either as something that we have incorporated as extensions of our bodies (embodied); the instruments through which we assess and interpret what is around us, making visible what is otherwise invisible (hermeneutic); as entities we interact with and which perform tasks (alterity); and forming the context in which we live (background).

Recognising the mediating roles of technology entails acknowledging that people, technology, and the environment cannot be approached in isolation (Verbeek, 2008). This insight supposes an ontological turn in which we move away from categorising between human and non-human, subject and object, ideas and matter, and towards seeing the world-building capacities in their relations (Latour, 1992). In other words, rather than separating people, technology, and the environment in which they are placed, the concept of mediation makes visible the many relations between them (Verbeek, 2008). For example, Georgiadou and Reckien (2018) explain how geo-information technologies such as remote sensing give us new perspectives and help us recognise problems that would otherwise not have been seen. By doing so, the geo-information technology hermeneutically mediates the way we perceive our environment.

Giving ontological priority to relations rather than materiality has been fundamental in conceptualising infrastructure (Karasti et al., 2016). Similar to technology, infrastructure is a fundamentally relational concept. However, whereas technology is also present when not put in action, infrastructure exists only as relational (Star & Ruhleder, 1996). A collection of pipes, water bodies, treatment plants, and valves only becomes infrastructure when they connect and relate to each other. Infrastructure's mediating role is therefore expressed in how it structures and is structured by its installed base, links with specific communities of practice, and the norms it embodies (Star & Ruhleder, 1996).

1.2.2 Infrastructuring the city

Within urban geography, this turn towards a relational ontology has resulted in an increased interest in the socio-materiality of the city and an expanding body of scholarly work providing rich analysis of the social and political nature of infrastructure (e.g., Criqui, 2020; Loftus, 2007; Luque-Ayala & Marvin, 2015; Niranjana, 2022). In this strand of urban research, infrastructure forms the support, or the essential fundament, for urban practice (Milan & Treré, 2019). Enmeshed in daily life, infrastructure allows for the interaction between nodes within the city. It facilitates the flow of water, electricity, people, goods, data, and ideas.

However, Graham and Marvin (2001) argue that urban research and practice have commonly envisioned city infrastructure as apolitical, binding 'public goods.' They state that this approach is blind to the messy ways infrastructure is bound to normative aspirations for the city (Graham & Marvin, 2001). As infrastructure prioritises certain connections – e.g., geographically proximate groups – over others, they can be at once binding and differentiating and expose the socially, spatially, and materially unjust outcomes of planning and design decisions (Kathiravelu, 2021; Nganyanyuka et al., 2018). This mediating capacity of infrastructuring is at times used strategically - such as the building of a highway that increases settler mobility in occupied Palestinian territories (Salamanca, 2015) or undermining the claims of slum-dwellers to drinking water reserves resulting in a situation of 'hydrological apartheid' in Mumbai (Graham et al., 2015). At other times differentiated access was unforeseen, often through the realisation that the real-life use of the infrastructure did not resemble the pre-existing blueprint (Simone, 2015).

To understand how infrastructure mediates within the city, we must consider its relational characteristics and approach it as a process rather than a product. As the foundation on which the city is built, infrastructure has constantly defined and redefined the development of urban areas and their people. However, contrary to what the word 'structure' implies, urban infrastructure is not static. The moment infrastructure is used, for example, when a water tap is opened, a jack is plugged in, or a road is maintained, new elements are added to the structure of the infra. Urban infrastructure is, therefore, constantly in-the-making. To emphasise this processual character of infrastructure, scholars have used the term 'infrastructuring' (Bowker et al., 2007; Karasti et al., 2016). Thinking about infrastructuring rather than infrastructure forces us to think in terms of flows that gradually change over time rather than fixations. Unpacking the ways infrastructure comes about and exploring how infrastructuring works gives an insight into the emergence of the tangled and 'thrown together' city (Amin & Thrift, 2017). In other words, understanding the process of infrastructuring is crucial for knowing the city (Pfeffer, 2018).

However, understanding infrastructuring is not an easy task. As Karasti et al. (2018) and Pfeffer (2018) bring forth, infrastructuring is the process in which different knowledges, humans, and artefacts align in creating a network that keeps evolving. Star and Ruhleder (1996, p. 113) define infrastructure as emergent from eight dimensions: (1) it is embedded, (2) it 'invisibly supports tasks,' (3) it reaches beyond scale and scope, (4) it is 'learned as part of membership,' (5) it 'shapes and is shaped by conventions of a community of practice,' (6) it 'embodies standards,' (7) it is 'built on an installed base,' and (8) it 'becomes visible upon breakdown.' Infrastructuring is thus emergent from the relations between ideas, people, and materials, without absolute boundaries and with the tendency to sink into the background until we (are forced to) consciously engage with it.

The characteristic of infrastructure being embedded and invisible until a moment of breakdown was demonstrated on the 13th of January 2019, when a sewerage pipe broke in the lower area of San Juan de Lurigancho, a district in Lima. It was estimated that more than 1500 people had been affected by the sewerage water that had flooded their homes, stores, and streets for three days (Flores, 2019). This event happened without warning, but later reconstructions indicated that the most likely explanation for the sudden rupture was the recent construction of an elevated metro station right above the main sewerage pipe. The weight of the station had caused deformities in the sewerage pipe, making it more vulnerable to blockage and pressure. Additionally, secondary water and sewerage pipes were relocated to create space for the metro station, affecting the in and outflow of water. Together, these constructions have most likely increased the pressure in the pipe and ultimately led to the rupture. The rupture also brought attention to the fact that the metro had been constructed by the Brazilian company Odebrecht - now known for their illegal payments to gain concessions for large-scale infrastructure projects throughout Latin America (Martinez Encarnación, 2019)– raising questions about the quality of the construction and the role of Lima's public officials in supervising the work. This event not only illustrates how little was known about what was happening below ground with the mounting pressure on the tubes until the moment of breakdown but also how various transport, water, financial, and political infrastructures and their relations were made visible through the process of 'infrastructural inversion' in which the background becomes the foreground, and the embedded structures and relations become visible, giving us an insight into its workings (Bowker et al., 2007; Star, 1999). As Purwar et al. (2020) point out, a breakdown can expose the interconnectedness of multiple infrastructures and can lead to long-lasting, cascading disruptions.

In general, in Lima, a city characterised by what Fernandez Maldonado (2008) refers to as 'reverse urbanisation,' infrastructure development rarely follows the planned trajectory. Past urban development often exposes the infrastructural plans that were never fully realised, frequently built on capitalist and modernist dreams. At times, these infrastructures and the anticipation they hold are openly visible, such as the never entirely constructed overfly bridges scattered along the Costa Verde. These were designed to integrate the beach with the districts on the cliffs but now form a series of disconnected staircases scattered along the coast. In other instances, the anticipated futures are only visible on paper. For example, the zoning plans once made for the district Pachacútec, in which planners had delineated roads, parks, and schools, anticipating organised urban development for the middle class. In practice, the middle class was not interested in moving to the city's far north, and the urban poor occupied the land, rezoning it according to their own logic and incrementally building their homes, neighbourhoods, and infrastructures.

These forms of breakdown, maintenance, repair, or appropriation are moments in which the pre-existing condition, or the installed base of the infrastructure, can be negotiated (Castán Broto & Bulkeley, 2015; Karasti et al., 2016). They are also the moments that illustrate how people participate in the process of infrastructuring (Ribes & Finholt, 2009). However, while acknowledging the tendency of infrastructure to become embedded and invisible, Truelove and Ruszczyk (2022) point out that rupture and breakdown only cause the public visibility of infrastructure. The infrastructure has always been visible to the people who were formally or informally actively part of constructing it. In their interrogation of the bodily and social lives of infrastructure, Truelove and Ruszczyk (2022) show how people and their labour are essential in linking fragmented infrastructures and service provision, although often without acknowledgement.

1.2.3 The political life of everyday infrastructure

Thinking through the concept of infrastructuring as relational and processual opens up analytical space to consider the politics within the everyday practices of infrastructuring. Paraphrasing bell hooks (1991): theory serves as a tool to imagine radically different futures. It is a space where we can critically question the status quo, the 'normalcy' of how things are arranged in society and the city, chart new ways for urban development, and make just practice possible. However, if theory does not represent or engage with daily life and on-the-ground practices, it serves no purpose (hooks, 1991).

Urban residents are embedded in multiple material infrastructures and more immaterial forms of infrastructure, such as social networks, urban master plans, or discourses about the right to water and citizenship (Kathiravelu, 2021). Various scholars have researched the relationships between infrastructure, bodies, and the state and how these shape everyday urban lives (Anand, 2017; Pilo', 2017; Simone, 2004; Truelove, 2019; Truelove & Ruszczyk, 2022). Focusing on the everyday is a move away from trying to locate power and pay more attention to the situated moments wherein infrastructure engages and enacts social relations and the (un)settling of these dynamics. By researching the mundane rather than the monumental, I give prominence to the people, places, and knowledges consistently excluded in dominant narratives regarding the promises that infrastructures evoke.

Sultana (2020) calls for understanding the relationships between infrastructure development and everyday life through an explicitly intersectional lens. Intersectionality, as an epistemic and analytical approach, draws on Black and queer feminist movements, which have stressed how configurations of racism, sexism, classism, and ageism exercise specific forms of oppression on each individual body (Ahmed, 2017). Intersectionality is an important notion because it forces us to examine how specific norms inscribed in technology and infrastructure can prescribe different forms of behaviour depending on one's societal position and multi-layered identities. In fields such as infrastructure engineering and smart urban development, turning to critical geography and, specifically, the work of decolonial feminist thinkers can help us better understand how daily struggles over resource access and distribution, visibility in data, and representation in decision-making, are tied to ongoing struggles over social and environmental justice, identity and power (Álvarez & Coolsaet, 2020; D'Ignazio & Klein, 2020; Mattern, 2021; Ricaurte, 2019).

For example, through the analysis of the role of women slum-dwellers in Dhaka, Bangladesh, in securing and managing water infrastructure, Sultana (2020) illustrates how the material infrastructure meshes with various forms of oppression based on class, race, gender, and citizenship status. The lack of water infrastructure has come to symbolise the disenfranchisement of the vulnerable within the state (Sultana, 2020). On the opposite side, we find that infrastructure tends to privilege already powerful actors, thereby hard-wiring their position within the city (Collective, n.d.). These dynamics highlight how issues of citizenship, consolidation, and urban integration have become mediated through infrastructure and how infrastructure enables residents to make a claim to the city and its resources (Anand, 2017; Sultana, 2020).

Likewise, in Lima, diversity is structured and ordered through social and material boundaries. Since the '60s, Lima's informal and incremental urbanisation pattern has inspired urban planning theory. Led by the work of Turner (1968), the auto-construction of the expanding neighbourhoods of Lima served to reframe informal urbanisation from problem to potential solution. This departs from the observation that, if provided opportunity and support, communities can successfully auto-construct living spaces and urban infrastructure according to their needs, incrementally and progressively consolidating their place in the city (Turner, 1968). Although this process has been successful to varying degrees in the earlier constructed neighbourhoods, there is a general recognition that this type of urbanisation is unsustainable for the future as it often results in socially segregated communities on terrains which are difficult to connect to essential infrastructure and prone to landslides (Fernandez Maldonado, 2015). Nevertheless, as Fernandez Maldonado (2015) writes, there is a lack of public policy to create a viable alternative, resulting in tension between planning and practice.

An example of socio-spatial segregation is the literal wall between one of Lima's wealthiest suburbs and the neighbouring organically built district (Figure 1.1). In colloquial speech amongst Lima's residents, this wall is referred to as *el muro de la vergüenza* (the wall of shame). It runs for 10km, separating the rich and poor living on two sides of the same hill. Zooming in on the left side of the photo in Figure 1.1, you can see the private pools of the urban rich in Lima and the public and private green areas needing artificial irrigation. On the right side of the image, you can see part of the expansive newly urbanised areas within the district of San Juan de Miraflores. On the right side, people are frequently not connected to the water infrastructure. This is one of the starkest, most visual examples of the infrastructural injustices in Lima.

I use the word injustice here to emphasise how this unequal water distribution is not simply a misfortune or the normal order of things. Instead, it is an inequality rendered injustice due to its structural and enduring character, a negligence to intervene by those in power, and the silent acceptance by the privileged class (Shklar, 1990). This aligns with Moroni (2020), who explains how justice needs to be discussed in relation to issues that depend on humans for their existence and agency. Regarding injustices in the city or the water distribution system, this means we have to see them in relation to the governance configurations that have allowed this situation to arrive and which did not (successfully) intervene to right this wrong (Moroni, 2020). Accordingly, researching how knowledge infrastructures can support just urban water governance requires unpacking and questioning the 'normal order' within the infrastructural system and paying attention to how hydrological injustices are created, experienced, and practised through everyday interactions (Rusca & Cleaver, 2022).

Figure 1.1 Aerial image of Lima. The middle line separating the villas on the left from the auto-constructed houses on the right is the 'wall of shame' seen from the sky. Image from Google Earth Version 9.165.0.1, (March 28, 2021). Lima, Peru, 12°07'21"

The injustices experienced in Lima's water distribution system make it an important case to explore the potential for knowledge infrastructures to contribute to more just water governance. Grounding the theoretical approach discussed in practice, the following section introduces the context of water governance in Peru and Lima.

1.3 Water governance and the Peruvian city

In 2009, the Peruvian water law was reformed, transferring the responsibility for water governance from the national to the local water authorities (Autoridades Locales de Agua, ALA), which operate on the river basin level. This law states that all water policies should be formulated in a participatory and integrated manner (Hordijk et al., 2014). Following these reforms, Hordijk et al. (2014, p. 138) argue that Peru's current political approach to water is best categorised as seeing water as ‘a public good with socio-cultural, economic and environmental value.’ Nevertheless, Criqui (2020) stresses the dissociation between political discourse, policy, and daily practice in Peru’s water management.

Since the Fujimori governments of the '90s, Peruvian water governance has been characterised by neoliberal policy and divestment in an attempt to privatise the state-owned water companies (Ioris, 2012b). It was argued that privatisation would increase the efficiency of the water sector and reduce the price of water due to market competition (Criqui, 2015; World Bank, 2016). However, as described at the beginning of this introduction, the plan to open the water sector to the economic market was strongly opposed, mainly by citizens of peripheral, newly urbanised neighbourhoods. By the same token, the troublesome examples of water privatisation in other cities in Latin America reduced the private sector's interest in taking up this task (Ioris, 2016). This resulted in a lack of political will to pursue privatisation and the abandonment of the goal (Fernandez Maldonado, 2008; World Bank, 2016).

While the political discourse has taken a more pro-poor stance, particularly in the context of the *Agua para todos* (water for all) campaign during the Alan García administration, policy and daily practice have continuously followed a more neoliberal trend, favouring conventional economic indicators such as network expansion and non-revenue water over alternative, pragmatic, approaches to service the urban poor (Criqui, 2020).

Contrary to the other regions of Peru, where the 2009 water legislation has officially transferred the responsibility for water management to the regional government bodies and local river basin councils, in Lima, the authority and resources remain with the national ministries (Filippi et al., 2014). Miranda Sara (2021) describes the water governance configuration in Lima as an 'institutional spaghetti' to convey how the relationships between the different organisations involved in water governance have become fragmented and entangled simultaneously. This starts with the fact that SEDAPAL, the public company which provides water and sewage for the metropolitan city of Lima-Callao (itself consisting of two cities spanning two provinces and divided into 50 district municipalities), remains under the dual responsibility of the Ministry of Housing, Construction and Sanitation, and the National Fund for Financing Economic Activities of the State. This has been possible due to a legislative decree passed by then president Ollanta Humala in 2015, which reiterated a previously existing law granting power to the national government, through the Ministry of Housing, Construction and Sanitation, as the governing body of the sanitation sector, and making it responsible for designing, regulating, and executing national sanitation policies and granting exploitation rights to providers of water and sanitation services (Decreto Legislativo N°1240, 2015). The Ministry of Housing, Construction and Sanitation can delegate these responsibilities to provincial governments, which has been done for all provinces except Lima and Callao.

In addition to this governmental and legislative fragmentation, Lima's water supply is also fragmented. Lima depends on three river basins for its water supply, the Chillon, Rimac, and Lurin rivers (see Figure 1.2 in section 1.4.2 and Figure 4.3 in chapter 4). While an inter-river basin council has been set up to facilitate the coordination between these territories, they are primarily governed by the local water authorities. As a result, the metropolitan and district municipalities have little to no voice in the policies of SEDAPAL and urban water governance (Hordijk et al., 2014).

One of the effects of the 'institutional spaghetti' is the fragmentation of the knowledge base within the water sector. Knowledge about water derived from data on water production, consumption, and quality is dispersed among actors and rarely codified and shared with other institutions (Filippi et al., 2014). Filippi et al. (2014) argue that knowledge is considered powerful leverage to maintain the current status quo in Peruvian water governance structures and the vested interests of the urban rich (Ioris, 2016), mining companies (Filippi et al., 2014), or hydropower plants (Hommes & Boelens, 2017). They conclude that ‘fostering knowledge integration in a way that emphasises the legitimacy of the different understandings, different concerns and hence different solutions might be a first step in challenging this power asymmetry as a trigger for transformation’ (Filippi et al., 2014, p. 545).

Previous research has addressed the power asymmetry in the knowledge informing water governance in Lima from different perspectives. For example, international research projects ReMap Lima and CLima Sin Riesgo have combined aerial imagery, 3D digital models, and participatory methods to map the different understandings and experiences of urban risks, including water security, in two districts of Lima (Allen et al., 2017; Lambert & Allen, 2016). By creating counter cartographies, Lambert and Allen (2016) present an alternative narrative of the city that visualises residents' daily challenges concerning water access. These maps stand in critical dialogue with the fragmented data shared by SEDAPAL.

While ReMap Lima and CLima Sin Riesgo focused on the everyday experiences of urban residents, others have analysed the role of knowledge from an institutional and metropolitan perspective (Ioris, 2012a, 2012b; Miranda Sara, 2021). Focusing on metropolitan water governance, Miranda Sara (2021) investigated how knowledge is produced and shared amongst institutions and actors. Her research elaborates on how knowledge and data are not neutral but are the product of *concertación* processes: an iterative and sensitive process of negotiation, contestation, and consensus-building between actors. Powerful networks, a lack of transparency, fragmentation, and the dominance of set discourses heavily shape this process and result in uneven participation and representation in the knowledge informing water governance policies in Lima (Miranda Sara, 2021). Lima's continued water governance challenges are symptomatic of the limited influence of the wider community within the judicial mechanisms, and attempts of collaboration between SEDAPAL, municipal government, and civil society actors are undermined by distrust between actors (Miranda Sara, 2021).

Additionally, several researchers have zoomed out and analysed Lima's water governance challenges in relation to the region, territory, and rural communities (see: Bleeker & Vos, 2019; Hommes & Boelens, 2017; Robert, 2019). Empirical studies into Lima's water governance from a political ecology perspective conclude how the dominant paradigm is defined by the 'glorification of engineering work' (Hommes & Boelens, 2017, p. 75) and formed through stakeholder consultation processes where marginalised groups are not included (Bleeker & Vos, 2019). Consequently, water governance in Peru has typically favoured neoliberal and technocratic interventions such as large-scale irrigation systems, water transfers, and hydropower plants over environmental, rural, and social concerns (Criqui, 2020; Hommes & Boelens, 2017).

Considering the scepticism of water officials towards discourses that propose nature-inclusive, communal, or indigenous approaches to water governance, valuable knowledge has been omitted in the current debates

(Vera Delgado & Zwarteveen, 2008). In response, Alencastre Calderón's (2012, 2013) work brings to the forefront the knowledge from marginalised urban and rural residents that are often overlooked or ignored. His research on ancestral water governance practices in the Andean highlands, or the tacit knowledge of Lima's urban dwellers regarding water management in the peri-urban areas, has been essential in bridging knowledge systems and opening up thinking about urban water governance beyond the dominant neoliberal frameworks.

The studies summarised above point toward the inherently political and contested nature of knowledge practices in Lima’s water governance across scales. These various research projects have in common the aim to correct the asymmetries in the knowledge applied to water governance in Lima and expose critical fault lines in how knowledge is generated and mobilised. Building on this work, this thesis explores three dimensions that are underrepresented in the current body of literature on water governance in Lima: (1) understanding the relationship between current digital infrastructures and the urban water governance system, (2) the different knowledge systems that contribute to water governance in the region, and (3) how we can contribute to just water governance by designing knowledge infrastructures. The following three sub-questions have been formulated to address these three dimensions and structure the empirical analysis of this thesis:

Q1: How do current data infrastructures challenge or reproduce unequal structures in Lima’s water governance?

The first sub-question pertains to the implementation of data infrastructures and how they challenge or reproduce unequal structures in Lima’s water governance. Considering how digitalisation has been a strategic priority for SEDAPAL in addressing water challenges, this sub-question attempts to unpack the relationship between the digital and water infrastructure and understand how it structures the relationship between the state and urban water consumers.

Q2: How do different actors and knowledge systems contribute to water governance in the region and Lima?

The second sub-question relates to the different knowledge systems contributing to water governance in the region. Research over the past decades has shown that there is much to be gained from the incorporation of tacit knowledge from indigenous, rural, and marginalised communities for water governance (Guevara Guillén et al., 2006; Miranda Sara & Baud, 2014). Yet, it was not until recently that we noticed an uptake of these perspectives in practice. This research aims to contribute to this dialogue between knowledge systems in theory through understanding how knowledge systems are hybridised, and in practice, by facilitating the exchange of knowledge through a digital participatory water observatory.

Q3: How can we design knowledge infrastructures that contribute to just water governance?

The third sub-question concerns the design of knowledge infrastructures to contribute to just water governance. The aforementioned literature (Lambert & Allen, 2016; Criqui, 2020; Miranda Sara, 2021) argues for a more deliberative and inclusive process for knowledge generation. In a similar sentiment, this thesis explores to which design principles knowledge infrastructures should adhere to contribute to more just data practices and water governance.

The remainder of this introductory section presents the methodological approach for addressing these sub-questions and researching the knowledge infrastructure for water governance in Lima from multiple scales and perspectives and with multiple methods.

1.4 Research methodology

The notion that infrastructure is relational and processual and should be studied as grounded in everyday urban life has important methodological implications. First, the relational character of infrastructure makes it difficult to methodologically delineate the research and scope of the object studied (Star & Ruhleder, 1996). Secondly, it implies doing fieldwork and observing how people interact with infrastructure on an everyday basis and getting to understand the creation of infrastructure through the relationships between human and non-human actors.

These two issues led me to follow a multi-scalar, multi-perspective, and qualitative multi-method approach. Each empirical chapter has its concise methodological section. The following section discusses the overarching methodological considerations and details how the empirical analysis and design relate to each other.

1.4.1 A multi-scalar, multi-perspective approach

The methodology in this research combines qualitative approaches in critical geography and science and technology studies (STS), actor-network theory (ANT), and social construction of technology (SCOT) research. Bringing together approaches from these research fields has particularly been helpful as a starting point for critical analysis of technological innovation, such as the use and implementation of digital technologies in water governance, as part of an emergent process created by the network of actors involved in infrastructuring and the region.

By tracing how relations between human and non-human actors are made, challenged, or unmade, STS, ANT, and SCOT allow for a detailed and situated description of the research subject and its context (Ruming, 2009).

Additionally, by adopting a topological rather than a topographical focus, these research approaches force the researcher to look beyond geographical boundaries that might, unrealistically, limit the complexity of the research subject (Ruming, 2009). Research in the fields of STS, ANT and SCOT has informed the perspective on infrastructure and technology as socially constructed (Akrich, 1992; Bijker, 2010), not neutral, and having agency to act back on society.

To unpack how the knowledge infrastructure in Lima's water distribution system is shaped, contains norms, and acts within the city, I approached the knowledge infrastructure from distinct points of view. Three main perspectives are considered in this research: the water company (SEDAPAL), the residents of Lima, and the rural community of San Pedro de Casta (Table 1.1) to represent different human actors in the network. These three actors have been chosen because they (i) hold distinct perspectives and positions within the water infrastructure and (ii) correspond to different units of analysis. By doing so, this research develops different narratives of infrastructuring. This allows us to analyse how the design of the infrastructure is negotiated, contested, and restructured and provides a better insight into how normative frameworks are (re-)inscribed into the fabric of the city.

By centring one of the three main actors of the network in each part of this research, it is possible to trace how certain viewpoints and ideas of actors are included in the infrastructure works while others are excluded. Here, I draw on Jasanoff's (2017) notion of the 'regime of sight' to conceptualise the relationship between each actor and the perspectives they represent. Jasanoff (2017) explains how knowledge generation is generally informed by a 'regime of sight' that dictates who is an authorised seer, what knowledge and political claims are considered truthful, and which discourses and practices are used to legitimise these claims. The 'view from nowhere' is that of the objective gaze, informed by modern-scientific methods for knowledge creation, and pertains to being outside of politics. The 'view from somewhere' is that of the tacit knower, whose knowledge is embodied and shared through experience. Finally, the 'view from everywhere' aims to represent and legitimise all perspectives and types of knowers (Jasanoff, 2017, p.3).

Table 1.1 Overview of the different actors and perspectives covered throughout the first three empirical chapters. Drawing on conceptualisations of Jasanoff (2017) and Bijker (2010).

	Chapter 2	Chapter 3	Chapter 4	Chapters 5 & 6
Main actors	SEDAPAL	Urban residents	Water professionals & rural residents	Urban residents
Regime of sight	View from nowhere	View from somewhere	View from everywhere	View from somewhere
Scale	Metropolitan city	Neighbourhood	River catchment	Metropolitan city
Unit of analysis	Sociotechnical ensemble	Singular artefacts	Knowledge system	Singular artefact

Thinking through these regimes of sight helps understand how the representation of the network constructed by human and non-human actors is only an image of what is made present while other elements are not seen (de Laet & Mol, 2000). Although a certain degree of reductionism cannot be avoided, it is important to be wary about whose views are reflected in presenting the network and whose voice is empowered by the research. To include the relations that are not part of the dominant frame in the representation of the sociotechnical system, Williams and Pollock (2012) suggest researching the infrastructure from multiple viewpoints and multiple sites. Looking through the perspective of diverse actors thus allows for constructing a more critical and layered description of the infrastructuring process.

Therefore, we included the perspectives of SEDAPAL, water professionals, and urban and rural residents as central actors in the water and knowledge infrastructures. Nevertheless, it has to be noted that while these actors are presented here as representative of a particular view on the urban infrastructure, the following chapters will illustrate how they are homogeneous in their perspectives and contain pluralities. Nonetheless, thinking in terms of these three perspectives is useful because it directs the scale on which each empirical chapter takes place. Constructing the story of infrastructuring in Lima entails jumping scales and exploring the relations between the neighbourhood, the metropolitan city, and the river catchment area. Zooming in and out helps unpack the network and deconstruct how introducing a new element can alter the relationships within the hydrosocial territory.

Finally, each empirical chapter focuses on a different 'unit of analysis.' Bijker (2010) offers a conceptualisation of the different units of analysis that can be analysed. The first unit of analysis in Bijker’s terms, which I focus on, is the sociotechnical ensemble, referring to the messy network of social and technical elements that exist in relative symmetry. In the sociotechnical ensemble, it is not clear what the dependent and independent variables are; both influence each other. In the case of chapter 2, the sociotechnical ensemble is the digital knowledge infrastructure implemented in Lima's water distribution system.

The second unit of analysis in this thesis is the singular artefact, again using Bijker’s term. The three singular artefacts analysed in chapters 3, 5, and 6 are the water meter, the customer service centre, and the *Observatorio Metropolitano de Agua* (MWO). As will be shown in the following chapters, zooming in on a singular artefact is powerful because it allows one to analyse (i) the embedding of norms in the design of the artefact and (ii) how it can be understood in relation to the sociotechnical network in which is it implemented (Bijker, 2010; de Laet & Mol, 2000). Additionally, researching a singular artefact exposes how non-human actors have agency within the system in that they structure relationships and steer human actions.

The third unit of analysis considered in this thesis is the knowledge system. This refers to the system of knowledge claims, standards and values, epistemologies, structures, and regions that inform our thinking about a particular issue (Muñoz-Erickson et al., 2017). Together, the following chapters analyse the knowledge infrastructure from different perspectives and at multiple geographical and conceptual scales.

1.4.2 Multi-method qualitative data collection

As explained in the previous sections, this study considers everyday practices of infrastructuring as the continuous conceptualisation, design, building, maintenance, and repair work that shapes the infrastructure into its current form (Ribes & Finholt, 2009). This is reflected in the methods deployed for the collection of primary data.

To this end, I travelled to Lima twice. The first time was for a month-long scoping study to get to know the city between February and March 2019. I returned to Lima in September 2019 and stayed until March 2020. This coincided with the start of the lockdowns in Europe and Latin America due to the Covid-19 pandemic.

The empirical material used for this thesis was collected mainly by means of semi-structured extended interviews, focus groups, and field visits. Specifically, I conducted 31 expert interviews, two expert focus groups, 19 interviews with urban residents, and ten in-person and four online focus groups with residents from three areas in Lima: José Carlos Mariátegui, Barrios Altos, and Miraflores in Lima. These conversations gave me insight into the perspective of urban residents. Through two visits to the village of San Pedro de Casta, a tour of the water infrastructure in the region, and conversations with community leaders in the village, I learned about the perspective of rural residents regarding water governance in the region. In addition, interviews and a focus group with employees of SEDAPAL and two tours at La Atarjea, Lima's main water treatment plant and the central offices of SEDAPAL helped me understand the infrastructure from the perspective of SEDAPAL.

Together, the analysis from these five key sites (see Figures 1.2 and 1.3) revealed the diversity of physical elements, actors, procedures, and information involved in water governance in Lima and San Pedro de Casta. As key fieldwork sites, they are representative of the diverging socio-economic, political, and symbolic places in the city and the region.

Beyond these five key sites, I have visited and interviewed residents in the districts Villa María del Triunfo, Barranco, and Comas in Lima and Pachacútec in Callao. The information collected during the conversations in and visits to these additional areas have been important in contextualising what I learned in the key sites and helped assess to what extent the insights gained are representative of other districts of Lima and Callao.

In addition, I attended events related to urban development and water governance in Lima, in-person and online, ranging from high-profile meetings of the metropolitan planning agency as an observer to citizens' panels about urban development, research presentations and industry conferences. And importantly, by way of living in Lima and speaking fluent Spanish, I engaged in all sorts of conversations and chit-chat with neighbours, housemates, friends, and taxi drivers, which helped me gain insights into how people resolve everyday problems related to water. The qualitative information was recorded through written notes or audio and transcribed. A complete overview of the data collected detailing which data is used in which chapter of this thesis is provided in appendix 1 and the respective chapters. Appendix 2 contains the interview guides used and appendix 3 the guides for the focus groups conducted. Appendix 4 provides the code books used for the thematic analysis of the qualitative data.

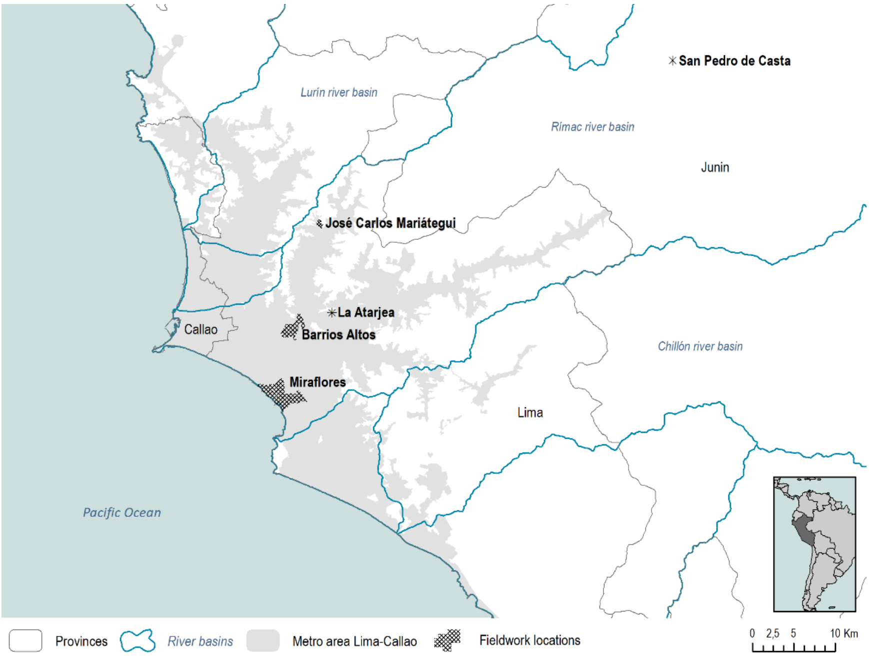

Figure 1.2 Map of fieldwork sites in Lima and the region. Map made by author. Administrative data from OCHA (July 17, 2020) https://data.humdata.org/dataset/cod-ab-per? [August 11, 2022). Urbanisation data from INEI Census 2007.

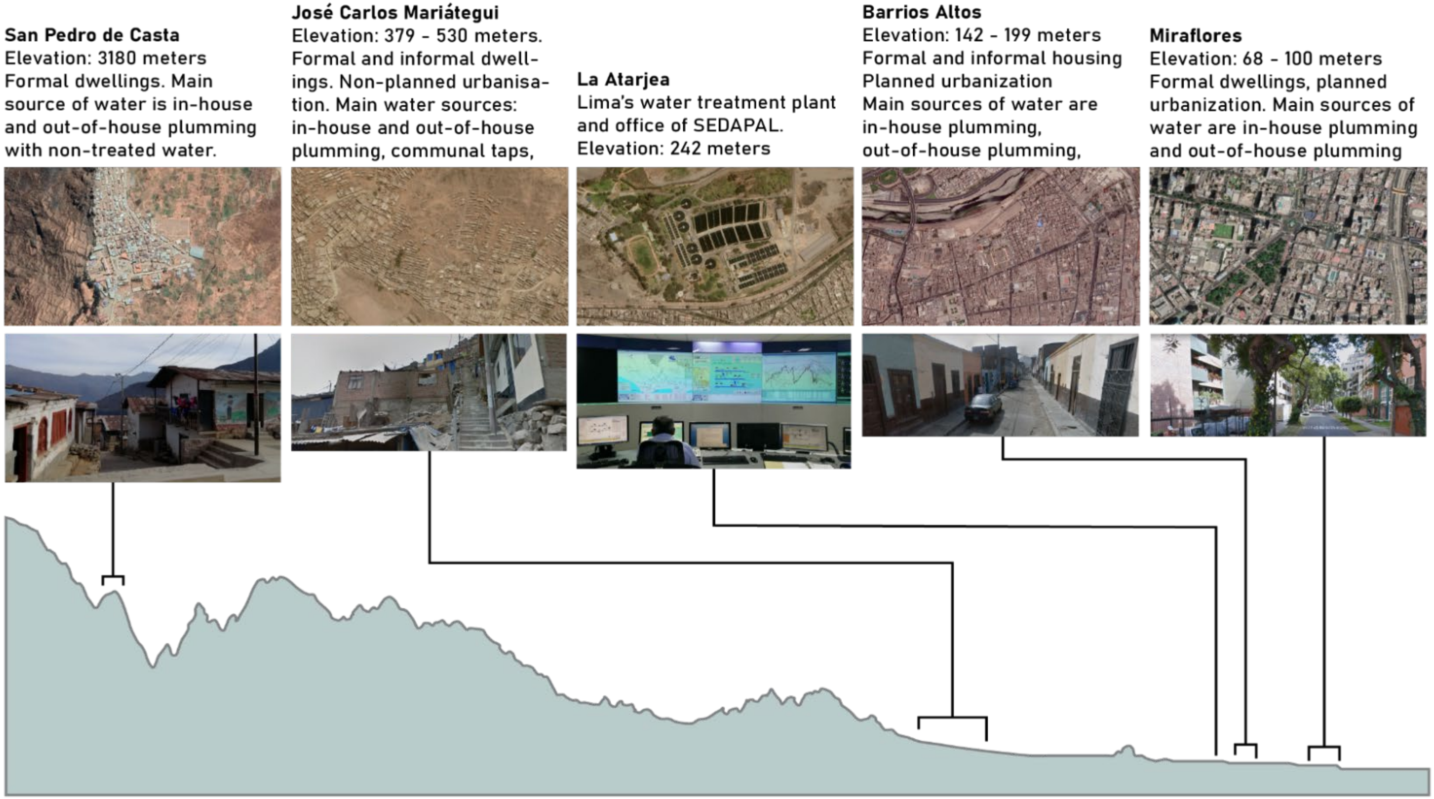

Figure 1.3 Overview of five key fieldwork sites in Lima. Image of SCADA system in La Atarjea from IDOM (2015). Elevation data, street view images and aerial images from Google Earth version 9.165.0.1, (March 28, 2021). Lima, Peru. Maxar Technologies, https://earth.google.com/web [March 19, 2022].

Combining different qualitative methods such as interviews, focus groups, and field visits provided an opportunity to highlight actors' experiences with the knowledge and water infrastructure. With this data, I was able to analyse the processes by which urban and rural residents manage their everyday social and material worlds. To partially account for the intersectional structures that shape these experiences, I worked with and interviewed people across socio-economic classes, gender identities, ages, ethnicities and geographies.

Residents from Jose Carlos Mariátegui, Barrios Altos, and Miraflores were invited to participate in the focus groups through the networks of civil society organisations (CENCA, CIDAP, and Foro Ciudades para la Vida) that have been working in and with communities in each respective neighbourhood for a long time. As a result, in general, the people participating in the focus groups were active residents in their neighbourhoods, sometimes taking up community leadership positions, and had prior experience with collaborative processes focused on urban development and research-related activities. The focus groups with residents were organised in community centres of each neighbourhood and moderated by Liliana Miranda Sara or me.

To guarantee all residents participating in the focus groups had the opportunity to speak and share their experiences, we started each round of focus groups with an elaborate introduction round. Additionally, we gave each person the chance to comment or elaborate on our interpretation of insights generated from the previous round of focus groups. Apart from providing the opportunity to delve deeper into the subject matter and receive feedback on earlier understandings of the discussions, dividing the focus groups into multiple rounds allowed us to create familiarity amongst each other as a group of researchers and participants. This was specifically important in the later stages of the research when we had to pivot from in-person to online collaborative design focus groups due to the Covid-19 pandemic. To compensate for the fact that women were underrepresented in several focus groups, I conducted additional semi-structured interviews with women. Interviewees were approached through CENCA, CIDAP, and Foro Ciudades para la Vida or snowballed from the network I developed while conducting the focus groups.

For the interviews with experts in water governance and urban development in Lima and the expert focus groups, key actors were identified through the network of Foro Ciudades para la Vida, academic networks, and the social interactions during professional and public meetings, workshops, and industry conferences. The interview guides are available in appendix 2, and the focus group guides are in appendix 3. The analysis of the data is detailed in the empirical chapters. All research activities undertaken as part of the development of the *Observatorio Metropolitano de Agua*, including the in-person and online focus groups, have been ethically approved by the research ethics review board of the University of Sheffield. The University of Twente has reviewed and approved the data management plan for this research, specifically focusing on confidentiality, privacy, transparency, and safety in data practices.

As the data collection approach illustrated, from the start, this research has been shaped through dialogue and discussion with civil society organisations, specifically Foro Ciudades para la Vida, alongside engineers from within and outside the government. And specifically, as chapters five and six are more action research-oriented, I have worked in collaboration with and alongside organisations and communities advocating for more just service provision and developing alternative models for water governance.

Remaining open to new collaborations and flexible to unforeseeable changes in the research project permitted me to pivot several times, seize opportunities as they presented themselves, and adjust to the changing research context as we entered a global pandemic. That said, the freedom permitted by such a research approach entails that this dissertation draws on a wide range of conceptual and methodological approaches. Returning to the two methodological challenges mentioned at the beginning of this section: the relational and processual characteristics of infrastructure have directed this research in various ways. First, it has steered me to analyse the knowledge and water infrastructure from the perspective of three main actors on three scales. Secondly, I have focused on the everyday interactions in the infrastructure. This informed the qualitative methods used for data gathering and opened up opportunities for more action-oriented and engaged research during the development of the *Observatorio Metropolitano de Agua* (Metropolitan Water Observatory, MWO), a move which I elaborate on in the following paragraphs. A detailed methodology of the action-oriented research, in the form of a collaborative design process informed partially by an additional structured literature review, is described in detail in chapters 5 and 6. Appendix 5 contains a detailed overview of the steps taken for to select the literature and case studies for review in chapter 5.

1.5 Positionality

In selecting what is considered part of the research and what is not, I contribute to establishing what is made present and what is made absent in the network. Accordingly, the commitment to a network approach requires me, as a researcher, to reflect on my position within the network and my actions in shaping and producing scientific knowledge and constructing the network itself (Law, 2004; Pelizza, 2010; Ruming, 2009). Specifically, I want to reflect on (i) my position as a European scholar, (ii) my involvement in the development of the *Observatorio Metropolitano de Agua*, and (iii) how external changes have influenced the trajectory of this thesis.

First, I must acknowledge how my position in the world and past and current experiences have informed the choice of area and study, my experience of fieldwork in Lima as a Latin-American city, and the analysis and writing in this dissertation. My experience as a European scholar has not only given me privilege and access in Lima but also informed my initial conceptualisations of water, justice, and territory - all fundamental notions within this work – through modernist and Western lenses. Recognising the limitations of my thinking is a process of learning new theories, approaches, and methods, as well as unlearning colonial and patriarchal thinking and frameworks (Aguilar & Icaza, 2021, and box 1). I write this in the present tense since this process is by no means near completion.

Being confronted with the question of how my background and view inform the interpretation of the material and analysis of this thesis means learning to understand myself within geographical, societal, and historical inequalities and plural epistemic and ontological traditions (de Sousa Santos, 2016; Miller et al., 2008). This stems from a recognition that knowledge is not created in a vacuum but shaped as part of a system of knowledge claims, values and standards, structures, and epistemologies (Muñoz-Erickson et al., 2017) and is profoundly emergent from the region (Wijsman & Feagan, 2019). Knowledge, including the knowledge presented in this thesis, is thus inherently positional and limited. To contribute to the production of knowledge rather than its erasure, I have aimed to stay close to the material and stories shared with me by many people in Lima and the region and to do justice to their experiences in my analysis of the events through theory and by my effort to understand their struggles through a lens of socio-economic and colonial injustice.

Second, becoming involved in the development of the *Observatorio Metropolitano de Agua* has had consequences on my position within the research. I moved from descriptive and theoretical research toward actionorientated and collaborative design approaches aiming at influencing policy and practice.

The choice to engage in design research as part of the *Observatorio Metropolitano de Agua* project was in part motivated by the insights gained through the first chapters of this thesis and the realisation that much water governance knowledge was not represented in the current digital infrastructure and in part by the opportunity to work together more closely with Foro Ciudades para la Vida, an NGO which advocates for just and sustainable urban transitions in Peruvian cities, and support their efforts to influence water governance policy in Lima. My involvement in the *Observatorio Metropolitano de Agua* project, therefore, not only had implications for the direction of the research but also concerning my entanglement with the research subject. Now, I was not only analysing what was happening, but actively trying to intervene in Lima's water governance and data practices by introducing a new technological artefact and collaborating with fellow scholars, activists, and community members.

I believe that pivoting towards more engaged and collaborative research has made this thesis more relevant as it has forced me to position this work within the debates on the varied forms of injustice experienced by residents in Lima. This speaks to the ways in which feminist and decolonial researchers relate to and interact with the multiple forms of resistance against patriarchy, (neo)colonialism, and capitalism. I hope my research and involvement in the development of the *Observatorio Metropolitano de Agua* can support these struggles. As Kabeer (1994, p. 80) writes:

> 'the "ways of knowing" that have dominated the production of knowledge [...] have played an important role in defining and legitimating particular viewpoints and methods. The production of knowledge is therefore a logical place to begin the project of reversals.'

Third, I want to highlight two seemingly unrelated changes in the global environment and my personal life that have changed my research approach and my conceptualisations of the issues researched.

The Covid-19 pandemic changed the methodology and context of this research. Specifically, due to the pandemic, the development of the *Observatorio Metropolitano de Agua* was delayed for a couple of months. As individuals working on this project, we were distracted by the rapid changes in the world we experienced. And as a team, we needed time to regroup and re-evaluate the potential contribution of our work. At first, we felt demotivated to work on the *Observatorio Metropolitano de Agua* in the face of such an urgent health crisis and considered investing our time and energy towards more pertinent work. However, the pandemic also instantly showed us how important and differentiating access to water is in Lima. While health guidelines recommended washing hands more regularly and maintaining social distance, some of Lima's residents did not have proper access to water at home. Hence, we pivoted our approach and continued the project.

More or less at the same time, I started working on a project together with Ana Maria Bustamante Duarte titled Dialogical Spaces for a Diverse University. This project was directly inspired by the Black Lives Matter movements in 2020 and aimed at reflecting more critically on our research, education, and general practices at the University of Twente. The 'Dialogical Spaces' consisted of a series of webinars and podcast episodes discussing issues related to inclusive education, research, and policy. The conversations that sprung from these activities have deeply informed my thinking, also in the course of the research.

I can locate how both these events have influenced the trajectory of this research in profound ways. Methodologically, we had to explore and experiment with online research methods to continue with the collaborative design process with high and low-resource communities. How we dealt with this is further explained in chapter 6. Conceptually, both the pandemic and the Dialogical Spaces project have made me much more aware of the structural and intersectional character of injustices and have directly informed the decision to use justice, specifically water and data justice, as a guiding framework in the development of the *Observatorio Metropolitano de Agua*. And finally, personally, working on the Dialogical Spaces has been a humbling exercise. Not only has it challenged me to be more reflective of the limitations of my own ability to 'know,' but it has also shown how academia, as a colonial enterprise, has structurally ignored the plurality of knowledge, knowledge producers, and means to share knowledge (Aguilar & Icaza, 2021). The impacts of these teachings on my intellectual development are particularly reflected in the later empirical chapters of this research, which explicitly engage with the pluralisation of knowledge systems and issues of justice on multiple layers.

In light of these reflections, it has to be emphasised that much of the knowledge written up in this thesis was new to me, not new to all. It builds on the knowledge shared by people who know much of this all along. My hope is that by drawing on different knowledge systems and sources, bringing together the diverging perspectives on water in the city, and using various methods for sharing our findings, this thesis generated new insights that help advance our understanding of the relationship between the infrastructure, data, and the city.

Box 1: Personal reflections on epistemological perspectives

In 1960, the Peruvian poet Javier Heraud wrote the poem El Rio (The River). I read this while on fieldwork in Lima, researching the digitalisation of urban water infrastructure. This poem struck me because it described the trajectory of a river, flowing from the high Andes, downstream through pastures and towns, to finally pass through the large city and join with the ocean. On its path, the river breaks rocks, nourishes plants, and flows through bodies of animals and people, mixing with their blood. Although Heraud does not mention the river's name, I always imagined it to be the trajectory of the Rimac, Lima's primary water source.

Heraud wrote the El Rio from a first-person narrative, transforming the river into a body with thoughts that shares its story with us. In literature and poetry, playing with the position of the narrator is a relatively common practice. Narrators can be objects, animals, spiritual creatures, or even the dead. When it comes to telling a story, authors do not discriminate. However, in scientific writing, playing around with the position of the narrator is much less common. In many scientific disciplines, the narrator is even wholly left out, forcing the writer to make awkward sentence constructions in an attempt to avoid having to use 'I' or 'we' in describing their findings. Other strands of science, specifically anthropology and critical sociology, have accepted the presence of a narrator, acknowledging how the 'scientist' is telling a story through research papers as the novelist is in books. Nevertheless, also in those disciplines, we rarely experience the story told from a completely different perspective, for example, from the perspective of the river.

This is rooted in the positivist epistemology that dominated all scientific disciplines and continues to be a structuring force in many. The relationship between the scientific narrator, sometimes not even present in writing, and what is described is that of the objective researcher and the subject. The subject is observed, its properties and behaviour are analysed, and this is abstracted into a jargon-filled piece that only those who speak the language of the scientist can decode.

Positivist science has not only defined the relationships between the researcher and what is researched but also determined who is allowed to engage in research and which knowledge is considered 'scientific.' This implies clear dichotomies between science and non-science, the researcher as a person and the natural, technological, or social as subjects to be researched.

As described in the previous sections of this thesis, different strands within the philosophy of science and technology have made a tremendous effort in overcoming the strict object-subject dichotomy and in opening up our thinking by critically engaging with the categories that we have created, as well as developing new research methodologies that provoke us to think through and with the thing we are analysing. Heraud, far ahead of his time, already deployed what we in research now refer to as 'following the thing' as a way to think through the river. In this poem, we do not only follow the river as it moves through different landscapes; the river itself describes its trajectory for us.

While this thesis is not narrated from the perspective of an object, I have been inspired by this art and scholarship in my theoretical and methodological approach. Theoretically, this is reflected in the relational approach that acknowledges the active participation of human and non-human entities in shaping the city. Methodologically, this is primarily reflected in the different points of view included in this research and the engagement with actors and sources outside of academia. From the starting point that I wanted to understand digitalisation from its 'source' to final product, this research jumps between describing the emergence of water governance approaches from knowledge systems to analysing the implementation of digital technology by SEDAPAL and residents and continues with thinking about how we can design it ourselves. Finally, in my writing, it is also reflected in the fact that as a researcher, I am an active agent in the research and present in the narrative.

1.6 Structure of the thesis

The remainder of the thesis is structured as follows. The five chapters that follow are each sub-projects addressing one of the three sub-research questions (Figure 1.4). Chapters 2, 3, 4, and 5 have been published as standalone publications in peer-reviewed journals. Chapter 6 combines a working paper and a peer-reviewed conference proceeding.

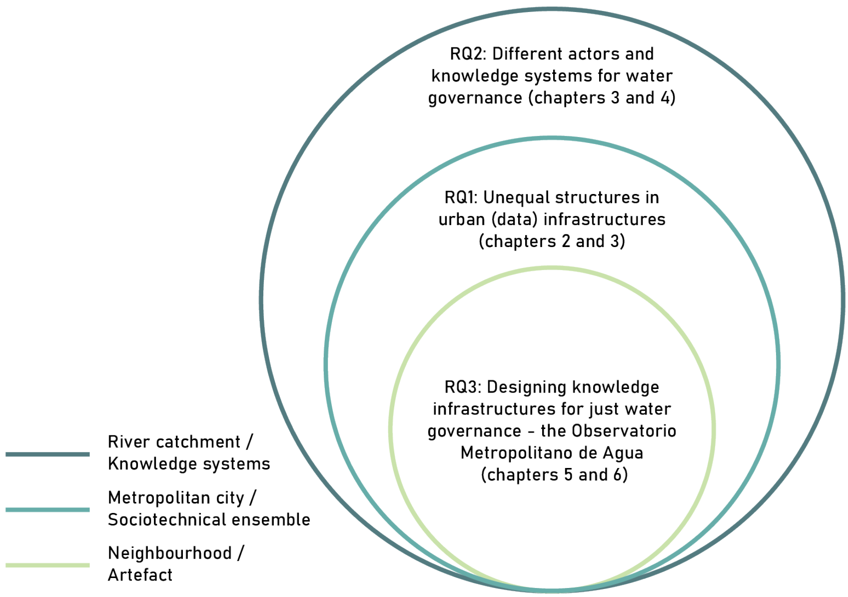

Figure 1.4 Relationship between the three sub-projects and corresponding publications within this thesis.

Figure 1.4 illustrates the relationship between the three sub-projects and corresponding publications in this thesis. In this figure, each circle represents a geographical scale (the river catchment, the metropolitan city, the neighbourhood), a unit of analysis (the knowledge systems, the sociotechnical ensemble, an artefact), and a conceptual aim corresponding to a sub-research question. Together, the sub-questions and sub-projects tie into each other and build towards understanding how knowledge infrastructures can support just urban water governance.

The first two empirical chapters (2 and 3) of this thesis focus on the digital infrastructure used for water governance in Lima from the perspective of SEDAPAL (chapter 2) and the perspective of urban residents (chapter 3). In both cases, we specifically analyse how the digital infrastructure (re)produces inequalities in the water infrastructure. From the metropolitan scale, I move down to the neighbourhood level to understand the diverse ways residents relate to digital infrastructure in the city. At both scales, we specifically analyse how the digital infrastructure (re)produces inequalities in the water infrastructure.

In chapter 4, we zoom out and analyse the different knowledge systems informing water governance approaches in the Rimac catchment area. This was a necessary step to appreciate the diverse forms of knowledge about water and water governance in the region and to be better able to situate the discussion on smart water governance in Lima within the broader context. It took a visit to the mountains and stepping into different theories and regimes of sight (Jasanoff, 2017) to see Lima as part of the Rimac river system, rather than only approaching it as a desert city. Moreover, going beyond the urban discussions on water governance was necessary to think more critically and comprehensively about the knowledge that should be included in the development and design of the *Observatorio Metropolitano de Agua*.

Chapters 5 and 6 are dedicated to exploring the potential of participatory urban observatories as knowledge infrastructures for creating collaborative pathways to more just smart urbanism. Chapter 5 proposes design principles to guide the development of just urban observatories, and chapter 6 describes the collaborative design process, which resulted in a prototype for the *Observatorio Metropolitano de Agua*. While chapter 4 zooms out and places the discussions in Lima within the broader regional and discursive context, the subsequent chapters (5 and 6) zoom in conceptually on data justice within urban water governance.

Chapter 7, the final chapter, synthesises the most important findings from the preceding five empirical chapters. While each of the empirical chapters focusses on a single scale and unit of analysis, chapter 7 brings together these various perspectives to discuss the dual potential of digital knowledge infrastructures in either reproducing the unjust orders in the city and the region or functioning as tools to contribute to more just water governance and urban futures. Finally, it elicits the main contributions of this thesis to theory and practice.

Chapter 2:

The datafication of water infrastructure and its implications for (il)legible water consumers

Abstract:

Redevelopments of Lima's water infrastructure aim to reduce inequalities in water consumption, connections, and coverage by implementing data technologies and claim to make urban water management more efficient. However, little research has been done on how the city's hydrosocial geography is shaped by the increasing use of data for the supervision and control of its water infrastructure. This article analyses the datafication of Lima's water infrastructure as the interplay between different legibility-making practices to understand how the use of multiple, interoperable and real-time data sources shapes the hydrosocial geography of the city as well as the relationship between Lima's main provider of water and sewerage services (SEDAPAL) and urban water consumers across three scales: newly urbanised areas, water sectors, and households. We conclude that, in an already unequal urban landscape, the datafication strategically (re)structures the relationship between SEDAPAL, as a state organisation managing the water infrastructure, and Lima's residents.

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2.1 Introduction

It is said that when the Spanish colonizers first settled in the Incan empire that has come to be known as the Republic of Peru, they arrived in January, the only time of the year in which the coast of Peru is not covered by a thick layer of fog and the rivers are flowing with water (Leonard, 2000). Wanting a port capital, the Spanish founded the ‘City of Kings’ along the Pacific coast and on the banks of the river Rimac, an area that had been inhabited and irrigated by Incan and pre-Incan communities, not knowing that the city would grow out to be the second-largest city of the world built in a desert (Allen et al., 2017; Leonard, 2000). Today, the City of Kings goes by the name of Lima and structurally faces water scarcity. With more than nine million people and 10 mm mean annual rainfall (Ioris, 2016), it is a constant challenge to guarantee the provision of water to all the inhabitants of the Lima Metropolitan area (Fernandez Maldonado, 2008; Miranda Sara et al., 2016). This is perhaps most clearly noted in the geographical and social inequalities in water consumption and water connections amongst residents and in water coverage over time (Fernandez Maldonado, 2008).

To address this inequality in water distribution, redevelopments of Lima’s water infrastructure aim to make the water infrastructure more efficient, reliable, and equitable by implementing ‘smart’ data technologies (SEDAPAL, 2014, 2015). Similar smart city narratives have steered cities worldwide to mimic the image of a high-tech, fully connected, data-driven urbanism (Luque-Ayala & Marvin, 2015; McFarlane & Söderström, 2017). Today, urban society, materiality, and economy have become intertwined with coded algorithms (Lindley et al., 2017; Shaw & Graham, 2017). Specifically concerning urban infrastructures, supervisory control and data acquisition (SCADA) systems have been extensively rolled out in cities globally to monitor and control flows in water, traffic, and electricity grids

(Kitchin & Dodge, 2017). These developments have spawned the idea that, with sophisticated and reliable digital technologies and data production, it will be possible to make the measurement and monitoring of infrastructures more efficient and equitable and reduce 'human insecurity' in the management and governance of urban flows (Kitchin et al., 2015; Luque-Ayala & Marvin, 2016; Taylor & Richter, 2017).

In the case of Lima, Peru, these expectations of 'smart city' technologies are no different. Digital data is assumed to provide faster and better monitoring of the fluctuation in the water pressure, detect leakages quicker, and improve the insights about water usage (SEDAPAL, 2015, 2018; World Bank, 2011). Underlying these efforts to implement digital data technologies in the infrastructure is the wish to manage the water that flows through the city more efficiently. The 'smartening' of the water infrastructure is embedded in the modernist ideal of the controllable and legible city, although the means to see the city have changed. Whereas previously, governing bodies relied on cadastral maps and paper-based censuses to monitor the city, today, digital data technologies are seen as essential tools to sense urban dynamics and make urban infrastructures legible in near-real-time (Glasmeier & Christopherson, 2015; Offenhuber, 2017). The premise is that by installing meters and implementing a supervisory system, it becomes possible to construct an informative representation of urban reality and 'see' the water flows through the data (Birnholtz & Bietz, 2003). These innovations would then help identify breakdowns and non-regulated tapping and improve water distribution amongst the consumers of the water infrastructure (SEDAPAL, 2015).

However, the idea of the smart city has extensively been critiqued, with researchers raising concerns about the often technocratic and neoliberal assumptions of the smart city discourse and concerns regarding the introduction of digital technologies in cities (Vanolo, 2014). Specifically, critics have pointed out the influence of large-scale measurements and big data on surveillance (Kitchin & Lauriault, 2018), the protection of privacy (Elwood, 2008; Kitchin & Dodge, 2017), the bias in the representation of people in the data (D'Ignazio & Klein, 2020), and the flow and possession of data (Taylor & Broeders, 2015).

This article contributes to these debates by analysing the effects of datafication of Lima's water infrastructure as layered legibility-making practices. As the gaze upon the city has become electronically mediated, we discuss how the hydrosocial geography and the relationship between residents and the state is shaped through multiple data sources. Informed by debates on socio-hydrology and hydrosocial research, we adopt hydrosocial geography as referring to the dynamic and mutually constitutive relationship between society and water (Wesselink et al., 2017) and their relationship with and across urban space. Such discussion is specifically important for Lima, where recent digitalisation efforts take place in an environment of persisting and especially pronounced hydrological inequality.

We structure the rest of the paper as follows. In section 2.2, we frame this research within the broader debates on smart urbanism from a sociotechnical perspective and describe the process of datafication as a practice of legibility-making from the perspective of Lima's Drinking Water and Sewerage Service, known by its Spanish acronym SEDAPAL. This is followed by the methodology (section 2.3). In sections 2.4 and 2.5, we describe the datafication of Lima's water infrastructure and analyse how the legibility- making practices on three scales – the mapping of settlements, the supervision of the water distribution system, and the metering of household water consumption – create a differentiated hydrosocial geography with distinct categories of water consumers. Finally, in section

2.6, we conclude with how layered legibility-making is dynamic and strategic in shaping the relationship between SEDAPAL and urban water consumers.

2.2 Conceptual approach

2.2.1 The datafication of urban infrastructure

Similarly to modernist approaches to urban planning (Rabari & Storper, 2015), mainstream smart city approaches are characterised by a technocratic view on urban space and processes (McFarlane & Söderström, 2017; Vanolo, 2014) and a strong belief in the potential of technology to sense and register complex urban interactions into quantitative data and translate them into objective and valuable knowledge (van Dijck, 2014).

In the often corporate-led transition toward smart cities, the process of datafication – referred to as the quantification of daily life (Mayer-Schönberger & Cuckier, 2013) – is presented to achieve a fully connected and governable city. Datafication of urban infrastructure can be described as the trend of increasingly using digital data in larger volumes and in increasing detail in infrastructural management (Heeks & Shekhar, 2019; Mayer-Schönberger & Cuckier, 2013).

The change in data production using digital technologies can have profound implications for the organisational structure and governance of our cities and for urban infrastructures. Critical urbanism has extensively discussed how 'smart' technologies and data can lead to reductionism in urban planning and technocratic governance (Luque- Ayala & Marvin, 2015; McFarlane & Söderström, 2017; Verrest & Pfeffer, 2018). From a development perspective, there has been a critical evaluation of the goals for becoming 'smart' and how the race to cyber cities is driven by capitalism and results in new global inequalities (Gaffney & Robertson, 2016; Taylor & Broeders, 2015). Moreover, feminist and post-colonial data studies have raised questions concerning representation in data and unpacked how data is inherently biased (D'Ignazio & Klein, 2020). Such studies reveal how data, be it big or small, are never pre-analytical or a-political. Instead, data are the product of a specific context and framed to serve a purpose (Kitchin et al., 2015). Policy, legislation, culture, and market forces steer what is worth knowing and who or what is counted in the city's datafied image.

Therefore, the approach we take in this study shifts attention to the relationships and interactions between the data and the water infrastructure in Lima. With such focus, we follow Karasti et al. (2018), Pfeffer (2018), and Bowker and Star (2000), who view infrastructural development as a process of aligning different forms of knowledge, humans, and artefacts; a process that stabilises into networks that may re-align again later in time. While being inspired by sociotechnical research of urban infrastructure and smart urbanism at a more general level (for example, Alda-Vidal et al., 2018; Amin & Thrift, 2017; Kaika, 2012; Kemerink-Seyoum et al., 2019; Swyngedouw, 2006), analytically, our study draws specifically on Scott's notion of legibility-making to describe datafication in Lima's water infrastructure and its effect on the city's hydrosocial geography. In the following section, we explain the concept of legibility-making and how its conceptualisation is useful to support our investigation.

2.2.2 Datafication through the lens of legibility-making

In his seminal book, 'Seeing Like a State,' Scott (1999) uses legibility-making to conceptualise the state-imposed processes of abstraction and simplification of real-world messiness to improve its management. Through different practices and techniques, such as the standardisation of measurement, the land cadastre, and the national census, the state maps its territory and registers its subjects. Scott (1999) emphasises how the state employs legibility-making practices as a tool for the state to increase the governability of people and territory. Legibility, in this sense, increases administrative order and control over its residents and resources and diminishes alternative knowledges and organisation systems.

Scott (1999) draws on a variety of empirical examples such as land administration, natural resources management, fiscal government, and urban planning to illustrate how large-scale administrative plans have tried, but ultimately failed, to simplify the complexity of the real world into manageable schemes and categories. However, as Scott's research repeatedly shows, this way of 'seeing like a state' cannot account for on-the-ground heterogeneity. As an analytical lens, legibility-making helps explore how different categories of people emerge and how, in doing so, the relationship between people and the state is defined.

As such, the concept of legibility-making makes for a useful tool in our approach to understand the datafication of Lima's water infrastructure. However, it is also necessary to distil how legibility-making practices in the age of smart cities differ from those of high-modernist states, as described by Scott (1999). Li (2005), for instance, argues that Scott's focus on the controlling and authoritarian relationship between the state and its citizens has overlooked the network of public and private actors that are working on the project of legibility-making.

Li (2005) points out that we need to consider also non-state actors in the processes of legibility-making. As datafication progresses, the role of private industry and its interactions with state actors in legibility-making has further increased (Taylor and Broeders, 2015). Today, it is a comprehensive network of organisations, individuals, and technologies that collect and maintain data and, in the process, negotiate to categorise and define urban spaces (Richter & Georgiadou, 2016).

As Luque-Ayala and Neves Maia (2019) point out, the rationale for making legible depends on the actors' aims. Whereas legibility-making of the state aims at increasing governability, corporate-led legibility-making is often driven by economic aspirations. In Rio de Janeiro, for example, the digital mapping of favelas has been led by corporate actors such as Google and Microsoft, with the self-proclaimed aim of the economic integration of the neighbourhoods and capturing georeferenced data (Luque-Ayala & Neves Maia, 2019).

Additionally, the properties of the data that underpin legibility-making practices in the smart city have changed compared to the legibility-making practices of the modernist city described by Scott (1999). Scott argues that the schemes of legibility and statecraft used in high-modernist states were, in their aim, not very different from the governance methods used by the societies preceding them. However, what drastically changed in the 20th century was the magnitude and range of the legibility-making practices. Through technological progress, the high-modernist state had gained the ability to map whole territories and achieve (near) universal registration of people and resources (Scott, 1999). With the more recent emergence of digital data technologies, the state has again gained new legibility-making tools. Kitchin and Lauriault (2018) unpack how the introduction of digital data technologies has increased the volume, velocity, variety (structured and unstructured), exhaustive scope, resolution, and relational nature of the data that is collected about people. What sets apart datafication as a legibility-making practice in the smart city compared to modernist legibility-making practices is that the data is digitally interoperable (favouring standardisation and the exchange of data), layered (favouring a fixed layering and ordering of data), potentially more diverse in source and structure, and sometimes collected in real-time (see, Table 2.1). In the transition toward smart urban governance, we need to consider the interactions between different databases created and curated by various actors involved in the project of legibility-making.

Table 2.1 Conceptual overview of commonalities and differences between legibility-making in the high-modernist city (Scott, 1999) and legibility-making in the smart city.

<table>
<tr><th></th><th></th><th>Legibility-making in the high-modernist city</th><th>Datafication - Legibility-making in smart city</th></tr>
<tr><td rowspan="3">Commonalities</td><td>Rationale</td><td colspan="2">Increasing administrative order and control over people, resources, and territories.</td></tr>
<tr><td>Means</td><td colspan="2">Large-scale data collection schemes focused on standardisation and simplification.</td></tr>
<tr><td>Effects</td><td colspan="2">Reduction of on-the-ground complexity into manageable categories and the deletion of diversity in knowledge. Increase in accountability of the state towards residents.</td></tr>
<tr><td rowspan="3">Differences</td><td>Rationale</td><td>Mainly state-led data collection aimed at increasing governability.</td><td>Multiple data collectors/collections and diverging rationales.</td></tr>
<tr><td>Means</td><td>Structured data from few sources. Longer-term periods of collection and updates.</td><td>Structured and unstructured data from multiple sources, including digital ones. Data is layered and largely interoperable. (Near) real-time collection and updating.</td></tr>
<tr><td>Effects</td><td>Reductionist and selective regarding relationships between the state, society, and data. Results in a dichotomy between legible and illegible.</td><td>Differentiation on multiple layers leading to degrees of (il)legibility.

(scope of this paper)</td></tr>
</table>

The effect of legibility for the state is, as Kalir and van Schendel (2017) write, a double-edged sword. On the one hand, counting and recording can increase the legibility of and governance over the territory it administers. On the other hand, the legibility of processes also increases the state's accountability toward the people who are registered (Kalir & van Schendel, 2017), determines resident's access to urban resources (Anand, 2017; Taylor & Richter, 2017), and reconfigures the alignment of people, data, and agency, rather than solving frictions (Pelizza, 2017). Legibility-making, thus, involves the conscious selection of what is recorded and what is not recorded (Kalir & van Schendel, 2017). The state constantly balances the logic of creating legibility and increasing state administration or maintaining illegibility and outsourcing responsibilities (Gandhi, 2017; Truelove, 2018).

Because the dynamics between legibility and illegibility-making are context-dependent, they may take different courses in states with high levels of informality and illegibility, for instance, in the Global South. As Truelove (2018) points out, not 'seeing' is oftentimes not an arbitrary failure to make legible, but the strategic creation of the absence of the state and its services. In these zones of illegibility alternative service provision strategies emerge, such as formal or informal markets (Wutich et al., 2016) or auto-constructed infrastructures built and managed by citizens (Hoefsloot et al., 2020). Moreover, through selective legibility and illegibility-making practices, a relationship between the state and its residents is created, and citizenship is determined (Gandhi, 2017)

Therefore, in this paper, we analyse the datafication of Lima's water infrastructure as legibility-making in the smart city to understand how the use of multiple data sources, which are layered, interoperable, and in near real-time, shapes the hydrosocial geography of the city as well as the relationship between Lima's main provider of water and sewerage services (SEDAPAL) and urban water consumers.

2.3 Methodology

We analyse the datafication of the water infrastructure from the viewpoint of Lima's state-owned drinking water and sewerage service, SEDAPAL. This research is based on 6-month fieldwork conducted from 2019 to 2020 in Lima, which combined qualitative research methods in the form of interviews, focus groups, site visits, and observations with informal conversations. In total, 12 in-depth interviews have been conducted with staff of different operational departments of SEDAPAL (five), civil society actors (three), and key experts in the field of water management and governance (five). The focus of the interviews was on the daily operation and use of the digital data infrastructure and the water distribution system. In interviews with engineers of SEDAPAL, we 'walked through' the digital data technologies that are used to monitor the water flows in the city, providing a glimpse into the infrastructure from SEDAPAL's perspective.

Additionally, we draw on conversations with residents to understand what is seen and what is overlooked by SEDAPAL through the process of datafication in Lima's water infrastructure. Between December 2019 and February 2020, three focus group discussions were conducted with residents from three districts of Lima (San Juan de Lurigancho, Barrios Altos, and Miraflores). Participants were encouraged to discuss the water service provision in their neighbourhoods. Each focus group lasted between 75 and 100 minutes. The three areas were chosen as they reflect, at least to some degree, Lima's range in socio-economic living conditions, (in)formality, and geographical location. The participants in the focus groups were recruited from already existing civil society networks in each district. As a result, many, although not all, participants had been previously active in urban development projects or research initiatives and often held leadership positions within their communities.

The site visits included formal and informal areas in Lima and the main water treatment plant, La Atarjea. The data, the text, notes, and transcripts were coded in ATLAS.ti™ based on an initial code list focusing on (i) the different elements in the water infrastructure (actors, digital technology, data, and the water distribution system) and (ii) the rationale for the design and functioning of the water infrastructure. See appendix 4 for the code book. Coding was conducted by the first author, who also collected the data in the field. The code list was adjusted and expanded during the process of analysis as new themes emerged. Based on this process, the three categories of legibility-making emerged that we will discuss in the following sections. These are the registration and mapping of the urban expansion area (2.4.1), the centralised supervision of the water distribution system (2.4.2), and the metering of household water consumption (2.4.3). In the final results section (2.4.4), we analyse the effects of legibility-making on water access.

2.4 Results: Practices of legibility-making

The legibility-making of Lima's water infrastructure can be best explained from the perspective of La Atarjea, Lima's main water treatment plant and the central node in the infrastructural network. There, from the offices on the site, the engineers of SEDAPAL can supervise the water pressure on the pipes at any given time and place in the primary network; and they can monitor the consumption and payments for the water and detect leakages or breakdowns. In the control rooms, they view the water distribution system through the data provided by sensors and meters installed throughout the infrastructure. These data are collected in a web-based geo-information system and presented in maps, charts, and models representing the water infrastructure. The screens, models, and tables they portray are legibility-making practices materialised. They translate the intricate infrastructural network into an image, which can be read at a glance.

This digital data infrastructure has been developed over the past decades through large-scale, bilateral, or multilateral infrastructural development projects (World Bank, 2011, 2018). The emphasis of these developments has been on creating a more efficient water infrastructure and should be seen in light of the discussion revolving around the privatisation of public services in Peru. During the neoliberal Fujimori governments in the '90s, and driven by the International Monetary Fund (IMF) structural adjustment programs, many of Peru's public services were privatised (Fernandez Maldonado, 2008; Ioris, 2012b). As part of this, SEDAPAL was stripped of many of its previous functions related to infrastructure implementation, maintenance, and repair. In its current 'lean' form, SEDAPAL has taken up the role of coordinator of the water infrastructure and contracts third parties to execute projects. While the privatisation was never completed, and SEDAPAL remains under the auspices of the Ministry of Housing, Construction and Sanitation and the Ministry of Economy and Finance, it is still an option discussed publicly (El Comercio, 2019; Ioris, 2012b). The main arguments for the privatisation of SEDAPAL have centred around the belief that privatising water management would improve management and give an economic incentive to make the system more efficient. As a response, SEDAPAL has taken up neoliberal policies and prioritised efficiency for water management (Ioris, 2012b).

The process of datafication that we describe in the following sections should be considered within this context as the aims of improving the efficiency of the water infrastructure and reducing non-revenue water have been driving rationales for the legibility-making of Lima's water infrastructure. In sections 4.1, 4.2, and 4.3, we describe in detail legibility-making practices on three scales that amount to the datafication of Lima's water infrastructure.

2.4.1 Practices of legibility-making of unplanned and underserviced settlements

Since 1950, Lima has experienced several phases of rapid urban growth in which people settled on barren lands haphazardly, incrementally forming new city districts in the process (Riofrío, 2003). The lack of data about Lima's unplanned settlements poses a challenge for SEDAPAL in planning for the expansion of the water infrastructure. Therefore, to breach this gap, SEDAPAL uses geo-technology to make newly constructed neighbourhoods (see, Figure 2.1) legible within their cartographic data.

Figure 2.1 Newly urbanised neighbourhood in José Carlos Mariátegui in San Juan de Lurigancho, Lima's largest district. Photo was taken by the first author.

These newly urbanised neighbourhoods, referred to by many names in the past (*barriadas, pueblos jóvenes, asentamientos humanos*), range from fairly planned and structured areas, according to the national urban planning regulation, to unplanned informal neighbourhoods lacking essential service provision. The residents of these newly established settlements often live in a state of pre-formalisation: their presence is acknowledged, albeit not yet registered in the several databases of the municipality and service providers that define formal citizenship. Up to today, the city's newest neighbourhoods are generally under-mapped (Lambert & Allen, 2016), and service networks such as water infrastructure and electricity often arrive years after the construction of the houses (Criqui, 2015; Fernandez Maldonado, 2008).

This trajectory goes in the opposite direction from the formal developments in Lima, where developers need to receive an expression of intent from SEDAPAL that they will be able and willing to provide water infrastructure to planned developments before receiving a construction licence from the municipality (Decreto supremo N°029, 2019).

According to the National Institute of Statistics and Information (INEI), 4% of Lima's residents are still pending connections (INEI, 2019). However, due to the lack of formal registration of residents, this number is widely contested. According to local experts, the breach in connection to the infrastructure ranges between 10% to 30% of Lima's real population.

Recently, SEDAPAL started using drones and geo-technology to map the newly urbanised areas and improve the planning for the expansion of the water infrastructure. The aerial images acquired by the drones are digitised and georeferenced by a tertiary company. In translating these images into a map, one of the main challenges lies in determining the boundaries between parcels. Some boundaries, such as roads and staircases, are visible in the image and can be included in the cartography. Yet, in other cases, it is impossible to demarcate one terrain from the other based on visual features, forcing SEDAPAL's engineers to estimate the boundaries. Each parcel is categorised depending on the type of built-up and the zoning plan of the municipality. This is important since people who have inhabited zones classified as archaeological sites or high-risk zones are considered illegal, and SEDAPAL will not be able to provide water infrastructure there. In addition to mapping newly built-up areas, aerial images are also used to estimate the terrain which has been prepared for development but where construction has not yet started. This provides an insight as to where future urbanisation will occur.

By combining the data from the aerial mapping with the maps SEDAPAL received from newly urbanised areas when they apply for a water connection, SEDAPAL is said to have the most up-to-date map of Lima. The maps of the unplanned settlements are meant to aid SEDAPAL in making a more accurate prognosis of the future water demand and speed up the processes of infrastructural delivery. Nevertheless, informal urbanisation in Lima continues, and new neighbourhoods are constructed on an almost daily basis. Hence, despite speeding up the mapping process by using digitised aerial images, SEDAPAL's cadastre cannot keep up with the reality of urban expansion.

Additionally, while the digital mapping of settlements by SEDAPAL is making new informal neighbourhoods legible, in practice, this does not change much for the processing of residents' requests for water provision. In 2004, the *Agua para todos* (Water for All) reform made it possible to receive a piped water connection with a 'proof of possession' (*constancia de posesión*) rather than a land title. This meant that many people without a land title could receive a water and sewerage connection by handing in proof of possession, accompanied by a perimeter and elevation map approved by the municipality and a neighbourhood map, including the exact location where the requested pipes and connections must be installed. The final document must be signed by an engineer of an accredited consulting company and the municipality and handed over in a hard copy to SEDAPAL.

As the power to recognise the claim to water by a resident does not lie with SEDAPAL but with the municipality, it is necessary to follow the formal application route and deliver a paper map. Without the literal stamp of approval and signature by the municipality, the digital map can only inform future plans; it does not serve to start the construction of the water infrastructure in the unplanned settlements.

Thus, although GIS technologies serve as a means to increase the digital legibility of unplanned settlements, due to the lack of legal power of the digital map, these settlements remain illegible in the official cadastre used to manage the water distribution system. The effects of not being legible are significant. It not only makes people underrepresented but also undermines the legitimacy of their claim to resources in the city and their contribution to infrastructure development. For example, SEDAPAL has an extensive customer service centre where registered clients can report their grievances via social media (Facebook, WhatsApp, Instagram, and Twitter), e-mail, phone, or video call. Residents, who are not yet registered as clients of SEDAPAL, cannot make use of this service and therefore cannot report the issues they encounter while waiting to be registered and connected to the water infrastructure. Hence, although partly legible digitally, the informal city cannot materialise this limited legibility into the further development of the water infrastructure and remains illegible in the cadastre and the customer service centre.

The geography of legibility, however, is not the mirror image of the formal city. As will be discussed in the following sections, each practice of legibility-making adds a new layer of legibility, and therefore illegibility, to the image of the city. In practice, the digital legibility-making of settlements adds to the distinction between formal neighbourhoods (fully legible), informal neighbourhoods that are digitally legible, and informal neighbourhoods that are fully illegible. They are thereby creating a more differentiated view than the black-and-white model of the formal and the informal city.

2.4.2 Practices of legibility-making of water distribution

The second practice of digital legibility-making is the centralised supervision of the water distribution system through the sectorisation and the associated implementation of the supervisory control and data acquisition (SCADA) system in Lima's water infrastructure. In 1996, through a series of partially externally funded development projects, SEDAPAL started with the re-organisation and division of the water distribution system into sectors to reduce the amount of non-revenue water and improve the efficiency of the distribution system. A sector is an area of around 2 km2 containing between 2000 and 5000 households which can be connected or disconnected from the main pipelines independently. Today, the water distribution network is divided into more than 480 sectors. Each sector is connected to the main pipes with one valve through which the water pressure can be monitored and controlled. To fully operate, the sector needs to be hermetically sealed and equipped with functioning macro- and micrometres. The macro-meter measures the total amount of water that flows into the sector, and the micrometre measures the consumption of water per building or household. When fully controlled, the difference in the balance between the macro- and micrometres in the sector should be less than 25%. This target for the maximum ratio of non-revenue water (NRW) was set by the Japan International Cooperation Agency (JICA) and the World Bank as funding agencies in line with international benchmarks (JICA, 2011).

The sectorisation of the water infrastructure aimed to improve water management in Lima by producing more accurate and timely data by sector. The measurements from the macro-meters are registered in a SCADA system and overseen from the central control room at the La Atarjea water treatment plant (see, Figure 2.2). As the overall supervision and control system, the SCADA system builds on and connects other geo-information systems in the operational branch of SEDAPAL. This allows SEDAPAL to control the water pressure from a distance, address interruptions, and schedule the water delivery. The division of the water distribution system into different sectors has become fundamental for the operational activities of SEDAPAL. It is not only the basis for their geoinformation system detailing the flow of water in the city, but it also provides data about the quality of the pipes and allows for more efficient repair work. Driven by the wish to become more efficient, the system is divided into easily legible and, therefore, governable and administrable segments.

Figure 2.2 The central control room at the La Atarjea water treatment plant. Source: (IDOM, 2015).

However, the legibility of the sectors is limited in two important ways. First, through the development and implementation of the sectoral system, SEDAPAL has attempted to anticipate future urban growth by already plotting sectors for areas which had not yet been inhabited. However, urbanisation in Lima does not always abide by the logic of the sectoral system. On the contrary, it responds to the implementation of technology in ways that were not anticipated. In practice, people often settle in physical proximity to already constructed water reservoirs, assuming this will increase their chances of being included in the future expansion of the piped infrastructure without being aware of the sectoral boundaries in place.

SEDAPAL makes a distinction between 'controlled' sectors and sectors that are not yet operational. Lack of operationality can be due to technological failure or the incomplete installation of meters and valves to seal the area hermetically. Several sectors are still in the process of implementation, meaning that SEDAPAL has delineated the boundary within their geo-information system but has not yet implemented the technology in practice. These sectors only exist in SEDAPAL's maps.

Second, there is a division between the supervisory system monitoring the sectors in the lower-lying areas, where water is circulated by gravity, and the city's areas at a higher altitude than La Atarjea (246 metres above sea level), in which pumps distribute the water. The two systems run in parallel, each monitoring a part of the water distribution system using different software and, most importantly, using a different frequency for data transmission. The SCADA system that collects data from the distribution system serviced by pumps depends on a public frequency that is often interrupted, losing the communication between the macro meters and the SCADA for months at a time. Contrastingly, the SCADA system for the part of the water distribution system driven by gravity has its own frequency and is, as a result, more reliable than the SCADA system for the pump-driven infrastructure. In general, the higher parts of the city, dependent on water from the pumps, are the newly constructed informal neighbourhoods.

According to one of SEDAPAL's engineers, it was not a deliberate choice to use two SCADA systems in parallel. Rather, it resulted from the public procurement system in which the bid for the second system in the pumpsupplied areas was won by a company using software that was not compatible with the already implemented SCADA for gravity-based circulation. The effect is that the water distribution system in the low-lying neighbourhoods is legible and, therefore, supervised in real-time. In contrast, the water distribution in the higher neighbourhoods is often illegible and goes unsupervised for extended periods.

Legibility of the water distribution system is crucial as it informs SEDAPAL's decisions regarding the pressure and continuity of the water provided. First, since leakages are not detected quickly in the illegible sectors, water pressure is reduced to lessen the risk of high water loss. Secondly, to maintain governance over water distribution and its consumption in the illegible sectors, SEDAPAL rations the water for those areas. Only sectors that are fully legible receive water for 24 hours per day. We will return to this in the following section.

The sectorisation and the SCADA system, as means for legibility-making, help SEDAPAL monitor water distribution and possible leakages within the infrastructure, making it more efficient. However, people who live in sectors where the technology is not fully implemented or where the SCADA system functions intermittently are illegible or only sporadically legible. This differentiation in the legibility of the water distribution system results in a higher and more regular water supply for those who are legible compared to people who are only partially legible or illegible.

2.4.3 Practices of legibility-making of water consumption

The third scale of legibility-making in the water infrastructure is the micro metering of household water consumption. As of December 2019, 95.4% of Lima's piped water connections are metered (SEDAPAL, 2019). The purpose of metering water consumption per household is twofold. Primarily, the meters allow for more accurate billing of the water consumed. Secondly, the fine-grained data generated by the micro-meters gives a more comprehensive insight into patterns of water consumption within the city. Keeping track of consumption patterns can help with the prognosis of future water needs and identify possible issues in the water infrastructure, such as leakages or clandestine consumption. Therefore, water meters have been an essential tool for SEDAPAL to reduce non-revenue water in their system.

Different types of micro-meters have been installed in Lima's households. Although the most recent meters can be read digitally, the majority of the meters are analogue and read manually by an employee of SEDAPAL (INACAL, 2020). The data retrieved from the meters is then digitised and incorporated into the supervisory and control system of the administrative processes of SEDAPAL. Similar to the SCADA monitoring of the water distribution system's operation, this digital data technology monitoring the water consumption and payment is stooled on GIS.

Nevertheless, while the overall coverage of the consumption meters in Lima is relatively high, we see two critical limitations in making water consumption legible. First, measuring household water consumption with micro-meters is based on the assumption that residents live in individual households. In practice, specifically in Lima's older districts, many residents live in multi-family housing units, such as apartment buildings or *quintas*, and rely on one entry point from which the water and the bill are divided among the tenants. SEDAPAL offers a guideline for the administration of the water amongst the tenants in which they suggest dividing the cost equally amongst each household, not taking into account the differences in consumption due to variations in the household size or water use. This requires a collective administration of the residents, and its success strongly depends on the community's organisational capacity. In these cases, the water consumption registered by SEDAPAL is that of the multi-family unit rather than the individual households. For the representation of people in the data, this is not insignificant as there can be up to 70 households within a *quinta*, and the number and height of apartment buildings in Lima are increasing.

Secondly, we see that the coverage of the meters within the city varies strongly from 41.3% in the least metered district to 99.9% in the most densely covered district (SEDAPAL, 2019). A partial explanation for this geographical difference lies in the lag in the implementation of meters by SEDAPAL in newly urbanised areas. Additionally, SEDAPAL argues that due to vandalism, the opposition of residents to the installation of the meters in their households, and the difficulty of planning the installation of meters in high-crime areas, some areas are under-metered (SEDAPAL, 2014). Within public discourse, the meters are perceived as unreliable, even raising the suspicion that they function as a tool for SEDAPAL to raise water bills (Hoefsloot et al., 2020). In several central districts, neighbourhoods have collectively opposed installing the meters. One SEDAPAL employee explained they had ceased their efforts to implement the water meters in certain areas since they had been harassed during their job. There are also cases reported where communities removed the meters upon installation. As a result of this resistance, whole blocks remain illegible in the water consumption data.

This is important as SEDAPAL argues that only households with a water meter installed should continuously receive water. The argument for this is that households, which are metered, tend to use less water than those that are not since they feel the financial consequences of water consumption directly in their monthly payments. The connections that do not have a meter are thus rationed and receive water only for a limited time per day, sometimes even as little as one hour.

Where meters have been installed, the digitised data of the meter helps monitor whether the water consumption follows the expected pattern. Outliers in the data can signal various problems in the system. A high outlier can point toward an unreported leak or a sudden increase in consumption (as the result of a family visit, for example). Low outliers can signal that the meter is broken, the consumption has gone down drastically, or the metered pipe has been bypassed by constructing a clandestine connection. Engineers of SEDAPAL are using Google Street View and Google Maps to see if they can identify what the probable causes may be. For example, a construction site, an abandoned house, or buildings with rental advertisements can explain a reduction in metered water consumption. On the other hand, buildings with newly constructed stories or laundry drying on the rooftop, in combination with very little recorded consumption, might point toward a clandestine connection.

Thus, making water consumption legible is integral to SEDAPAL's strategy to reduce non-revenue water and increase the infrastructure's efficiency. Nevertheless, in effect, it also provides SEDAPAL with arguments to ration the water delivery to households that are not metered. In addition, the data of the water meters, in combination with Google Street View and Google Maps, allows SEDAPAL to inspect changes in water consumption patterns on the household level at a much finer granularity than previously possible.

2.4.4 Water access while illegible

The nature of urban development in Lima illustrates how attempts of legibility-making fail to deal with the speed and the uncertain and unpredictable nature of urban expansion and that the data created about the new settlements and water consumers of Lima excludes people and practices of accessing water resources. However, these illegible water consumers do deploy various strategies to access water. As described previously, they either buy water by trucks with water tanks (see, Figure 2.3), share connections with neighbours or create clandestine connections to the pipelines. The water consumed through these alternative or clandestine methods is not only poorly regulated and often sold at a higher price than the water delivered through the pipes. Importantly, as SEDAPAL is not the water vendor, the water quality is not monitored and hence not guaranteed by SEDAPAL.

Figure 2.3 Truck with water tank (camión cisterna) selling water to people and neighbourhoods that are not connected to the piped water network. Photo was taken by the first author.

While their water consumption is absent from the data used to manage the water infrastructure, it is present in the dominant narrative about water distribution in the city. In policy documents and master plans, their consumption is described as ‘illegal’ or ‘clandestine’ and grouped with other illegible water flows such as leakages and overflows under the category of non-revenue water (SEDAPAL, 2014; SUNASS, 2017a).

As the discourse around the datafication of Lima's water infrastructure focuses on the reduction of non-revenue water, the people not counted are, by association, identified as illegal. On the ground, SEDAPAL is testing different strategies to detect illegible connections. In addition to using Google products to verify consumption patterns that are illogic according to the data, SEDAPAL is experimenting with the use of a ground-penetrating radar, or georadar, to survey the subsurface of the city for pipes. The georadar, installed on a small cart, can detect pipes and determine their type and width, making it possible to corroborate whether or not SEDAPAL has constructed the pipes. Any clandestine connections detected are removed, and the households connected will be fined.

2.5 Interpretation: Degrees of (il)legibility and their effects on water provision and consumers

From the vantage point of SEDAPAL, looking through the data and following the legibility-making practices, we identified how the data image of the water infrastructure only partially represents the city. Legible are those parts of the city that are at one and the same time: mapped in SEDAPAL's cadastre, monitored in the SCADA system and measured through the household water meters. However, on-the-ground reality, in which people receive water at irregular times, settle outside of pre-defined sector boundaries, and are not registered in the administrative databases, defies attempts to generate a fully comprehensive and standardised data image of the city. For every legibility-making practice that we discussed, we see that there is also illegibility created. These outcomes can be layered in different ways and, as such, create different degrees of legibility and illegibility in the hydrosocial geography across the city.

These findings align with other research that demonstrates how data are not fixed or objective but a link in a long chain of actions and decisions (Kitchin et al., 2016; Richter & Georgiadou, 2016). Specific about datafication is that (il)legibility-making practices are layered; and people become categorised in multiple ways through a bundle of digital, technical, and spatial contingencies. In other words, datafication – understood as the interplay between different legibility-making practices that are running partially concurrently – determines the relationship between SEDAPAL, as a state organisation, and Lima's residents.

Table 2.2 summarises how the interlinkages between the three scales of legibility-making practices analysed in section 4 create a differentiated hydrosocial geography. That is, a geography characterised by distinct categories of water consumers as well as by varying, corresponding effects on water delivery. Four types of water consumers in the city emerge from our analysis as a result of different degrees of (il)legibility: (i) the registered and metered water consumer, (ii) the registered, non-metered water consumer, (iii) the alternative water consumer, and (iv) the 'illegal' water consumer (Table 2.2).

By unpacking the datafication of Lima's water infrastructure as layered legibility-making practices, we see how the differentiation in water consumers is not the sole result of the unruliness of Lima's urban sprawl, the lack of control over water flows, or the unwillingness of residents to work within the imposed structure for water governance. Although all these elements play a part, the categorisation of water consumers, as emerged from our analysis, is, at the same time, the result of the, sometimes arbitrary, choices made in the development of digital data technologies. As such, what appear to be purely technical interventions in the infrastructure and practices of legibility-making are not independent of the broader political

Table 2.2 Summary of the identified types of water consumers that emerge from the datafication of the water infrastructure.

		Registered* and metered water consumer	Registered, non-metered water consumer	Alternative* water consumer	'Illegal'* water consumer
Means of legibility-making practices:	Of settlements: Cadastre and drone mapping	Yes	Yes	Pre-formalisation	Pre-formalisation
	In water distribution: Sectorisation and SCADA systems	Yes	Yes / No	Yes / No	No
	Of water consumption: Micrometre, Google products, and Georadar	Yes	No	No	No / Yes**
Effects of (il)legibility on water distribution:	Water quality	Monitored	Monitored	Non-monitored	n/a
	Price	Pays a low rate for actual consumption	Pays a low rate for estimated consumption	Pays a high rate for actual consumption	n/a
	Reliability	High – continuous water supply	Low – rationed water supply	Low – rationed water supply	n/a

* Registered water consumers receive water from the public piped water infrastructure. Alternative water consumers often receive water from tanker trucks or communal water taps. 'Illegal' water consumers receive water via clandestine connections.
** 'Illegal' water consumers are strategically made legible by SEDAPAL using Google products and a georadar for the purpose of policing.

landscape (Amin & Thrift, 2017). The more comprehensive and detailed view of the water infrastructure makes it easier to control water flows within the city, one of the main goals of SEDAPAL. While at the same time, it has also provided the reasoning to deliver less water to illegible consumers and inspect unexpected water consumption patterns. Hence, as a result of the datafication, the water infrastructure has become more efficient to manage for SEDAPAL, more reliable for registered and metered water consumers, but less equitable for the residents at large. In other words, the direct impact of the datafication is the implicit and hierarchical categorisation made between water consumers, and the effects of this categorisation are experienced through the differences in the quality, price and reliability of the distributed water. As illustrated in table 2.2, the order created between water consumers in the data and urbanised and not-yet-urbanised areas exposes the interactions between (il)legibility, infrastructural development, and the relationships between the state and its residents (Sultana, 2020) and demonstrates how people living in conditions illegible by the state are subjected to illegalisation as a governance strategy (Roy, 2018).

This, in turn, illustrates how legibility-making and illegibility-making are – sometimes strategic – parts of urban governance (Gandhi, 2017; Kalir & van Schendel, 2017). On the one hand, data can be created to make the inequality in water connections and consumption visible and accelerate the process of service provision. In addition, the exact enumeration of the people living in Lima in different degrees of informality and their water needs can serve as a tool to hold SEDAPAL accountable for the delivery of water services. On the other hand, as SEDAPAL has the mandate to connect all citizens of Lima to the water infrastructure, it can be strategic for SEDAPAL to maintain illegibility in areas that are difficult to connect to the infrastructure due to economic, political, or topographical reasons. At the same time, SEDAPAL uses Google products and the georadar selectively to make clandestine connections legible and police the people who consume water via those systems.

2.6 Conclusion

With the rapid implementation of digital data technologies in urban infrastructures, we are beginning to grapple with the effects of data on the distribution patterns of public services and resources. In this article, we aimed to answer how datafication, as layered legibility-making practices, shapes Lima's hydrosocial geography and affects residents as distinct water consumers. The case of Lima's water infrastructure interventions illustrates how implementing 'smart' technologies and integrating multiple data sources for resource management increases the administrative order and control over urban resources. Yet, at the same time, datafication does not automatically lead to the further incorporation of residents into the water network but produces new distinctions between spaces and between people. Moreover, this research argues how this act of differentiation structures the relationship between the water provider and consumer and produces – more or less unintentionally – new categories of water consumers, which we have represented as four types.

Politically, the most significant distinction that emerges is that between the registered water consumers, on the one hand, and the deviant cases, the 'illegal' water consumer, on the other. The crux lies in the normative notions attributed to the categories created (Roy, 2018). We see the implications of datafication in how it distinguishes between the consumers, who are legible, and those consumers, who are illegible and whose consumption is, in turn, criminalised and who become categorised as 'illegal consumers' (Offenhuber, 2017; Pilo', 2017; Roy, 2018). In other words, datafication, especially through its – in this case, at first sight implicit – categorisations – mediates people's claims and access to water resources, a key lesson that is similar to arguments made in research on Indian water infrastructure (Anand, 2017).

Thus, despite the rhetoric focusing on the benefits of data production for efficient infrastructural management, we observe that through a bundle of digital, technical, and spatial contingencies, (il)legibility-making practices create differential geographies in the city beyond the formal/informal dichotomy. Table 2.2 illustrates that the layering of legibility-making practices differentiates water consumers according to multiple characteristics and creates a gradient in legibility rather than a black and white image. This differentiation between these categories is not fixed but continuously reconfigured through the production and bundling of data. And, importantly, through the strategic movement of people in and out of sight of administration and public service provision by the state.

The water infrastructure analysed in this paper shows the value of approaching smart city developments as layered legibility-making practices. We found that in the smart city, where various structured and unstructured sources of data come together and databases are made interoperable, it becomes increasingly important to consider not only the role of a variety of actors beyond the state that are making legible (Li, 2005; Taylor & Richter, 2017) but also the links between the variety of data sources and understand their interplay.

As newer streams of data and associated technologies interlink with existing practices and infrastructure, the longer-term effects on the distribution of urban resources remain dynamic and not entirely predictable. Future research will have to focus on how and where the top-down governance practices meet with the everyday practices of people living in cities and consuming urban resources. This would reveal how the everyday experiences of people living in cities are processed and enacted through infrastructural development. As the case of Lima shows, this is specifically important in cities characterised by large socio-economic, spatial, and hydrological inequalities, where digital data technologies seek to increase equality and homogenisation but seem to introduce new differentiations, multiple layers of boundaries, and as such, reproduce the nature of inequality.

Chapter 3:

Expert-amateurs and smart citizens: how digitalisation reconfigures Lima's water infrastructure

Abstract:

In Lima, residents are fundamental co-creators of the urban water infrastructure, taking up various roles in the operation, maintenance, and expansion of the water distribution system. As Lima's potable water company presses the transition from decentralised and auto-constructed to centralised and digital, this article explores how the implementation of digital infrastructure reconfigures the role of residents in the water distribution system. Our analysis draws on an ethnographic research approach, using formal and informal interviews, and focus groups in three areas representing Lima's diversity in settlement categories and types of water consumers. By analysing the digitalisation of Lima's water infrastructure through the perspective of its residents, this research contributes to understanding how top-down, digital governance practices mediate the agency and everyday experiences of people living in Southern cities. We observe that the digitalisation of the water infrastructure marginalises the participation of the 'expert-amateur,' a crucial role in the development of urban areas in the Global South, while providing more space for the 'smart citizen' to engage in infrastructuring. This article concludes that to overcome the perpetual creation of the centre and the periphery through digitalisation, urban infrastructure management should be sensitive to residents' diverse strategies in managing resources.

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3.1 Transitioning from fragmented towards integrated infrastructure

This article explores how the water infrastructure of Lima transforms materially and organisationally as SEDAPAL, Lima's potable water and sewerage company, presses the transition from decentralised and auto-constructed to centralised and digital and what this means for the roles of urban residents in the process of infrastructuring. The history of Lima's infrastructural growth is one of auto-construction. In the absence of government service provision in the city-becoming, residents have created fragmented networks of water distribution systems with a large variety in materials, efficiency, and functioning. These auto-constructed systems have different iterations, some are more, and some are less controlled, but in almost all cases, they are communal in nature. As a result, the water infrastructure in Lima is a patchwork of planned as well as auto-constructed infrastructures, only connected by the water that flows through them.

One of the primary objectives of SEDAPAL is to unify these different water distribution systems and create one homogeneous infrastructure that services all of the city's residents. Aside from expanding the water pipes within the city, SEDAPAL aims to achieve an integrated and centralised infrastructure by implementing digital information technologies. The digital, in this case, refers to the collection of technologies used to generate, distribute, analyse, and use data for infrastructural management (Star & Ruhleder, 1996). This includes data acquisition technologies, such as meters and sensors, and the geo-information systems—digital by nature—used for the management and analysis of water-related data. Under the banner of creating a more efficient and easily controllable network, SEDAPAL has implemented digital information and data acquisition systems, making it possible to monitor the operational and commercial sides of the infrastructure in one web-based geo-information system (SEDAPAL, 2015). These digital infrastructures make the system legible, albeit to various degrees, and facilitate the centralisation of Lima's water management (Hoefsloot, Pfeffer, & Richter, 2019).

The implementation of digital infrastructures works towards achieving what Graham and Marvin (2001, p. 73) have called the 'modern infrastructure ideal.' They argue that the modernist image of fully integrated and standardised infrastructure, as developed in Western countries, has been exported as ideal for infrastructural provision to colonial and post-colonial cities. However, since the 1980s, neoliberal politics have led to the unbundling of these integrated infrastructures, resulting in unequal service provision where urban elites are connected, and urban poor are disconnected. In Graham and Marvin's work, this transition from integrated towards splintered is presented as characteristic of our time. However, Coutard (2008), drawing specifically on case studies in the Global South, argues that many cities have always been unbundled, and their infrastructures are fragmented and segregated. While the normative imaginary of centralised and universal service provision continues to be a powerful tool in shaping infrastructural planning worldwide, Coutard (2008, p. 1818) suggests that in Southern cities, 'recent evolution does not involve a passage from an integrated system to an unbundled one, but rather a passage from one more or less unbundled system to another.' Bulkeley, McGuirk, and Dowling (2016) argue that to understand the implications of smart city developments for urban residents; research should engage more directly with the material politics on the development of digital infrastructures. This requires opening up to the diverse forms of agency at work in the process of infrastructuring and asking who is included and who benefits from technological transformations (Bulkeley et al., 2016).

Hence, to understand the social implications of these dynamics, we have to unpack how they play out in specific socioeconomic and material structures and reconfigure the script of the infrastructure. The concept of the script (Akrich, 1992) refers to the embedded logic of the socio-material structure that steers the interaction with users (Jelsma, 2006). The script of the infrastructure prescribes roles for users and technology as 'actors' in a play. Yet, the script is continuously rewritten through users who change the system according to their own logic or the implementation of new technologies (Jelsma, 2006). Previous scholarship in smart urbanism has foregrounded how digital infrastructures re-inscribe the governing of flows within the city by integrating physical and information systems spatially and hierarchically (Marvin & Luque-Ayala, 2017); the implications of smart city policies in urban development (Verrest & Pfeffer, 2018); and emphasised how the general rhetoric of the smart city prioritises an increase in surveillance and efficiency (Kitchin, Maalsen, & McArdle, 2016; Luque-Ayala & Marvin, 2015; Vanolo, 2014). Yet, there is a need to understand how these integrative transformations affect residents' influence, control, and self-determination in urban development (Marvin & Luque-Ayala, 2017). The imaginary of the smart city is so strongly coupled with high-tech innovations and private-public partnerships that the resident is often not considered or simply conceptualised as a 'data provider' (Calzada, 2018; Vanolo, 2016). With sensing applications in mobile devices, homes, vehicles, and city-wide infrastructures, residents are continually producing data that are incorporated into smart city products (Rabari & Storper, 2015). Data is created while residents simply perform their daily routines (Calzada, 2018).

Today, the discourse about the smart city is shifting towards a more resident-centred framework in which people are no longer seen as instrumental to the technological development of the city but as their co-developers (Calzada, 2018). This strongly resonates with the development in Western cities, where urban planning has moved from modernist master plans to smart cities and is now progressively allowing for diverse forms of resident participation in the construction of urban space. Hajer and Dassen (2014) argue that the truly smart city should integrate residents into the process of developing infrastructure. They reason that, with an increasingly educated society, the community is a valuable source of information and energy, and its collective intelligence should be harvested.

Vanolo (2016) describes how the resident, and their role, is imagined differently in various discourses of the smart city. Within the neoliberal discourse of the smart city, the 'smart citizen' is a homogeneous category of people who are digitally connected, educated, and willing to participate (Vanolo, 2016). Optimistic about the potential of digital technologies to empower and democratise, it is argued that the smart city amplifies the voice of residents in the planning and construction of urban space (Shelton & Lodato, 2019). Nevertheless, Shelton and Lodato (2019) explain that the smart citizen has to adhere to the confinement of the technocratic and neoliberal political and material practices of the smart city. Only those who can invoke particular forms of expertise tied to policy-making or technological development can participate. Effectively, less privileged residents who do not have this form of professional or institutional capital are overlooked or excluded (Shelton & Lodato, 2019; Tenney & Sieber, 2016). Hence, 'smart citizenship' is a reductionist and exclusionary category, reserved only for those who are privileged to be documented as citizens of the city and have the education and capital to participate in the digitised system. However, in Southern cities, also non-registered and non-connected residents have always been active as fundamental co-creators of the city (Button, 2017; Holston, 1991). As builders, managers, and maintenance workers, they have constructed and operated urban infrastructure, living through its many iterations (Simone, 2019). Kuznetsov and Paulos (2010) introduce the character of the 'expert-amateur,' emphasising the fact that the people who are involved in these community constructions have advanced knowledge about the artefact or system they co-construct. Yet, they do so outside of the professionalised and commercial sphere. The expert-amateur is oftentimes autodidact or has gained knowledge and skills while learning from peers.

Therefore, mindful of these differences in the positions and capacities that residents can have within urban infrastructure, we ask: How does the digital infrastructure reconfigure the roles within the water distribution system in Lima, now imagined as centralised and digital, rather than decentralised and auto-constructed? By analysing the digitalisation of Lima's water infrastructure through the perspective of its residents, this research contributes to understanding how top-down, digital governance practices mediate the agency and everyday experiences of people living in Southern cities.

We specifically zoom into two technologies implemented in Lima's water infrastructure: the household water meter and the customer contact centre. These two technologies are now standard practice in many cities worldwide yet play a crucial role in the digitalisation of the water infrastructure through their production of data. The meter produces numerical data about water consumption within the city. The customer contact centre allows SEDAPAL to register textual and visual data about the functioning of the water infrastructure. Due to their relative fine spatial (households rather than water sectors) and temporal scales (monthly for the meters and continuous for the customer contact centre), they provide insights into water consumption patterns and operational issues. Most importantly, the meter and the customer contact centre function as an interface between the consumer and service provider (Pilo', 2017). By measuring the household water consumption and the registration of the type and location of the complaints submitted by residents, the meter and the customer contact centre translate the interaction of Lima's residents with the water infrastructure into data. The data produced by these technologies allow for the registration of problems and water flows that were illegible before their implementation and are, therefore, important in the production and redefinition of relationships within the infrastructure (Kragh-Furbo & Walker, 2018).

3.2 Methodology

Six months of fieldwork in Lima during 2019 and 2020 form the empirical basis of this article. It is part of a larger research project focusing on the implementation and impacts of digital infrastructure in Lima's water management. This research project employed an iterative ethnographic strategy for data collection and analysis. Twenty-five interviews were conducted with experts in the field, including engineers working for SEDAPAL and academics, and representatives of community and civil society organisations. The interviews varied in structure and focus, depending on the context of the conversation and the person interviewed. We then conducted seven focus groups (FG) with residents asking them about how they access water, administer their consumption, and perceive the digitalisation of the water infrastructure. Residents from three neighbourhoods were invited: José Carlos Mariátegui, Barrios Altos, and Miraflores. These three neighbourhoods were selected to represent the city's diversity in socioeconomic development, geography, and degree of formalisation (Figure 3.1). José Carlos Mariátegui, situated on the periphery of Lima, has developed mostly during the last two decades through the process of auto-construction, as will be described further below. The majority of the residents in José Carlos Mariátegui live in conditions of extreme poverty. Barrios Altos, the 'high neighbourhoods,' is one of the oldest areas of Lima. Lending its name from the fact that it is situated on a small hill and thus higher than the main square of the city, the neighbourhoods historically developed as housing for the non-noble families of the early colony. Although it has gone through many different phases in the past, today, it is a middle and low-income neighbourhood. The third district where we conducted our research, Miraflores, is the city's main upper-class residential district and forms the centre of Lima's tourism industry. Modern high-rise apartment complexes characterise it.

José Carlos Mariátegui	Barrios Altos	Miraflores
Peri-urban	Historical centre	Tourist and commercial centre
Auto-constructed	Planned	Planned
High degree of extreme poverty	Poor and middle class	Upper-class

Figure 3.1 Aerial and street views of the three neighbourhoods from which residents participated in the focus groups. Street view and aerial images from Google Earth Version 9.165.0.1. Lima, Peru. Maxar Technologies, https://earth.google.com/web [December 05, 2020].

This research specifically focused on these three areas to compare the different roles of residents in the water infrastructure across urban classes and living conditions. Previous research has analysed issues related to water infrastructure, water access, and water use amongst the urban poor in Lima and Latin America (Allen et al., 2017; Brown & Pena, 2016; Fernandez Maldonado, 2008). Yet, few studies have included the practices and perspectives of the urban middle class and elite in discussing the process of infrastructuring. The participants in the focus groups thus represent users of auto-constructed infrastructures and digitised and integrated infrastructures. Since the focus groups attracted more older adults than youth, we organised an additional focus group with Limeños aged 18–30.Additionally, we organised two meetings with experts in the field to discuss the technological development of the water infrastructure and generate knowledge about the possible futures for Lima's water distribution system. The first meeting included experts from different strands of government, academia, and civil society groups. The second expert meeting was with researchers and engineers of SEDAPAL. The focus groups and expert meetings lasted between one and two-and-a-half hours and were recorded and transcribed.

We used the analogy of the 'script' (Akrich, 1992) to analyse how the design of the infrastructure defines the roles of, and interactions amongst, residents and technology within the system as it transitions from decentralised and auto-constructed to centralised and digital. Jelsma (2006) conceptualises the script as a prescriptive force that steers the behaviour of a technology's users in a certain direction that matches its inscribed logic and redistributes roles, responsibilities, and power within the sociotechnical network. Thus, the script of the infrastructure shapes the role of a person within the system and encourages certain 'desirable' actions while discouraging 'undesirable' use (Jelsma, 2006). The infrastructural script can be moralising in the sense that it steers towards practices that align with its embedded normative framework. By making the 'better' option more convenient, residents are nudged towards conforming with the 'integrated infrastructural ideal' (Koop, van Dorssen, & Brouwer, 2019). Nevertheless, this relationship is bidirectional. The users of the system, in this case, the residents of Lima, might envision different roles for themselves and re-inscribe the infrastructure through their actions and based on their experience and situated knowledge (Akrich, 1992; Rose et al., 2018).

Using ATLAS.ti™, we conducted a thematic analysis of the focus group transcripts as well as the individual interviews, coding for different roles within the infrastructural development (planning, construction, operation, maintenance, and replacement) as the main themes and paying specific attention to narratives that explained people's perception of, and attitude towards, the implementation and use of digital infrastructures for the administration of water consumption (see appendix 4 for the codebook). Three main themes emerged out of the analysis process: (i) How people have auto-constructed their domestic and communal water infrastructures, (ii) how the meter and the customer contact centre change the script for the operation of the infrastructure, and (iii) how the meter and customer contact centre redefine the roles of, and interaction between, SEDAPAL and Lima's water consumers based on embedded norms. These three themes correspond with the three results sections 3.1, 3.2, and 3.3. Throughout the text, translated quotes from the verbatim transcripts illustrate the residents' experiences and interactions with the digital infrastructure and complement our empirical data with findings from the literature.

3.3 Results

3.3.1 Lima built by expert-amateurs: residents as engineers, constructors, and maintainers

Like other Latin American metropoles, Lima has grown mainly through the building of dwellings, neighbourhoods, and infrastructure by its residents (Amin, 2014; Caldeira, 2017; Fernandez Maldonado, 2008; Holston, 2009). In this section, we analyse the script of the auto-constructed infrastructure and illustrate how, depending on their geographical location and socioeconomic context, residents have shaped the water distribution system to fit their needs and inscribed it according to their own logic, with SEDAPAL often only having very little formal influence as the provider of water to the central distribution point or vendor of water to the trucks that serve the area.

Lima's urban expansion was particularly fast from the 1950s to the 1970s, during which internal migration toward the city was particularly large (Ioris, 2012a). Due to the lack of available housing to accommodate the growing number of residents in Lima, people started to organise themselves, occupying barren lands on the fringe of the city, building their first settlements, and constructing primary infrastructure such as water and electricity networks (Ioris, 2012a). This form of auto-constructed urbanisation continues today. With every new generation, the peripheral edge of the city has moved further outwards and upwards, stretching over the hills surrounding the city. In general, Lima's most impoverished families live in the farthest and most precarious dwellings.

Although this form of urban and infrastructural development is especially prevalent in the newly urbanised areas in the city's periphery, auto-construction also exists in the heart of the city and its most affluent neighbourhoods. As Caldeira (2017) argues, the 'urban periphery' is not, by definition, physically located on the urban fringes. Peripheral urbanisation and auto-construction can exist in all geographical locations. Holston (1991) describes auto-construction as the process in which people construct neighbourhoods under precarious circumstances, physically, legally, and socially, and slowly consolidate their right to the city through the formalisation of their dwellings. The auto-construction of housing and infrastructure is impactful, not only because it is the construction of something out of nothing but because it is a process in which settlements gradually transform into urban districts and squatters into citizens (Holston, 1991).

It is estimated that about 60% of Lima's urban area is auto-constructed (Metzger, Gluski, Robert, & Sierra, 2015). Today, many of the districts that have been constructed by residents in the 20th century are fully consolidated and integrated into the urban fabric (Fernandez Maldonado, 2008). Many more recently inhabited areas are still in the midst of this process. These auto-constructing communities, often living in partial informality, form a driving force in the urbanisation of Lima, including the expansion of its water distribution system. Residents continue to play an essential role in the development, operation, and maintenance of the water infrastructure. However, it is a fine line between appreciating the resourcefulness and creativity in auto-construction without romanticising the retreat of the state in service provision (Jiménez, 2014). In contrast to self-built neighbourhoods, co-housing, and participatory planning practices in the Global North, auto-construction in urban centres in the Global South is often a symptom of poverty and born out of necessity due to the lack of basic services provided by the state (Caldeira, 2017).

In peripheral neighbourhoods, residents invest their labour and time in laying pipes, building reservoirs, and designing a system of pumps, tanks, and hoses to distribute water to the different homes in the neighbourhood. In the central areas of Lima, such as Barrios Altos, where piped infrastructure is often physically close, but individual households or *quintas* (traditional courtyards with multi-household dwellings) are not yet connected, people construct clandestine connections to the primary grid or the networks of their neighbours. As a result, one Barrios Altos resident explained that the system is often overburdened:

> 'We do not respect the laws. We do not comply….While I pay, there are five neighbours who pay nothing, and now I have to bathe at 6 pm or at 5 pm if I want to bathe at 10 or 11, I can't, I don't get it. In Barrios Altos, I am next to the river or near, and I cannot take a bath because it does not reach me, because from the pipe that comes five people are pulling [water].'
>
> *(FG, Barrios Altos, 12 February 2020)*

On the city's edge, in José Carlos Mariátegui, geography plays a significant role in the types of systems that have been developed. The steepness of the hills and the quality of the roads that connect the area determine whether or not trucks carrying water (*cisternas*) can access the residents. In the most distant areas, where the *cisternas* cannot reach, residents generally construct a communal reservoir in a lower-laying part of the area. From this reservoir, the water is pumped through a network of hoses that service the different households. This system requires frequent maintenance and repair as the pump, and the hoses are vulnerable to breakdown. Even for those who do live along the route of the *cisternas*, access to water remains a challenge. Residents are never entirely certain when the truck will pass their homes and if it will stop. To mitigate this, many residents have invested in constructing water reservoirs that, when filled, will last them for a couple of days.

Additionally, community boards coordinate the water management and administration within their areas (see, Figure 3.2) and work towards formalising the water distribution system in cooperation with SEDAPAL. The success of these practices varies and depends largely on the community's capacity to self-organise and work together. On a smaller scale, and in communities that are serviced by SEDAPAL, residents tweak the system: households install reservoirs on their roofs to guarantee a continuous supply of water despite cuts, they implement filters so they can drink water from the tap, or even build connections between the sink and the toilet to ensure that dishwater can be reused.

Analysing the script of the auto-constructed infrastructure, we find that residents play a crucial role in all phases of the infrastructural life cycle. The distinction between the service provider and the consumers is blurred. Residents, as 'expert-amateurs,' play a significant role in continuously expanding, improving, and maintaining the infrastructure (Caldeira, 2017; Kuznetsov & Paulos, 2010). They take up the role of engineer, builder, and manager in one, thereby blurring the distinction between service provider and consumer and adjusting the infrastructure to align with their needs and practices. Contrary to the formal infrastructural planning in Lima, which is a highly bureaucratic process, the auto-constructed infrastructure can respond quickly to the changing needs of residents. Within the auto-constructed infrastructure, the demarcations between the different stages of the infrastructural cycle are less clear, continually moving between planning, construction, operation, and maintenance. Nonetheless, aside from calls to residents to save water and consume responsibly, SEDAPAL's master plans often do not acknowledge their labour and knowledge in shaping the water distribution system. Although some of these constructions have been in place for decades, the work of residents is almost without exception characterised as tinkering around in the margins. The systems they construct are seen as provisional, a placeholder for when SEDAPAL integrates these areas in their centralised and digitised infrastructure.

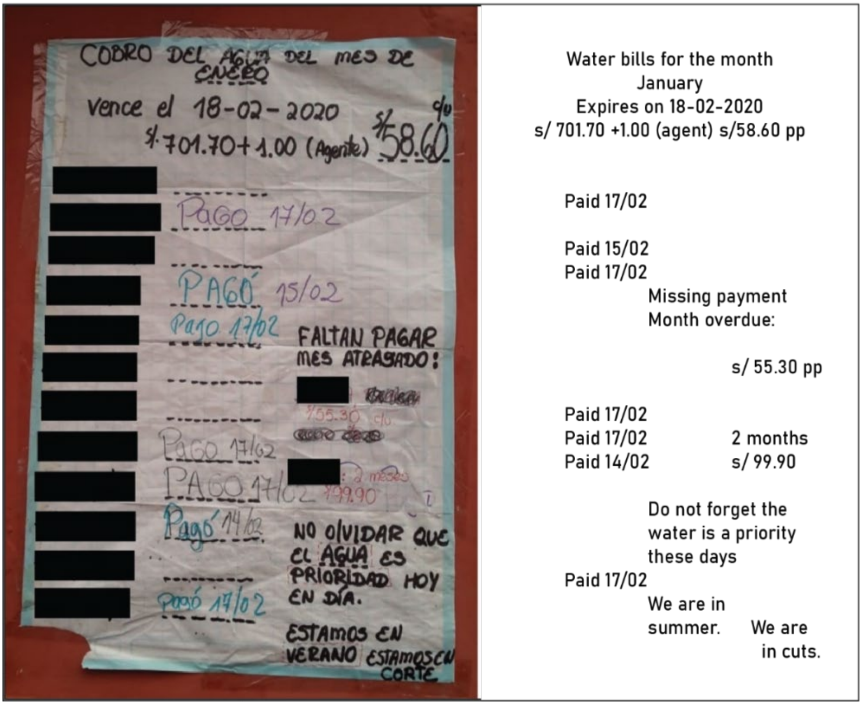

Figure 3.2 Poster on the communal wall in quinta, keeping track of the payments for the water bills. At the time, 58.60 soles corresponded to €16 or $17.3. Photo: Liliana Miranda Sara. Translation by the authors.

3.3.2 How digitalisation redistributes roles within the operation of Lima's water infrastructure

As the infrastructure transitions from decentralised and auto-constructed to centralised and digital, we see that tasks that previously were the domain of the residents are now shifted towards SEDAPAL as the main service provider. In this section, we analyse how the introduction of the water meter and the customer contact centre have (i) facilitated the centralisation of the operation of the water infrastructure and (ii) re-inscribed the roles of residents within the operation of the water distribution system.

Operationally, the meter and customer contact centre are efficient tools for monitoring the consumption behaviour of users and the functioning of Lima's water infrastructure right from the central water treatment plant, La Atarjea. The implementation of the meter helps to centralise the control and supervision of the infrastructure, bringing Lima's water distribution network one step closer to the 'integrated infrastructure ideal.' The meter enables the enumeration of the water consumed on a small scale and the inclusion of this data in the GIS-based systems used for the supervision and operation of the water distribution system. The type of meter implemented varies depending on the technology available at the time of installation, the width of the pipe, and the pressure of the flow. As a result, some household consumption meters in Lima need to be read manually, while others can potentially be read at a distance through electronic pulse emitters or radio frequencies (INACAL, 2020). In December 2019, 95% of the residential connections to the piped water infrastructure were metered. However, the meter coverage ranges from 41% in the least-covered district to near full coverage in other districts (SEDAPAL, 2019). Households with an unmetered are charged a flat rate based on the average hours of water supply, or communities share a water bill and self-manage their payment. Upon the meter's arrival, households receive an individual bill reflecting the meter's measurement of the amount of water consumed that month. Additionally, through the meters, SEDAPAL can detect leakages and clandestine connections much easier, which leads to a reduction in the percentage of non-revenue water in their system.

Likewise, the textual and visual data generated through the customer contact centre help SEDAPAL monitor the infrastructure through residents' reports, effectively providing feedback on the system's functioning. Initially, SEPAPAL hosted the call centre itself, to which users could report issues with the infrastructure via phone. Today, the contact centre has been outsourced and expanded, integrating various media such as e-mail, social media (Facebook, Twitter, and Instagram), a chatbot, video calls, and photo sharing into one service. The calls and the operator's movements on-screen are recorded and compiled in a file linked to the caller's customer number and, therefore, disclosing personal information such as their address and geo-location. This allows the operator to return to the conversation at any moment later in time. With the operators recording incidents and passing on this information to the relevant directories, SEDAPAL has a continuous flow of digital information coming in, reporting on the quality of its service.

In both cases, we see that the data provide information about the operation of the infrastructure on multiple levels. The data from the meter, translated into a water bill, offers residents information about their consumption patterns and can serve as a gauge to keep track of changes or failures in the system. In a number of cases, residents had received extremely high bills due to undetected ruptures or leakages in the pipes. Talking about this issue, one participant explained:

> We have had serious problems because a receipt for 6000 has arrived! 6000 as if we lived three, two more buildings, or we would have a large pool. Of course, you pay first and then you reclaim [the money]. But we found the flaw. It was at the entrance.
>
> *(FG, Miraflores, 23 January 2020)*

Additionally, the spatially fine-grained (household scale) and monthly updated data from the household consumption meters provide information to SEDAPAL on the functioning of its water distribution system. Similarly, the reports continuously coming in through the customer contact centre offer information on the function of the water infrastructure through the eyes of the residents. There is, of course, a bias in the self-reporting of residents as they will more likely report issues that affect them negatively rather than positively, either in their access to water or financially. Yet, through the customer contact centre, SEDAPAL can capture issues that would otherwise go unreported.

At the operational level, the imperative of achieving a fully integrated infrastructure, and hence, the implementation of digital infrastructure to supervise and control the water distribution system from a central point, has been a powerful driver in the reconfiguration of information flows and relationships within the system. For residents, the digital infrastructure signifies a transition in the roles they have within the system. The implementation of the water meter shifts the administration of the water bills from the residents to SEDAPAL. From constructors, engineers, and bookkeepers, residents transition into the role of 'smart citizens' and form a critical link in the provision of data. Specifically, they play a crucial role in constructing new information flows, both to SEDAPAL and their communities and households. While the meters gather background information about household consumption, rendering residents into passive data providers, the customer contact centre relies on the active involvement of consumers in reporting the malfunctioning of the system. As a result, in the script of the digitised infrastructure, residents take up different roles than in the auto-constructed infrastructure. Rather than physically constructing or operating the infrastructure, they re-inscribe it through their passive or active production of data.

3.3.3 How digitalisation reconfigures residents according to its embedded normative framework

In this section, we analyse how the re-scription from auto-constructed to digital infrastructure is tied to concerns about the integrity of the technology and how the meter and customer contact centre prescribe residents the roles of 'smart citizens' and 'responsible users' rather than auto-constructors based on the infrastructure's embedded norms.

In conversations with SEDAPAL, the digital information infrastructure represents the modernisation of the distribution system and overall 'progress.' Modernisation, in this case, signifies a clear relationship between the residents as customers and SEDAPAL as the sole service provider. Particularly in the *quintas* of Barrios Altos, the residents welcomed this transition. From our analysis, it emerged that the administration of the water consumption amongst these communities was often paired with stress and conflict, either due to the fact that not all neighbours would pay their respective share in time or because people would construct clandestine connections to avoid payment. Whereas previously, it was necessary for several households to make collective agreements about payment of the water bill, the meter individualises this process and decreases one's dependency on neighbours. One participant alluded to the way the meter offers residents a certain degree of protection from their neighbours. They explained that the meter provides transparency concerning who is paying for the water and therefore makes it visible who has constructed a clandestine connection and is 'stealing' the water from their neighbours.

While this change is welcomed by many, the implementation of the meter is also regarded with suspicion by others. The residents expressed uncertainty about interpreting the data generated by the meter and its accuracy in reflecting the households' consumption. For example, it was not understood how it was possible that after the implementation of the meter, their water bill had gone up. Or, in Miraflores, why their consumption was registered as so much higher than in other areas. During FGs, participants hypothesised that these issues could be explained by the quality of the meters installed:

> You see the meters that SEDAPAL puts, the air passes and [the meter] rotates and should not rotate for the air, only when the liquid passes
>
> *(FG, Barrios Altos, 12 December 2019)*

Or by SEDAPAL taking advantage of the opacity in the data flows to their benefit:

> Participant 1: It may also be that they are inflating the consumption.
>
> Participant 2: I wouldn't be surprised at all.
>
> *(FG, Miraflores, 23 January 2020)*

As a result of this lack of trust in the integrity of the technology and SEDAPAL, in Miraflores, the overwhelmingly highly educated crowd in the focus group discussed the possibility of partnering with accredited laboratories to measure the accuracy of the meter and check the water quality. In discussing their options, the importance of working together with an official notary and working with certified material was emphasised to avoid all possibilities of not being taken seriously. Similar concerns were voiced, and possibilities for actions discussed in Barrios Altos and José

Carlos Mariátegui. However, contrary to the specialist approach discussed by the residents in Miraflores, the envisioned options of residents in Barrios Altos and José Carlos Mariátegui were to file complaints with SEDAPAL directly via the customer contact centre or on social media, a process which was described as tedious and often dead-ended:

> Participant 1: I think you can report what's happening on social media, right?
>
> Participant 2: Yes, but they never answer you, one calls for any accident, your pipe breaks, and they never answer. It is a bit difficult to talk to them.
>
> Participant 3: Practically, they have [the customer contact centre] as a screen.
>
> *(FG, José Carlos Mariátegui, 11 December 2019)*

Thus, although designed as an instrument for enhancing the service provision to the users and improving the residents' relationship with SEDAPAL, in conversations, residents frequently shared their frustrations with us regarding the customer contact centre. Residents explained they were put on hold for a long time and that when they managed to get through, they did not receive the help they expected. On the other hand, officials of SEDAPAL said that there are often inconsistencies in user reports, and people try to twist the truth for it to suit them better.

This highlights the contradictions in people's responses to the implementation of digital infrastructures and the roles they play in their becoming. The (digital) technologies, and by extension, the digital data they produce, change the script of the system by creating new information flows between the infrastructure and SEDAPAL, as well as between the residents and their water consumption. This suggests an increase in efficiency and transparency: two much-needed properties for the administration of basic services (Ioris, 2016; Martinez, Pfeffer, & van Dijk, 2011). Additionally, since users with a meter see the changes in their consumption pattern directly reflected in the monthly water bill, the presence of the meter incentivises responsible water consumption (Brown & Pena, 2016). However, given residents' general scepticism towards the integrity and capacity of SEDAPAL, the meter represents the presence of an institution that is mistrusted, and it is widely linked to stories of malfunctioning.

We notice a difference in the ways that residents coming from various socioeconomic backgrounds navigate these contradictions. As part of the residents embrace the implementation of the meters, others have refused to have them installed in their neighbourhoods or have taken them out of the infrastructure upon installation. This is closely tied to normative discussions about what it means to be a responsible consumer of water. While scepticism towards SEDAPAL and the water meters are widespread, residents who refuse to have meters installed are often questioned for their motives. It was stated by fellow residents and SEDAPAL alike that their unacceptance of the water meter and unwillingness to share information came from a wish to maintain clandestine connections rather than concerns about the integrity of the technology. The distrust towards these communities is reflected in the policies of SEDAPAL, which only provides water 24/7 to infrastructural sectors with meters installed. The other sectors are rationed and receive water for limited hours per day since it is assumed that non-metered residents will consume irresponsibly.

Thus, the meter and the customer contact centre, as pivotal objects in the digitalisation of Lima's water infrastructure, reconfigure the role of residents within the system, not only operationally but also morally. The meter contributes to the independence of households in their administration of water consumption and can serve as a tool for people to become 'responsible water consumers.' The people who opt out of this transition are regarded as irresponsible consumers and punished for not following the script. Interestingly, the digitalisation of the infrastructure does not lead to a similar transition in residents' perception of SEDAPAL and the state at large. The meter does not improve the public image of SEDAPAL by increasing efficiency and transparency. In practice, quite the opposite has occurred. By its association with SEDAPAL, the meter is perceived and experienced as counterfactual and part of a fraudulent infrastructural assemblage.

3.4 Agency and self-determination within digitised infrastructure

As Simone (2019) writes, urban residents inhabit the process of urbanisation rather than the place. This is specifically true for Lima's working-class residents who live through the different iterations of the script of the water infrastructure, which requires different tasks, relationships, and skills from them each time. Focusing on the work that is necessary to construct and operate infrastructure illustrates how this transition does not take place automatically, nor is it always considered to be an improvement. The ways that residents relate to these changes are multiple, as are their strategies to navigate them.

This research has analysed how the digitalisation of the infrastructure alters the script of the system and redistributes tasks, roles, and responsibilities within the infrastructure. The construction and administration of the water infrastructure have increasingly become a governmental rather than a communal effort, reflecting the centralisation of the infrastructural system. In the script of the auto-constructed infrastructure, people's roles are best conceptualised as 'expert-amateurs' (Kuznetsov & Paulos, 2010). The qualification of 'expert' is important in this case since the residents have advanced tacit knowledge about the needs of the community and the design, operation, and administration of the water distribution systems they have developed. As auto-constructed systems are formalised and augmented with digitised infrastructure, residents transition from these roles into various types of data providers, i.e., smart citizens.

The conceptualisation of residents' roles as 'smart citizens' is a useful heuristic to think through the exclusionary ways in which the position of people within the infrastructure changes (Calzada, 2018; Vanolo, 2016). When only digitally enabled participation, be it active or passive, is considered valuable, the work and engagement of non-digital residents remain hidden (Tenney & Sieber, 2016). Our analysis shows that despite the normative push of the infrastructure to mould people into 'responsible consumers' or 'smart citizens,' residents find different ways to exercise their agency. This includes opting out of the system, providing information in the shape of data, questioning the workings of the (digital) infrastructure, and critically engaging with SEDAPAL's policies through protests, marches, and public debate. Residents' practices often go against the logic of the integrated infrastructure. They 'disobey' the normative script, sometimes leading to tensions while doing so (Akrich, 1992; Jelsma, 2006).

Nonetheless, the skills needed to exercise agency in the new script are drastically different from the previous forms of the infrastructure. Within the digitised system, an understanding of (digital) technology and (data) policy becomes more important than constructing expertise or communal organisation skills. Digitalisation reconfigures the agency of the residents around the expertise of the 'smart citizen' and, as such, prescribes who has the capacity to act (Pilo', 2017; Shelton & Lodato, 2019). We see this illustrated in the different strategies employed by the residents in Barrios

Altos and Miraflores to verify the measurements of the water meter. For non-digital residents, the digital infrastructure can be exclusionary and opaque, whereas these residents were considered experts within the auto-constructed infrastructure. As such, the digitalisation of the infrastructure has implications for the self-determination and agency of Lima's residents. Explicitly considering the underlying socioeconomic inequalities in Lima, attention should be paid to developing a system that fosters the participation of all residents and avoids the peripheralisation based on knowledge asymmetry (Rabari & Storper, 2015).

It is essential to consider the differences between the digitalisation trajectory in formalised infrastructures and cities compared to auto-constructed spaces. Particularly, as stressed by Vanolo (2016), smart cities are not built on empty land, and a variation in starting points leads to differences in the degrees of residents' participation that emerge. This is not only relevant when comparing various neighbourhoods within the city of Lima but also when we conceptualise the influence of digital infrastructures between cities in the North and the South. The differences between residents with metered connections in Miraflores and Barrios Altos show how digitalisation does not create homogeneous 'smart citizens' in Lima. Depending on the connections and skills of residents, 'smart citizens' can be integrated or excluded by the digital infrastructure. Similarly, just as the 'smart citizen' should not be considered as either a passive data point or an engaged co-developer (Vanolo, 2016), the 'expert amateurs' are at once marginalised and actively re-inscribing the infrastructure in their neighbourhoods or households.

Therefore, the case of Lima shows how thinking about integration and unbundling (Graham & Marvin, 2001) in a successive manner is not useful in the context of Lima, as both processes are happening at the same time. The digital infrastructure has effectively led to an increase in the centralisation and integration of the water infrastructure and led to better service provision for citizens who are formally connected. Digital infrastructures are a useful tool in the operation of the water distribution system, provide the opportunity for people to voice their critique via the customer contact centre, and cater to the individual household rather than the community. Nevertheless, simultaneously, the digitalisation of the infrastructure increases the differentiation in terms of influence and agency and further disenfranchises people and places with little material and socioeconomic connections. While auto-construction continues to be an important form of infrastructural development in Lima, the changes in the infrastructural script hamper people from finding innovative ways to construct and manage water systems according to their own logic, a characteristic of auto-constructed systems which has advanced service provision in areas that are not (yet) serviced by SEDAPAL. As residents are required to switch roles and adapt their capacities to what is considered desirable within the integrated infrastructure, digitalisation can further marginalise people and neighbourhoods in particular life situations (Caldeira, 2017; Malgieri & Niklas, 2020).

3.5 The peripheralisation of the non-digital

As the smart city and its technologies unfold over the world, it is important to consider the integrity of the digital infrastructures that are called into being. This makes us think about what infrastructures are required to foster connection and inclusion in the margins. Our analysis of how digital infrastructures change the script of the water distribution system has shown how digitalisation is not only a matter of efficiency but also leads to the reconfiguration and moralisation of the position of diverse actors within the infrastructural system. Digitalisation, as a result of the further transformation of auto-constructed to digital infrastructure, contributes to the further peripheralisation of the non-digital city and the non-digital resident as an exceptional category outside of modern society. The role of the expert-amateur in the auto-constructed infrastructure becomes the 'absent citizen' (Shelton & Lodato, 2019) in the smart city. The acknowledgement of heterogeneity and differentiation can not only attune policies towards the particularities of implementing digital infrastructures in a Southern context (Coutard, 2008) but also make aware of how these transitions shift the roles of residents within the system. To overcome the perpetual creation of the centre and the periphery through digitalisation, urban water management should be sensitive to residents' innovative ways of getting access to water and managing resources within their households and communities. Future research on smart cities can take inspiration from the expert-amateurs in working towards technological and urban development that cultivates the self-determination of residents and ownership over the (digital) infrastructures created.

Chapter 4:

An emerging knowledge system for future water governance: sowing water for Lima

Abstract:

As urban infrastructures are built to last for decades, each infrastructure contains the anticipation for an uncertain future: a city-to-come, often built on capitalist and modernist dreams. In Lima, Peru, the model for water infrastructure development has long been a technocratic one, driven by values such as efficiency and modernisation. However, facing a dual challenge of climate change and continuing urban growth, Lima's water utility agency, SEDAPAL, is increasingly integrating elements of Andean water governance systems – commonly referred to as the sowing and harvesting of water – in its future strategies to maintain urban water security. Our approach builds on knowledge system analysis to examine the different approaches to water governance as distinctive manifestations of understanding the socio-ecological changes in Lima's hydrosocial territory and how they are negotiated and integrated into Lima's infrastructure futures. Drawing on qualitative fieldwork in Lima and the Rímac watershed, our findings highlight the tension concerning what is incorporated in hybrid knowledge systems and what is side-lined. We conclude that, in the process of futuring, the integrations of knowledge systems should acknowledge plurality in epistemologies and positions and consider the historical contingencies that shape the exchanges between knowledge systems.

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4.1 Introduction

Situated on the arid coast of Peru and the valley of the Rímac River, Lima's development has been characterised by its environment and the struggle to maintain water security (Bell, 2015). This persists today as the dual trends of urbanisation and climate change pose a challenge for planning Lima's water infrastructure and enhance the level of uncertainty in future scenarios. Since climate change is not only a future problem but one the world is experiencing today, the uncertainty does not necessarily lie in the question if these trends will continue but rather how climate change will affect the Andean ecosystems on which Lima depends for its water. Similarly, urbanisation patterns have been uncertain in their pace and direction as the city has expanded in areas not anticipated for living, now sprawling over hills that were previously considered inhabitable.

Lima is thus experiencing a transition into a world whose material conditions we cannot properly anticipate, nor are we able to envision what their consequences will be for societies and ecosystems. In an attempt to address this uncertainty in future challenges, the water utility agency for the metropolitan area of Lima-Callao (SEDAPAL), as well as the national superintendence of water services (SUNASS), have adopted a multitude of strategies in the past, ranging from smart infrastructural development to the construction of the *transbase*, a tunnel that transfers water from the Amazon side of the Andes to the river catchment areas that service Lima (Hommes & Boelens, 2017). However, more recently, SEDAPAL has increasingly been integrating a pre-Hispanic water governance practice prevalent in large parts of the Peruvian Andes, commonly referred to as the sowing and harvesting of water (*siembra y cosecha de agua*), in its future strategies to maintain urban water security.

Specifically in the sector of urban water governance, which has long been characterised for its technocratic approach and the domination of engineering as the main knowledge-producing discipline (Hurlimann et al., 2017), the incorporation of nature-based solutions and indigenous technologies in water governance and infrastructural planning deserves our attention. Against a backdrop of a persisting colonial legacy of unequal socio-economic development, political exclusion and epistemic violence, the question arises to what extent the incorporation of the Andean model for water governance acknowledges epistemic diversity, the plurality in positions and perspectives, and works towards the empowerment of all actors in the process of futuring.

This paper draws on knowledge systems analysis (Muñoz-Erickson et al., 2017; Wijsman & Feagan, 2019) to examine the different models of water governance as distinctive manifestations of understanding the socio-ecological changes in Lima's hydrosocial territory (Boelens et al., 2016) and how they are negotiated and integrated into Lima's infrastructure futures. We contribute to the theory on infrastructural development in uncertain urban futures by empirically analysing how different knowledge systems are hybridised and incorporated into practice.

4.2 Theoretical Framework

Speculation as to what urban future is to come is an inherent part of planning the city and informs urban governments' strategies for dealing with uncertainty (Leszczynski, 2016). Leszczynski (2016) describes this as the process of 'futuring', for example, the ways that urban planning and governance engage with future visions in a material and discursive manner. The transformation of the noun 'future' into the gerund 'futuring' emphasises the processual character of articulating urban futures, in which different viewpoints are negotiated, contested and mobilised (Hajer &

Pelzer, 2018). Specifically, infrastructures built to last for decades hold in them the plans for the city-to-come. They form the temporal materialisation of these anticipated futures. Which shape infrastructures take is informed by the context where they emerge and the knowledge system that favours their materialisation. Hajer and Pelzer (2018) accentuate how a representation of reality is articulated through negotiation and the mobilisation of knowledge. Space, relationships and entities are established and agreed upon by a certain group and form the basis for decision-making and future planning. Hence, it is important to question whose knowledge, values, and needs inform future-oriented approaches (Wyborn et al., 2016). Knowledge system analysis helps one to understand the process and context through which a dominant viewpoint emerges within specific socio-ecological systems (Wijsman & Feagan, 2019).

Drawing on Foucauldian scholarship on the inseparability of power and knowledge, Muñoz-Erickson et al. (2017, p. 1) define a knowledge system as 'the social practices through which knowledge, ideas, and beliefs are produced, circulated, and put into action'. This definition of knowledge systems and their analysis emphasises their relationality and raises the need to critically question the role of power and material in shaping knowledge systems (Muñoz-Erickson et al., 2017). The knowledge system analysis framework (Muñoz-Erickson et al., 2017) builds on literature on knowledge co-production (Jasanoff, 2004) and focuses on three focus areas: the elements of the knowledge system (knowledge claims, values and standards, epistemologies, and structures), the function of the knowledge system which includes the application and circulation of knowledge, and the political and organisational complexity of knowledge systems.

Knowledge systems are thus analysed as products of a specific institutional and political context (Muñoz-Erickson, 2014). However, what we consider knowledge and how we produce knowledge are fundamentally tied to whom we consider knowledgeable and the sites of knowledge production (Wijsman & Feagan, 2019). In other words, the analysis of the different knowledge systems that inform governance should be sensitive toward the reproduction of colonial relationships and the continuation of epistemic violence towards structurally marginalised communities (Jimenez & Roberts, 2019). In an aim to establish a feminist and decolonial analysis of knowledge systems, Wijsman and Feagan (2019) state that (1) knowledge systems should be understood as localised and spatially specific; (2) we should acknowledge the plurality of values and perspectives amongst, and within, knowledge systems; and (3) that the analysis of knowledge systems needs to address the distribution of power along colonial and patriarchal lines that undermine the legitimacy of knowledge systems emerging out of non-dominant societies. As the geographical position and the knowledge systems are intertwined, the region is not only a polygon on a map but an epistemic point of view. The ways we perceive problems and their solutions are materially and epistemically grounded in the region (Glass et al., 2019). Vice versa, rooted in debates on hydrosocial territories and socio-hydrology, both Robert (2019) and Molle (2009) stress the social and political nature of the region within water governance approaches. We use the concept 'hydrosocial territories' – without a hyphen between 'hydro' and 'social'– to emphasise how water, society and territory are intrinsically linked and co-evolve through human and biophysical practices (Boelens et al., 2016). Notions such as the 'river basin' or 'catchment area' pertain to a natural order, yet, in practice, their boundaries are determined not only by geographical space but also by political negotiation and cultural practices (Molle, 2009).

This is important as each knowledge system represents a specific 'regime of sight' and carries its specific mechanisms to validate information and legitimise decision-making (Jasanoff, 2017). Jasanoff (2017) distinguishes three general regimes of sight: (1) the view of nowhere representing the imagined objectivity of modernist science; (2) the view from everywhere representing the view of the expert which draws on reason; and (3) the view of somewhere representing personal and authentic experience. Each viewpoint has merit, and in each viewpoint, certain issues are seen while others are overlooked. More importantly, each viewpoint reveals a new pathway or vision for future development (Muñoz-Erickson, 2014). Thus, it is important that the experiences, initiatives and knowledge that sprout from the different regions, being the city of Lima or the Andes, are considered within their regional context (Alencastre Calderón, 2013).

Hence, in this paper, we analyse how different knowledge systems, with their specific regimes of sights, emerge as valuable and actionable in the context of future water insecurity in the Rímac watershed. We draw on Zimmerer and Bell (2015) as a starting point to distinguish between Andean knowledge systems (AKS) and modern-scientific knowledge systems (MSKS) and analyse the distinct modes of thinking about resource governance in the region of Lima. Based on Zimmerer and Bell (2015), we define the AKS as the indigenous knowledge system that is emergent from and rooted in the Andean landscape, cultures and epistemology. Within this definition, indigenous knowledge refers to knowledge that is historically and culturally rooted in a specific community and serves as a means 'to express what people know and create new knowledge from the intersection of their capacities and development challenges' (Fabiyi & Oloukoi, 2013, p. 3). The AKS is closely tied to the relational ontology that has defined the worldview of Andean, and particularly Quechua communities. Contrasting with the modernist worldview, the Andean cosmovision is not based on the strict delineation between nature and culture but instead sees it as a responsibility of society to be in harmony with the natural realm (Ramírez González, 2020; Ulloa et al., 2021).

The MSKS is defined as the knowledge system that derives the principles of rigorous academic research as propagated in originally European (academic) traditions and which have become dominant in academia worldwide and claim universal relevance (Agrawal, 1995). We have added the hyphen in 'modern-scientific' to underscore that it specifically refers to the modernist and positivist traditions in scientific research as opposed to other forms of scientific scholarship. Through colonisation, the MSKS has gained dominance in most of today's countries, effectively erasing knowledge systems indigenous to colonised countries in its process (Escobar, 1998). Also, in juridically decolonial states, the legacy of colonisation continues in denoting other forms of knowledge production and eradicating epistemic diversity (de Sousa Santos, 2016; Grosfoguel, 2011). Multiple authors have written about how indigenous systems of water governance (Hidalgo et al., 2017; Ulloa et al., 2021; Vera Delgado & Zwarteveen, 2008) or nature conservation (Escobar, 1998) have been stigmatised as 'backward' and ignored within water governance policies in Latin America. In effect, Lima's water sector has been characterised by an economic and modernist discourse, and SEDAPAL's dominant water governance model can best be labelled as integrated water resource management (IWRM) (Miranda Sara et al., 2017). Worldwide, IWRM has been welcomed as a blueprint approach for coordinating various water uses (hydropower, domestic and industrial supply, irrigation) and increasing control over water as a natural resource (Molle, 2009). In Lima, this form of 'modernising' water governance has additionally been characterised by the processes of infrastructural expansion and the neoliberal policy reforms that stimulate public-private partnerships in water management (Ioris, 2016).

Nevertheless, much due to the resilience and resistance of indigenous peoples (Ulloa et al., 2021; Wilson & Inkster, 2018; Zimmerer & Bell, 2015), AKS have prevailed over time and are playing an increasingly important role in the regional governance of the hydrosocial territory. Zimmerer and Bell (2015) analyse historically how, in the context of landscape governance, different knowledge systems in the Andean countries of Latin America and how these have mutually influenced each other ever since colonisation. Similarly, Ulloa et al. (2021) describe how community groups in the Andes strategically appropriate techno-scientific methods and knowledge to rearticulate their local knowledge and be acknowledged as experts in the field of environmental governance. For example, by incorporating local knowledge on weather forecasts and agricultural trends with climate modelling, new strategies for climate crisis adaptation can be devised (Valdivia et al., 2010). These encounters have informed hybrid governance models that combine worldviews, epistemologies, values and structures of MSKS and AKS. The hybridisation is often the result of prolonged struggle and negotiation over each of these elements (Ulloa et al., 2021).It is from this framework (Figure 4.1) that we analyse the transition towards a 'new water culture' as the encounter between two knowledge systems and a negotiation regarding knowledge claims, values and standards, epistemologies, structures, and regions.

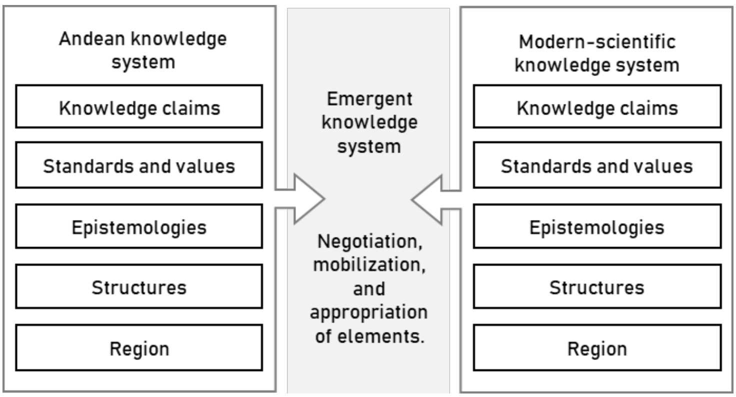

Figure 4.1 Conceptual framework for the encounter between the Andean knowledge systems (AKS) and modern-scientific knowledge systems (MSKS) in water governance. Source: Authors based on Muñoz-Erickson et al. (2017) and Wijsman and Feagan (2019).

We will first and briefly present our research approach in the third section. The fourth section uses insights from the framework development of Muñoz-Erickson et al. (2017) to analyse the MSKS and the AKS in relation to the water governance approaches. Finally, in the fifth section, we discuss the emergence of a hybrid water governance approach for addressing the future challenges in the Rímac watershed.

4.3 Context, methods and positionality

Empirically, this paper is based on data collected during a six-month fieldwork period in Lima in 2019–20. This included field visits, observations and seven interviews with water governance and management experts of SEDAPAL, local government and civil society within Lima. Additionally, two focus groups were conducted: one with employees of SEDAPAL and another with experts from research institutions, government and civil society. Each interview was between 30 and 90 minutes and conducted in Spanish or English, depending on the interviewee's proficiency in either language. The focus group meetings were, on average, 2 hours and conducted in Spanish. The focus group meetings were transcribed and coded in ATLAS.ti™ according to the principles of thematic analysis.

During two field visits to San Pedro de Casta, we interviewed community leaders and visited the sites where pre-Hispanic infrastructure called *amunas* are being renovated. Amunas are best described as small channels that slow the flow of rainwater so the soil can absorb it (Figure 4.2). Water sown in the upper parts naturally emerges from the subsoil during the dry season in the springs located near the communities, effectively extending the wet season (Ochoa-Tocachi et al., 2019). Their foundation has, in many cases, been there for centuries, but they have not been maintained continuously. The amunas are particular to the central Andes of Peru (Martos-Rosillo et al., 2020). However, similar water governance and management approaches based on the sowing and harvesting of water can be observed in other Latin American countries such as Chile, Ecuador and Bolivia. Using the *waru* – a pre-Hispanic water management technique used by Aymara people to mitigate fluctuating precipitation patterns in southern Peru and Bolivia – as an example, Earls (2009) explains how water management systems emergent from the Peruvian Andes each conform to the logic of a particular landscape and watershed.

Figure 4.2 A restored amuna. Photo: Aquafondo (aquafondo.org.pe)

By looking into the case of the amunas, we illustrate how indigenous knowledge systems emergent from Andean cultures and landscapes are present in and inform water governance approaches in the Rímac River basin. Specifically, the recuperation of the amunas in San Pedro de Casta has explicitly gained much attention over recent years due to its proximity to Lima, making it an interesting case to analyse in relation to the water governance models emerging from the city. San Pedro de Casta is a village of 928 inhabitants (INEI, 2018) in the Santa Eulalia River's upper catchment, the primary water source for the Rímac River (Figure 4.3). Its community depends mainly on small-holder farming and cattle-rearing for daily subsistence and income.

Finally, the first author attended a series of high-level, multi-stakeholder meetings to develop a new master plan for the metropolitan area of Lima-Callao, and the ExpoAgua 2019 (in person) and 2020 (online), the annual conference on water infrastructure and technology in Peru. The field visits and attended meetings were documented in notes by the first author. Master plans and advisory reports of SEDAPAL and SUNASS have been used as additional material in analysing the integration of the two models in SEDAPAL's current strategies.

We analysed the documents and interview data based on four elements of knowledge systems (Muñoz-Erickson et al., 2017): knowledge claims, values and standards, epistemologies, and structures. Knowledge claims are defined as the non-verifiable statements that represent a specific worldview; values and standards are the normative principles that steer decision-making processes; epistemologies are the ways of knowing and reasoning about the world; and structures are the social and institutional networks which create and facilitate a certain knowledge system (Muñoz-Erickson et al., 2017). In line with Wijsman and Feagan's (2019) decolonial and feminist intervention in knowledge system analysis, we added the element 'region' in our analysis to emphasise the localised and situated character of the knowledge systems we are discussing. The region, in this case, represents the geographical boundaries of the infrastructural system discussed and what and who is considered part of the hydrosocial territory. These five elements resulted in five code-groups for the analysis in ATLAS.ti™. The coding was conducted by the first author (see appendix 4 for the codebook).

It is important to note that by breaking down the knowledge systems into these elements and separately analysing them, we are going against the holistic approaches that underpin the AKS and follow the methodology in which we are trained that aligns more with modern-scientific approaches to knowledge generation.

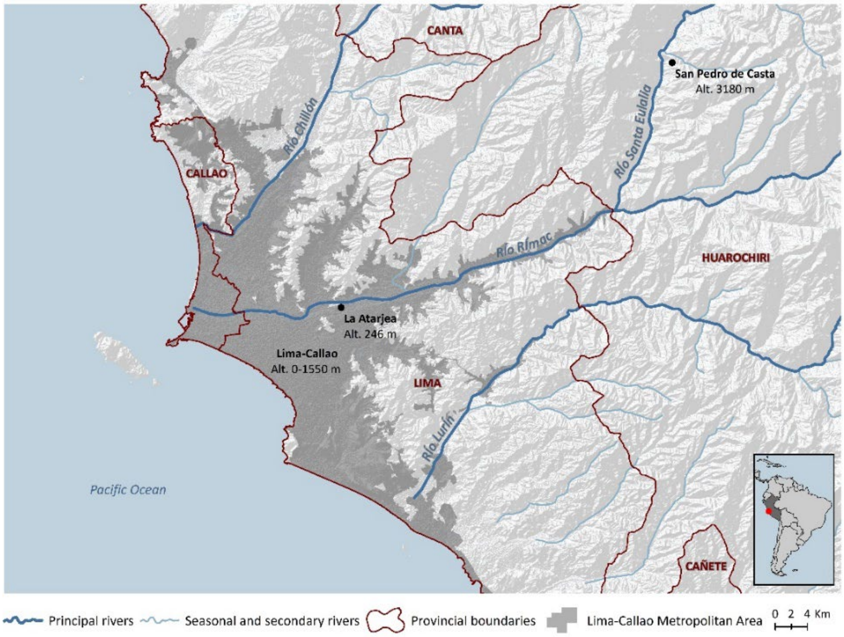

Figure 4.3 Map of the research region. Map made by authors. Data from the 2007 and 2017 national censuses of Peru.

Moreover, considering that we are researchers from and/or affiliated with a university in the Global North, we want to take the opportunity to reflect on the tension that arises due to this position. We feel it important to address this fact since we will be discussing knowledge systems that have long been oppressed by the very traditions in which we are trained. We acknowledge that our positionality severely limits our understanding of the Andean knowledge and the cosmovision on which it is built. Therefore, in describing the AKS and Andean model for water governance, we have specifically built our research not only on the fieldwork we undertook but also on academic and non-academic sources from Peru and Andean communities in particular.

We have structured the findings section of this paper primarily according to the elements of the knowledge systems analysis framework describing the knowledge claims, the values and standards, the epistemologies, and the region. The structures of the knowledge systems, and their main actors, are described throughout all sections of the findings. However, first, we will describe the ExpoAgua of 2019 as a literal and symbolic space of encounter between the two knowledge systems and their visions for the future water governance in the Rímac watershed.

4.4 The encounter between modern-scientific and indigenous knowledge

In 2019, the ExpoAgua, Peru's leading annual technical fair for the water sector, was themed *Hacia una Nueva Cultura del Agua*, or 'Towards a New Water Culture'. During the three-day gathering, national and international companies, governments, and knowledge institutions had the opportunity to present their interpretation of a new water culture. The visions for the future of the water sector ranged from fully digitised infrastructures in which virtual reality will allow to travel through water pipes and semi-automated water distribution systems to socio-ecological imaginings in which the city and its surrounding landscapes are fully harmonised.

In general, the organisations presenting these different anticipations of the futures can be categorised along predictable lines. Engineers from multinational firms presented their newest innovations and technological futures while civil society organisations and researchers urged for a more ecological and human-centred system.

Strikingly, SEDAPAL crossed these lines and participated in both narratives. On day 1, SEDAPAL presented a narrative characterised by smart technological innovation. On day 2, their presentation revolved around maintaining ecosystem services and promoting responsible consumption. Perhaps most important, during the closing speech of the 2019 event, the president of SEDAPAL expressed the ambition to invest in the maintenance of water sources, granting particular attention to the *Sembramos Agua* (We Sow Water) projects that draw from pre-Hispanic Andean water governance approaches. This ambition was solidified in December 2020 with the signing of a cooperation agreement between SEDAPAL and the regional government of Lima to start the development of activities following the principles of sowing and harvesting water that should benefit communities in the upper river basins of the Chillón, Rímac and Lurín, as well as the Lima-Callao metropolitan area (Gobierno Regional de Lima, 2020). The Sembramos Agua projects are aimed to take place in 40 areas in the provinces of Huarochiri and Canta (Figure 4.3) and focus on reforestation, the recuperation of amunas and the construction of reservoirs. SEDAPAL will finance the projects by investing 1% of the monthly water bill collection in Lima and Callao into a dedicated fund (Bleeker & Vos, 2019; SUNASS, 2017b). At the end of 2020, it was estimated that this investment fund held up to 100 million soles (US$24.5 million), earmarked for nature-based solutions and the protection of ecosystem services (Gobierno Regional de Lima, 2020).

This crossing of lines and the participation in both narratives is exemplary for the increased interest in Andean water governance systems and aligns with the current tendency of SEDAPAL to give more relevance to environmental issues within water management and reduce the inequalities between urban and rural water consumers (Robert, 2019). However, the implementation of projects and actual investment has been postponed several times due to a lack of institutional will within SEDAPAL and delays in creating legal and technical structures that allow for the execution of the plans (Bleeker & Vos, 2019). Community leaders from San Pedro de Casta we spoke with at the time the ExpoAgua 2019 took place indicated they had been 'knocking on SEDAPAL's door'[1] to get institutional and financial support for their work to little avail, even though their activities recuperating the amunas fit within the ambitions of the Sembramos Agua projects.

Nevertheless, the acknowledgement of these Andean infrastructures and their integration in the future projections of Lima's water infrastructure marks a divergence in what has been the hegemonic discourse in Peru's water governance for the past decades. As a result, at least as presented during the ExpoAgua conferences, a new hybrid model for water governance emerges that draws on MSKS and AKS to articulate their vision for the future. In the following sections, we unpack per element of a knowledge system where these two visions for water governance meet and where there is still room for further engagement.

4.4.1 Knowledge claims: what is water and what is the river?

To unpack the emergence of a hybrid water governance model, we first need to ask what water is and what the river is according to the different knowledge systems we analyse. These questions are crucial as the conceptualisations of water and the river inform our ideas about how they should be governed (Wilson & Inkster, 2018). More profoundly, focusing on

[1] Interview with a community leader, San Pedro de Casta, 28 September 2019

how water and the river are defined brings attention to these elements' social, cultural and political connotations.

Indicative of the worldview of the MSKS are words such as 'water supply and demand', 'natural resources' and the 'Rímac system'. By defining water as a resource, the governance approach that follows from this conceptualisation is, in its basis, an economic model driven by the dynamics of offer and demand. This is reflected in the schematic models created of the watersheds, which represent the Rímac and Santa Eulalia rivers as a series of demand and supply nodes, connected via transmission links representing either natural streams (rivers, creeks, springs) or engineered canals (Bell, 2022). In such a schematic and linear representation, the river is defined by its function to transport water to urban consumers. As one SEDAPAL engineer described, 'the Rímac is no longer a river but a canal that serves the domestic and industrial consumption of Lima-Callao'[2]. This representation of the watershed is simplified – without cultural and spiritual connotations – yet effective. It allows us to model future scenarios and speculate about the interventions that might mitigate the challenges to water security.

Within MSKS, not only the watershed is simplified. Water itself is abstracted to its chemical and physical properties (Calderón, 2000), and water scarcity and loss are considered to occur in the context of poor management and outdated technologies. The proposed solutions to mitigate water scarcity are therefore open, highly technocratic, and driven by commercial ambitions and efficiency. Specifically, during the Fujimori and García administrations in the 1990s and 2000s, water was narrowly approached through the frame of scarcity, a problem that was rationalised to require

[2] Focus group with SEDAPAL engineers, 19 February 2020.

more infrastructural development and market involvement (Ioris, 2016). In Lima, modernising water has also been the process of commodifying water.

Since in the AKS water is defined as omnipresent, a totality that is simultaneously part of all others[3], there are no meticulous delineations between nature, technology and society such as defined within modern-scientific thinking in the AKS. This holistic approach to water that characterises the AKS is reflected in the models for water governance that have emerged in the Andes (Alencastre Calderón, 2013). In the words of one of the community leaders interviewed in San Pedro de Casta: 'water is life and not easily abstracted into one dimension.'[4] They continued to explain how water, as the gift of the Apu (the mountain, the supreme deity) for the survival of all living beings, is both physical and spiritual. This worldview is reflected in traditions such as water festivals during which the community pays tribute to the deities that bring the rain season and maintenance efforts organised annually in anticipation of the rainy season (Ministerio de Vivienda Construcción y Saneamiento, 2007).

While the worldviews in the AKS and the MSKS result in different water governance models, we notice points of encounter between 'water is life' and 'modern water' in thinking about future water security. Foremost, in the recent focus on nature-based solutions and the integration of spiritual connotations to water in the communication of SEDAPAL. Whereas SEDAPAL's 2014–2040 master plan did not yet mention the amunas or other nature-based solutions, they have gained a prominent place in their promotional and educational material, as shown during the ExpoAgua conferences. For example, in 2018, SEDAPAL developed and published a

[3] Indigenous water governance expert, personal communication, 12 February 2020.
[4] Interview with a community leader, San Pedro de Casta, 7 December 2019.

serious game[5] for educating children about water security challenges and our responsibility to maintain harmony between people, nature and the ecosystem at large. It tells the story of César, the spirit of the river catchment (in the body of a water drop wearing a hat reminiscent of the chullo, a style traditionally linked to communities living in the Andean highlands), who wakes up after 1000 years to help recuperate the catchment area. Players can help the spirit of the watershed keep the river healthy and adapt to climate change by choosing between different types of interventions such as removing factories, planting trees or recovering ancestral practices such as the amunas in the upper, middle and lower catchment areas.

Vice versa, we notice a similar movement in how the Sembramos Agua projects have adopted elements of the 'modern water' worldview in arguing for the value of the amunas. The current national and international recognition of their potential to help mitigate the effects of climate change has motivated the community of San Pedro de Casta to collaborate with local non-governmental organisations (NGOs) to restore the amunas to their functioning state. As part of the process of the sowing and harvesting of water, the amunas are a tool in the active and circular engagement with the mountain, the soil, the rain and the water bodies to maintain water security. Specifically, community leaders framed the amunas as a technique to secure water resources not only for the village and agriculture but also for Lima. In doing so, the focus is more on the restorative potential of the amunas rather than the spiritual and ritualistic dimensions of 'water is life'. One civil society expert explained: 'when you hear the villagers talk about water resources, rather than using the Quechua world for water, yaku, they are taking away,

[5] Sembrando Agua, developed by SEDAPAL EGASE (SEDAPAL's environmental management and ecosystem services team) and ANEVI CORP. Game design by Bryan Silva and Ottoman Silva from ANEVI CORP. Published in 2017 by SEDAPAL. For a full explanation of the game, see https://www.youtube.com/watch?v=rjV_FL7a9k0/.

diminishing what they have to communicate to be accepted.'[6] As we will unpack further in the following sections, this framing of the amunas as servicing Lima's water security helps in the village's strategic positioning in relation to the city and in seeking collaborations with researchers and NGOs.

4.4.2 Values and standards

The notion of responsibility is fundamental to understanding how these two knowledge systems interact as it is a central value in both the AKS and MSKS and crucial in thinking about future water governance. Particularly, the recent focus on the Sembramos Agua projects fits within a general shift towards the increased valuation of ecosystems for water security and the redefinition of responsible water governance within IWRM as dominant water governance discourse in Lima (Miranda Sara et al., 2017).

Similar to other indigenous nations (Wilson & Inkster, 2018), the values for water governance in the AKS derive from the idea of mutual responsibility for mutual survival. Commenting on the water distribution between irrigation, human consumption or cattle, one of San Pedro de Casta's residents explained it is impossible to create a hierarchy in needs as all entities depended on water and each other. Therefore, there is a responsibility to care for all humans and more-than-human entities, including natural, geophysical and spiritual bodies. However, in conversation, some disagreement emerged over the distribution of water. While some community leaders stated all entities have an equal right to water, others argued responsible water governance should first serve humans and human needs. Nonetheless, a standard for 'good' water governance emerges from this sense of reciprocal responsibility (Ramírez

[6] Expert focus group, 21 January 2020.

González, 2020) which is reflected in the fact that the construction, maintenance and administration of water infrastructures, such as the amunas and the water distribution system, are organised communally.

Robert (2019) explains how the IWRM approach in Lima departs from a distinct logic that sees water as a public service. As a result, responsible water governance is generally defined in terms of guaranteeing the quality and the environmental and financial sustainability of water service provision for domestic and industrial consumers (Robert, 2019). Most notably, these values are demonstrated in the effective canalisation of the River Rímac through the construction of the three water-transfer projects within the main watershed (Hommes & Boelens, 2017) and the implementation of digital technologies for the real-time monitoring of water flows within the city (Hoefsloot et al., 2020). These projects are often financed by the national government and bilateral donors and executed by international consortia (Hommes & Boelens, 2017). Correspondingly, Lima's water governance is often evaluated based on international benchmarks and values of neighbouring countries. This is illustrated in how the coverage is low considering what 'can be expected of an upper-middle-income country'[7] or in the recurring statement that the percentage of non-revenue water is one of the lowest in Latin America. Effectively, within the MSKS, the standard for what is considered 'good' water governance is largely based on the quality of water governance in the larger region.

With the increased recognition of future risks to water security due to climate change and urbanisation, environmental sustainability – approached as the maintenance of water resources for the future – has become a more central value. SEDAPAL's 2014–2040 master plan includes several climate change adaptation and mitigation policies, such as the

[7] Focus group with SEDAPAL engineers, 19 February 2020.

payment for ecosystem services in the upper river basin, aimed to help conserve and administer water resources. However, always from an economic justification. As the World Bank writes in its advice for the future sustainability of Lima's water services: 'Water plays a critical role in the growth of the Peruvian economy' (World Bank, 2018, p. 10).

Combining a focus on efficiency, quantity, quality and reliability with sustainability, these policies represent the 'new water culture' presented during the ExpoAgua. Nevertheless, within this emergent sustainable approach to water governance, the sense of responsibility towards the more-than-human world is quite thin as it is based on a human-centred approach rather than grounded in a logic that presupposes the relationality of all beings including more-than-human entities. Thus, in practice, the encounter between the two knowledge systems means that the mitigation of natural degradation is presented as a cost-effective means to improve water services in the city today and, in the long run, serve urban well-being and economic prosperity (Bleeker & Vos, 2019).

4.4.3 Epistemologies and knowledge circulation

The third dimension in knowledge system analysis concerns the way of knowing and knowledge flows. In 2018, Peru enacted the Law on Climate Change with the purpose of establishing principles for the coordination, articulation and execution of public policy for the mitigation and adaptation to climate change. Within this law (Ley Marco Sobre el Cambio Climático), the first-mentioned focus for integrated climate change management is the recuperation, valorisation and use of traditional knowledge from indigenous peoples in designing climate change mitigation and adaptation measures. Recognising the expertise of indigenous peoples marks a departure from previous paradigms that have suppressed knowledge produced outside of modernist science.

Historically, water problems in Lima have been defined as infrastructural and managerial problems rather than natural, which favoured engineering knowledge emerging from MSKS in thinking about possible solutions (Bell, 2015). Today, this still speaks to an enduring orientation towards exact measurements and computational modelling based on numeric data to supervise and plan the water infrastructure (Hoefsloot et al., 2020). In several interviews, SEDAPAL has been critiqued on its conceptual 'tunnel vision'[8] regarding what is considered valuable knowledge and the resulting overreliance on engineering interventions to solve water governance issues. A civil society leader interviewed echoed this view and explained how hydrological 'expertise' is a characteristic reserved for engineers, if possible, with degrees from private or foreign universities. Other expertise or ways to generate knowledge are disregarded as irrelevant. Several interviewees emphasised the need for more interdisciplinary perspectives on water governance, including insights from other scientific fields such as urban studies or physics. Others argued that SEDAPAL should include other ways of knowing, to be more open toward tacit and indigenous knowledge.

The Andean water governance approach primarily draws on the experiential, tacit and context-embedded knowledge of communities such as San Pedro de Casta. Information is thus empirical, knowledge is generated through lived experience, often held by the elders and community leaders, and infrastructures are nature-based and produced through manual work. Traditionally, this knowledge is gained and shared through experience and oral history rather than numeric data or written text and generally not recognised within the MSKS. In a focus group with experts from SEDAPAL, one participant commented on the role of the amunas in increasing water security. While the 'rescuing traditional knowledge for the

[8] Expert interview, 5 October 2019.

use of the amunas'[9] was valued, the expert was not convinced of their role in providing a solution to Lima's water challenges. They continued that it was not considered possible to 'sell' them as a solution for Lima's water problems due to uncertainty over the quantification of what percentage of water volume available could be attributed to the amunas.

The importance of numeric data and modern-scientific knowledge in strategically positioning the amunas in relation to the city is not lost on the community of San Pedro de Casta. Community representatives have actively searched for collaborations with researchers from Peruvian and international universities to explore and document the effects of their work according to the guidelines of the MSKS. For example, over the past years, master's students from a university in Lima have visited San Pedro de Casta annually as part of an elective course on water management. In Huamantanga, a village in the neighbouring Chillón River catchment area, Ochoa-Tocachi et al. (2019) collaborated with the community and local authorities to measure the effectiveness of the amunas in stalling the water run-off. In spite of the fact that the AKS profoundly challenges positivist epistemologies, using modern-scientific research practices to 'proof', the outcome of the Sembramos Agua projects in maintaining water sources for the whole catchment area not only valorises their work within the IWRM model but also within their respective communities. As Ulloa et al. (2021) note, communities have learned to speak the language of the 'experts' and, in the case of San Pedro de Casta, are in the process of translating their knowledge to be incorporated into MSKS.

National and international NGOs play an important role as 'translators' between these two systems by funding academic research and pilot projects in which they gather modern-scientific knowledge from numeric data about

[9] Focus group with SEDAPAL engineers, 19 February 2020.

the functioning and effects of the amunas as nature-based solutions. As a particular form of codified knowledge, data are important in financial decision-making and help guarantee the continuation of international and national funding. In the words of a director of an NGO: ‘data is important to move investment money.’[10] They argued that with the payment for ecosystem services scheme, the financial and administrative structure had been created to invest in green infrastructure. Quantifying the impact of a potential investment through pilot studies is key in actually mobilising these funds. Today, several academic articles have been published about the recuperation of the amunas (Ochoa-Tocachi et al., 2019; Peña Laureano et al., 2016), adding ‘legitimacy’ to their experience and work within the mainstream discourse and effectively validating elements of the Andean water governance model as an approach for maintaining water security for the city.

Although this translation is effective, it also steers the AKS to assimilate to the epistemologies of the MSKS rather than appreciating the Andean ways of knowing and knowledge-sharing for their own worth. This is problematic as it assumes a hierarchy between ways of knowing, contrary to the values of knowledge co-production (Muñoz-Erickson, 2014). Several residents in San Pedro de Casta referred to the Sembramos Agua projects as important for the re-acquirement of knowledge partially forgotten. The amunas and the water governance system are closely tied to their historical legacy and ways of knowing that have long been oppressed through colonialism. Hence, recuperating the amunas and the knowledge systems they are built from are closely linked to acts of decolonising epistemologies.

[10] Expert interview, 3 December 2019.

4.4.4 Regional perspectives

Throughout the previous sections, one of the recurring themes has been the relationship between the city of Lima and the village of San Pedro de Casta in the encounter of the two knowledge systems. This section will further explore these dynamics and unpack how the 'region' and the knowledge systems co-produce each other. Central to this dynamic is the geographical, political and cultural delineation of the boundaries of the region for water governance (Molle, 2009). Practice proves that these boundaries are malleable depending on the issue discussed. They can be flexible when discussing Lima's need to access water from outside of its provincial limit. For example, in developing a new metropolitan master plan, the planning institute explored the possibility of including the rivers north and south of the metropolitan area within their proposal to maintain future water security. Or as illustrated in the formation of the council for water resource management, which overarches the catchment areas of the Chillón, Rímac and Lurín rivers. This council was installed to harmonise the scale of water governance with the natural boundaries of the landscape rather than administrative boundaries and, in the process, reconfigure the relationships between urban and rural actors in water governance (Robert, 2019).

Nevertheless, Robert (2019) explains how the river council has been confined by administrative boundaries and governmental hierarchies. As SEDAPAL and SUNASS fall under the auspices of the national government, the main decision-making power is centralised at the state level. Water users are invited to participate in the decision-making of the river council. Still, the coordination between the different water authorities is weak, and the municipalities of Lima and Callao have little influence over the water within their territories (Bleeker & Vos, 2019; Hordijk et al., 2014).

Yet, the lines drawn on the map become fixed when discussing the need to provide good quality and quantity drinking water to communities that have settled or live outside the metropolitan area. As explained by an employee of the municipality of Lima-Callao: 'In the ideal world, the administration and management model would be on the scale of the watershed,'[11] but for communities outside of the administrative boundaries of SEDAPAL, it does not have the institutional mandate nor the responsibility to provide water to those areas. These lie with the communal water authorities, the *Junta Administrativa de Servicios de Saneamiento* (JASS), which are supported by the *Ministerio de Vivienda, Construcción y Saneamiento* (Ministry of Housing, Construction and Sanitation).

While the IWRM model predominantly aims to operate top-down at the scale of the three basins that flow through the province of Lima (Alencastre Calderón, 2013; Robert, 2019), the Andean models for water governance predate the national and local water authorities' artificial administrative boundaries. They are primarily defined by geographical and natural features in the terrain, such as the mountain's isoline, the river basin, the flora and fauna (Earls, 2009). More importantly, as illustrated through the annual water festival, the Andean approach in San Pedro de Casta also considers non-material elements (spiritual, past and future) to be part of the system. Reflecting upon these differences in viewpoints regarding water governance between San Pedro de Casta and Lima, one interviewee stated: 'they look from the city up, and we look from the mountain down.'[12] Looking from the mountain down, it is emphasised that in addition to being a critical resource for human life, water is fundamental for other dimensions of rural life, such as cattle rearing (water is needed to maintain green pastures) and the

[11] Expert focus group, 21 January 2020.

[12] Group conversation with community leaders, San Pedro de Casta, 28 September 2019.

protection against environmental risks such as landslides (water is needed for reforestation). Additionally, looking from the mountain down, you can see the city as a metropolis sprawling over three large river valleys with water and green ecosystems that need to be valued and safeguarded. From the viewpoint of the city up, Lima is imagined in a desert. A particular framing that is reinforced in both popular and academic writing by the continuous repetition of the statistic that Lima, behind Cairo, is the second-largest city situated in a desert. Looking through this lens, it is easy to follow the analysis that there is an absolute water shortage and that water needs to be retrieved from additional sources such as the other side of the Andes or the Pacific ocean.

4.5 (A)Symmetric hybridisation of knowledge systems

The increased risks of water scarcity due to climate change and urbanisation have raised the need for innovative approaches for future water governance. In this paper, we have analysed how knowledge is negotiated and mobilised in preparation for challenges to come within the Rímac watershed and beyond. These dynamics are particular to the process of futuring: where different visions for the future come together and materialise in plans and infrastructure (Hajer & Pelzer, 2018; Leszczynski, 2016). Informed by indigenous movements, struggles and resistance in Peru, Latin America and worldwide, there is an increased valuation for indigenous knowledge systems and governance approaches. It is in the encounter of the knowledge systems that a hybrid and forward-looking approach to water governance emerges as presented during the ExpoAgua.

Table 4.1 Elements of the Andean knowledge systems (AKS) and modern-scientific knowledge systems (MSKS).

		Andean knowledge system (AKS)	Modern-scientific knowledge system (MSKS)	Hybrid knowledge system
Elements	*Knowledge Claims*	'Water is life' - Andean cosmovision	'Modern water'	Water is a natural resource
	Values and Standards	Communal responsibility for communal well being	Quality, quantity, efficiency, and reliability	Sustainability: Maintaining resource levels for wellbeing
	Epistemo-logies	Context embedded and tacit ways of knowing	Engineering and experimental methodologies and conceptual approaches	Modern-scientific methods to research Andean infrastructures
	Structures	Andean communities	(Inter)national collaborations characterised by public-private partnerships in knowledge production	Community projects supported by international research and civil society organisations.
	Region	The Andes. Includes human and more-than-human entities.	The inter-river basin of the Chillon, Rimac, and Lurin.	The inter-river basin of the Chillon, Rimac, and Lurin.
Water governance models.		Siembra y cosecha de agua (sowing and harvesting of water)	Integrated water resource management (IWRM)	Sustainable water governance: 'new water culture' captured in the Sembramos Agua projects

Previous literature has often analysed the acknowledgement of indigenous knowledge systems and models for water governance related to conflicts over the access to and maintenance of clean water in the context of capital-intensive infrastructural projects such as dams or large-scale irrigation projects that directly impact the water security of indigenous communities (Hidalgo et al., 2017; Swyngedouw & Boelens, 2018; Ulloa et al., 2021; Wilson & Inkster, 2018). The case of the Sembramos Agua projects we have analysed, however, is not linked to a direct conflict between two parties but is seen as a potential strategy to mitigate climate change risks to both the city and the Andean communities. Breaking down the knowledge systems from which the different water governance models emerge into their elements, it is evident how they fundamentally differ. Yet, both models, although different in their knowledge claims, values, epistemologies, structures, and regions, have both undergone a certain degree of hybridisation by adopting elements of each other's knowledge systems to adapt their ways of knowing and water governance practices (Table 4.1).

Nonetheless, while both sides seek collaborations to address the current and future challenges for water security, the power disparities between the AKS and the MSKS result in asymmetries in at least two respects. First, insights emergent from the AKS are only considered seriously after being translated to the MSKS. Second, the Andean water governance model is mainly acknowledged for its value in relation to the city, not in and of itself. We will discuss the former first and afterwards return to the latter.

The power of the MSKS depends not only on the structures that reinforce its position but also on the methodologies it uses that are presented as objective and standardised ways of knowing: a view from nowhere (Jasanoff, 2017). Complex socio-environmental systems are schematically represented in supply-demand models in which the landscape and the watershed are producers of water as a resource and the city as its main consumer (Bleeker & Vos, 2019). In other words, the MSKS is selective in what it considers as part of the system and towards the knowledge it integrates. As illustrated in our analysis of the knowledge claims and epistemologies of the two knowledge systems, this imagined objective and decontextualised approach are fundamentally different from the relational and embedded approach to water governance that is emergent from the AKS. Despite the expansive view of the hybrid water governance approach in bringing together these two systems, the main encounters have been focused on translating the knowledge from the AKS to the MSKS. The dominance of the structure and epistemologies of the MSKS is so powerful that rather than opening up towards other ways of knowing, it steers the AKS to assimilate. By mobilising methods, and experts from MSKS to validate the Andean water governance model, it becomes possible to integrate the infrastructures and insights for water governance without further engagement with its fundamental knowledge claims, epistemologies, structures and region in which it is situated. This assumes the possibility of context-free models for water governance yet, at the same time, depends on the physical and intellectual labour of communities that have been marginalised since colonisation.

Because indigenous knowledge systems' worth is constantly questioned (Ulloa et al., 2021), dynamics such as those just described are the rule rather than the exception. As detailed by Ulloa et al. (2021), the power of the MSKS is recognised and mobilised by indigenous peoples to position themselves and their knowledge strategically within emerging hybrid knowledge systems. In a similar fashion, through collaborations with NGOs and universities in Peru and abroad, the community of San Pedro de Casta is engaging with modern-scientific approaches to make their evidence 'credible'.

The second asymmetry we identify is in the repurposing of the Andean water governance system for the city. Although some attention is given to the Andean water governance model's pre-colonial roots and the people who have constructed them, this is often misguided to the extent that the approach of sowing and harvesting water is re-functionalised to serve the interest of the Lima-Callao metropolitan area and are rarely understood in their own terms. This is illustrated in the discursive framing of the amunas as infrastructures that maintain water security in the upper and lower catchment areas and the institutional and financial frameworks created to stimulate the recuperation of the amunas within the Sembramos Agua projects. Specifically, the payment for ecosystem services scheme frames the amunas as a cost-effective intervention to secure water resources for urban and industrial consumers (Bleeker & Vos, 2019) and serves as a tool to reconfigure the boundaries of the region for Lima's water capture (Robert, 2019).

The analysis shows us that although the repurposing of the amunas for the city is driven mainly by non-governmental and governmental actors based in Lima, the community of San Pedro de Casta appropriates this narrative to drive home their point for nature-based, indigenous water governance and gain support for their efforts. By emphasising the importance of the intended benefit for the overall watershed, including Lima, they can attract financial and institutional assistance.

However, as the Andean landscapes and infrastructures gain acknowledgement for their importance in maintaining water security for the city, we have to be wary of the risk of them being identified as only serving the metropolitan region. In the face of continued urbanisation and climate change, the metropolitan government is exploring possibilities to increase access to watersheds outside its juridical territory. If the landscapes of San Pedro de Casta are seen as crucial for water production, it might warrant the metropolitan government's control over the watershed and limit the community's sovereignty over water sources. As Mehta et al. (2012) argue, water grabbing is often an incremental process made possible through the reappropriation and financialisation of natural resources and negotiations between actors of unequal power.

Hence, in both respects, we find that the asymmetry results from the dominance of one knowledge system and one centre of knowledge production. The emerging hybrid water governance model is an example of the opening up for plurality in future imaginaries and how two different knowledge systems can be in dialogue (de Sousa Santos, 2016). Nevertheless, the rules for the exchange of knowledge are set by the dominant knowledge system, and other water governance models are only considered if they contribute to its aims. As such, it is possible that the selective repurposing of the amunas to create more productive hydrosocial territories will undercut the common aspirations of both the modern-scientific and the Andean approach to water governance of maintaining water security. Moreover, the repurposing of the amunas for the city reproduces the colonial conceptualisation of the river as a 'linear feature' servicing the urban consumers and with rural waters (Bell, 2022, p. 4). Being more open to water's cultural and spiritual connotations could inspire us to see the problems with water distribution and use within the city in a different light. Specifically, moving closer to the Andean definition of good water governance, which builds on a relational worldview, might inspire a collective sense of responsibility regarding water use amongst Lima's residents and institutions.

This makes us reflect on how we can acknowledge the progress made in recognising the value of plural knowledge systems while also questioning the losses along the way; how this encounter requires leaving behind spirituality, culture, and tradition to be included in the emerging knowledge system. On the basis of these experiences, what, then, might be the conditions for symmetrical hybridisation between modern-scientific and indigenous knowledge systems? de Sousa Santos (2016) argues it is possible to bring together different ways of knowing in a 'decolonial mestizaje', for example, a form of hybridity which acknowledges epistemological plurality and is committed to socio-economic and environmental justice. Hence, we suggest two principles for symmetrical encounters between knowledge systems for future planning. First, we propose that there has to be an acknowledgement that all knowledge systems are emergent from particular worldviews, values, epistemologies, structures and regions. By accepting this, we open up the possibility of plurality in all these elements. As the Andean and modern-scientific water governance models collide and contradict, situatedness is not theoretical; the solutions that are proposed emerge out of a legacy of knowledge and science yet, at the same time, follow directly from the local challenges faced within the Rímac watershed. The cultural and regional context from which a knowledge system emerges, it being either the spiritual landscape of the Andes or the globalised and metropolitan urbanity of Lima, is crucial for understanding anticipations for future challenges and, as a result, present different solutions to mitigate water insecurity. Second, in line with Bell (2022), we argue that we must keep history in mind. This specifically refers to the acknowledgement of the patterns of coloniality on which knowledge systems operate. If we do not acknowledge how structural inequalities echo in today's encounters between people and knowledge systems, we will most likely reproduce these inequalities.

4.6 Conclusions

What the climate crisis and urbanisation challenges make apparent is that we are witnessing a critical moment in time, one in which we know that basic conditions of our planetary system and societal organisation are changing, yet we cannot predict how it will unfold. Evidently, these changes have far-reaching ecological and societal consequences pressing us to think beyond the governance approaches that have been dominant thus far (Miranda Sara et al., 2016). Hajer and Pelzer (2018) describe how thinking about future governance approaches is a process that occurs on multiple levels and in consecutive stages. In this paper, we draw on knowledge system analysis to examine the process of futuring at one stage, namely the emergence of a hybrid approach to water governance as a result of the encounter between modern-scientific and AKS, as presented during the ExpoAgua conferences. Our analysis highlighted the tension concerning what is incorporated in hybrid knowledge systems and what is side-lined. Specifically, it shows how the hybridisation of knowledge systems is an active process during which epistemologies are appropriated, values are exchanged, and actors reposition themselves within the structure of the emergent knowledge system.

Returning to our question – to what extent the incorporation of the AKS into Lima's water governance practices acknowledges epistemic diversity, the plurality in positions and perspectives, and works towards the empowerment of all actors in the process of futuring – we conclude that it is possible to see how the hybridisation of the two systems might represent a new chapter in water governance which is open to diverging perspectives for water governance to address current and future environmental challenges. Yet, at the same time, considering the situatedness of knowledge (de Sousa Santos, 2016; Wijsman & Feagan, 2019), it becomes apparent that as knowledge is extracted from its regional context and mobilised to serve other regions and people, this hybridisation is asymmetric and does not work towards overcoming structural inequalities amongst actors and between knowledge systems. This is not to say that there is no other way. In the process of futuring, the integration of knowledge systems should embrace plurality in epistemologies and positions and consider the historical contingencies that shape the exchanges between knowledge systems. We encourage further research to empirically investigate the potential and challenges for achieving real transformation by thinking through and with multiple knowledge systems in developing just futures.

Chapter 5:

Eliciting design principles using a data justice framework for participatory urban water governance observatories

Abstract:

Participatory urban observatories can potentially improve transparency in infrastructure governance, offer opportunities for residents' engagement, and amplify the voice of marginalised people in urban governance. While often optimistically presented as a tool to address empowerment issues in the Global South, participatory urban observatories are critiqued for reproducing urban inequalities in the digital infrastructure. In this paper, we review the design and implementation of participatory urban observatories and dashboards in public (water) infrastructure governance and their potential to contribute to data justice. This paper responds to calls for data justice by examining how participatory urban observatories are (or are not) conducive to inclusive data practices. Additionally, we contribute to bridging the divide between data justice in theory and practice by eliciting design principles. The principles highlight the importance of creating smart city interventions collaboratively to avoid reproducing unjust systems and to imagine new ways of enacting a more just city.

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5.1 Introduction

Digital infrastructures are seen as important opportunities to address managerial, social, and environmental issues in the water sector (Amankwaa et al., 2021). Recognising the many challenges in the water sector, specifically in cities where a large portion of the water consumption is 'off-grid,' digital innovations are framed within water security and justice agendas as directly relevant to reducing inequalities in the water distribution system by creating greater efficiency and accountability. While many of the steps in the datafication – defined as the increasing availability, use, and effect of data (Heeks & Shekhar, 2019) – of the water sector are government-led initiatives, frequently in alliance with multinational companies (Taylor & Richter, 2017), Jimenez, Delgado, et al. (2022) argue that, for innovation to contribute to development, datafication should seek to be a participatory process which builds on the exchange of knowledge between epistemic communities.

It is from this perspective that we are interested in the design and implementation of participatory urban observatories and dashboards in public (water) infrastructure governance and their potential to contribute to data justice. A wide range of participatory urban observatories and dashboards have been developed within academic and non-academic settings, which, in theory, aim to amplify the voice of residents in urban governance.

This paper responds to calls for data justice by examining how participatory urban observatories are (or are not) conducive to inclusive data practices (see: Heeks & Renken, 2018; Krishna, 2021; Martin & Taylor, 2021; Qureshi, 2020). The aim of this paper is to elicit principles for the design and development of a just participatory urban observatory for water governance. By drawing from both theory (academic literature) and practice (participatory urban observatories currently in use), we hope to contribute to bridging the divide between data justice in theory and practice and set out to formulate principles applicable in the design processes. Rather than prescribing action, these principles are intended to serve as a set of considerations in developing future observatories that contribute to data justice. Following Milan and Treré (2019), we strive to relate the datafication of the water sector to bottom-up practices of data creation, which centre on the knowledge and agency of diverse urban residents in water governance.

The paper structure is as follows: we will set the scene and introduce the issues relating to the datafication of the water sector in Section 5.2. In Section 5.3, we work towards developing a definition of participatory urban dashboards and observatories and elaborate on the data justice framework for reviewing participatory urban dashboards and observatories. We turn to the work of Taylor (2017) and Heeks and Shekhar (2019), specifically their conceptualisations of data justice and how it can be useful in thinking about principles for the development and design of data observatories in marginalised communities in the Global South. Following Taylor's (2017) data justice framework, we review the participatory observatories based on three pillars: visibility, engagement with technology, and non-discrimination. Section 5.4 provides the methodology for the structured review of academic and non-academic examples of participatory urban dashboards and observatories. Section 5.5 presents the results of the analysis of the academic literature, i.e. the review of the participatory urban dashboards and observatories based on their function as an infrastructure for (Section 5.5.1) visibility and participatory practices, (Section 5.5.2) embeddedness in decision-making, and (Section 5.5.3) non-discrimination. In Section 5.6, we review the observatories in the field of urban water governance to formulate design principles applicable in practice. Finally, in Section 5.7, we develop recommendations for the design of participatory urban observatories that work towards data justice within urban water governance and present our concluding remarks in Section 5.8.

5.2 Datafication of the water sector

Urban administrations have progressively implemented sensors, meters, and supervisory control and data acquisition (SCADA) systems to ensure the supply and monitoring of potable water through urban space (Kitchin et al., 2018). These systems, and the data they collect, are attractive to policymakers because they present the messiness of urban water infrastructure in near real-time updated maps, tables, and graphs, implying a sense of insight and control. Moreover, they are typically promoted by an overwhelmingly positive vision of data governance in the Global South – a term we use with caution to refer to the plural geographical spaces and epistemological traditions that have been, and continue to be, suppressed in the colonial world order (Milan & Treré, 2019; Pansera, 2018) – as they address issues of empowerment for the most marginalised people (Masiero & Das, 2019; Taylor & Richter, 2017). From a central control room, they monitor water flows within the urban water infrastructure, from the treatment plant to the final consumer (Richter, 2018). In doing so, these digital infrastructures go a long way in determining how we conceive the city, who is part of it, and what knowledge we include in thinking about urban water governance.

The use of SCADA systems for water management fits within the ongoing development of using digital infrastructures and data technologies for the management of urban infrastructures (Barns, 2018). Since the late 1980s, a myriad of systems has been developed, often taking shape as control rooms or web and mobile phone applications built on emergent data science and digital infrastructure (Mattern, 2015). Within smart city discourses, these technologies have been referred to as indicator suits, urban dashboards, observatories, or benchmarking systems (Kitchin et al., 2015). However, typical of most of these systems is that they integrate various data sources and visualisations intending to support governments, residents, and businesses in decision-making (Mattern, 2015). But perhaps more importantly, the urban observatories work as instruments aiming to inform planning and policy-making, increase transparency towards residents, and inspire future scenarios for urban spaces (Dickey et al., 2021; Valenzuela-Montes & Carvalho-Cortes Silva, 2015).

Despite their potential, Mattern (2021) writes how dashboards are not only tools to make visible and monitor but also actively obscure urban processes, shape our definition of the city, and black box the functioning and the creation and processing of data. Specifically, Mattern (2021) explains how seeing the city-as-computer, in which infrastructure has to be made smart to operate efficiently, limits not only the types of (digital) information flows that are executable but also the types of information and expertise we consider valuable. Observatories embody a specific regime of sight. Often, this is presented as a view from nowhere, the idea that through the numbers and graphs portrayed on the map, a contextless viewpoint can be created that allows for an objective interpretation of what is perceived (Jasanoff, 2017). This line of sight often reproduces current inequalities, excludes other city perspectives, and overlooks alternative approaches to infrastructure management. Notably, in the context of managing urban water infrastructure, this view from nowhere, as portrayed by the spatial data infrastructures such as the SCADA systems, may omit other types of data and perspectives on water governance (Hoefsloot, Richter, et al., 2022).

The seamless and frictionless city the SCADA systems are designed and developed for rarely exists. Specifically, in cities in the Global South – looking at the city from the streets rather than the control room – presents a different picture of the water infrastructure. One in which water disproportionally flows in affluent neighbourhoods and does not reach new informal settlements on the periphery. It also provides a different experience of how the system breaks down and is maintained and (re)constructed by residents in strategic and improvised ways (Anand, 2017; Hoefsloot et al., 2020). By taking up these different roles, residents themselves largely overcome the gap of being underserviced within the material infrastructure by, for instance, acting as the engineers, constructors, and maintainers of the water distribution system within their neighbourhoods and households. Within these conditions, an important portion of urban residents is not only structurally underserviced but also structurally underrepresented in the data, leading to the further peripheralisation of the non-digital city (Hoefsloot et al., 2020).

Yet, as will be illustrated in the following sections of this research, these valid concerns with the use of urban observatories in infrastructure management are accompanied by a belief that digital infrastructures such as dashboards or observatories can potentially increase transparency in public governance, offer opportunities for residents' engagement, and support grass-roots data collection initiatives (Dickey et al., 2021; Viale Pereira et al., 2017).

5.3 Data justice and the participatory urban observatory

5.3.1 Defining participatory urban observatories

We are not the first to explore the potential of data to address complex urban issues in more collaborative and participatory ways. Specifically, others have written about collaborative data projects and citizen science to democratise data practices, stimulate a sense of ownership and right to the datafied city, and foster self-organisation and collective governance of urban processes (de Lange, 2019). However, we look at one specific infrastructure, the participatory urban observatory, as a tool in doing so and adopt a data justice approach to evaluate these observatories.

In the literature, the terms observatory and dashboard are both used to refer to a wide variety of organisations and technologies which function as interfaces between the person and the city (Lock et al., 2020; Mattern, 2021). A participatory urban observatory or dashboard can be characterised by its aim to redirect the use of digital technologies for participatory (spatial) knowledge generation about the city, creating awareness, fostering dialogue, and facilitating data exchange between local governments and urban residents (Castell et al., 2015). This can come in many forms. For example, the cases reviewed in this paper range in scope from distributed sensor networks to map sounds in the city (Botteldooren et al., 2013) and semi-automated web-GIS models to monitor flood risks based on crowdsourced imagery (Ardaya et al., 2019) to comprehensive urban knowledge institutions (Acuto et al., 2021) and critical counter-mapping platforms (Mattern, 2021).

While both terms (dashboard and observatory) are often used interchangeably, in this paper, we continue with observatory since this concept encapsulates the objective of perceiving urban issues and steers away from more technocratic imaginaries of a city that can be monitored and controlled from a single digital interface. Drawing on Lock et al. (2020), we define participatory urban observatories based on three important building blocks: (1) they serve as an infrastructure to contribute to the collection and sharing of knowledge about an urban context to inform decision-making; (2) they use geo-information tools – which can range from conceptual counter cartographies to geo-information systems with a distributed sensor network and earth observation data – to monitor urban issues within a confined spatial-temporal context; and (3) urban residents participate in the development or operation of the observatory by defining, observing, understanding, validating, or contesting urban issues.

This final point is important as participatory observatories often depart from the notion that residents of urban spaces have expert knowledge about the social, cultural, and material context in which they live. Whether as datafied 'smart-citizens' or auto-constructing 'expert-amateurs,' residents are important nodes in the exchange of expertise and knowledge about the city and the development of urban infrastructure (Hoefsloot et al., 2020). It is also precisely this aspect that makes it interesting to consider participatory urban observatories from a data justice perspective. As tasks that were previously in the domain of the state (Scott, 1999), such as the collection, processing, and use of data for decision-making about public infrastructures, shift towards residents, we might notice tensions regarding visibility, transparency, and representation within the data (Taylor & Broeders, 2015). Smart city infrastructures such as participatory urban observatories occupy an ambiguous place in this transition (Offenhuber, 2017). Hence, it is important to design them in ways that contribute to data justice in the city.

5.3.2 The data justice framework and how it forms a starting point for evaluating the potential of the participatory urban observatories in achieving just transformations in cities

In this section, we discuss the data justice framework in relation to participatory observatories and urban datafication to build our framework for reviewing the case studies of participatory urban observatories in water management.

Data justice emerges as an approach that seeks to investigate society's increasing datafication, which has become extremely prevalent in shaping policy, discourse, and practice (Cinnamon, 2020; Qureshi, 2020). Many interpretations of data justice exist based on concerns about ethical challenges that a data-driven society causes in both the Global North and the Global South (Dencik et al., 2016; Heeks & Shekhar, 2019). For instance, in the context of international development, Heeks (2017, p. 2) defines data justice as 'the specification and pursuit of ethical standards for data-related resources, processes, and structures.' This definition assumes a number of dimensions to be considered, from examining how the data is handled to the extent to which societal interests and power support fair outcomes for everyone.

Taylor (2017, p. 8) defines data justice as balancing and grappling with

> 'the need to be represented but also the possibility of the need to opt-out of data collection or processing, the need to preserve one's autonomy with regard to data-producing technologies and the need to be protected from and to challenge data-driven discrimination.'

This conception of data justice emphasises how data can be both empowering in the sense that it makes injustices visible and harmful, as it can increase surveillance and policing of marginalised communities and reproduce structural discrimination. Hence, according to Taylor (2017), data justice is only possible if people have access to, can engage with, and contest the data and digital infrastructures created.

Data justice has been applied to examine the datafication processes of antipoverty programs, like the Unique Identification Project (Aadhaar) in India (Masiero & Das, 2019); which demonstrates how digital platforms, designed to prevent breaches and maximise program effectiveness, actually lead to further injustices in the system. It has also been adopted to evaluate digital identity systems for refugee and displaced communities (Martin & Taylor, 2021; Schoemaker et al., 2020).

These cases demonstrate that data justice requires a multidimensional focus that considers both outcomes and processes. As a result, the data justice framework is structured along three pillars: visibility, engagement with technology, and non-discrimination. Visibility refers to the access to representation as well as the right to informational privacy; engagement with technology entails that people maintain autonomy within the data system and can take share in the benefits provided by the data; and finally, non-discrimination means that people have the ability to challenge biases and the systems work towards preventing discrimination in all its possible forms (Taylor, 2017). For each pillar, we have conceptualised what these principles might entail for participatory urban observatories.

5.3.3 Visibility, engagement, and non-discrimination.

Visibility refers to the access to truthful representation within the data and the right to informational privacy, meaning the right not to be visible within the data (Taylor, 2017).

The effect of invisibility, or the omission of data on marginalised communities in governance and decision-making, should not be understated (D'Ignazio & Klein, 2020; Ricaurte, 2019). D'Ignazio and Klein (2020) show via a multitude of examples how the invisibility of marginalised groups such as people of colour, women, queer, and disabled people in government and research data has not only resulted in the neglect of their needs but has also caused harm through the development of racist and sexist (digital) technologies and poor policy-making. Similarly, Ricaurte (2019) refers to 'government-enforced invisibility' to capture how government-led datafication practices often reproduce colonial and patriarchal hierarchies that lead to the erasure of marginalised communities' experiences and contributions to the creation of data and knowledge.

Hence, the word 'access' in Taylor's conceptualisation of visibility is paramount. Access to visibility-making practices gives people and organisations the power to define what should be made visible and through which methods and indicators. Access also allows residents to opt out of the system and choose not to make certain issues visible (Martin & Taylor, 2021). In other words, access goes beyond binary conceptualisations of connectivity (you are either fully connected or you are not) and refers to the abilities of people, including people from resource-deprived and marginalised communities, to participate according to differing needs, capabilities, and values (Roberts & Hernandez, 2019).

This brings us to the second pillar of Taylor's data justice framework: engagement with the technology. Taylor (2017) identifies two important components of engagement with technology. The first is the freedom to control one's engagement and disengagement with data technology (Schoemaker et al., 2020). This entails that people have the autonomy to choose to take part in the data technology or opt out and self-determine the degree of one's visibility. Secondly, engagement with the technology refers to the use of technology with the larger political, economic, and ecological landscape. Important in this regard is that the data should not be monopolised for capitalist gains, but all should be able to benefit from it. In practice, engagement calls for participatory methods or co-design, where actors have an active role in and ownership over the information technologies used in public decision-making (Jacobs et al., 2019). Taylor (2017) positions the data justice framework within a capability approach to emphasise how the just handling of data is not only about the functionalities of a tool but should consider an individual's agency and capability to act according to what they value and have reason to value.

Baibarac-Duignan and de Lange (2021) distil a number of productive insights for understanding (dis)engagement in the datafied city. In their work, Baibarac-Duignan and de Lange (2021, p. 5) offer a 'controversy-based' definition of engagement as the democratic processes of issue formation, otherwise understood as the transformation of something that was considered a matter-of-fact into a point of concern within a certain space and time. Big data and smart city applications are often decontextualised and removed from people's everyday experiences. For engagement, it is necessary that data is made less abstract. It is also necessary that the data and the platforms are situated – localised and contextualised – in the urban and social context (Baibarac-Duignan & de Lange, 2021; McFarlane & Söderström, 2017).

If we relate this to the participatory urban observatories, visibility and engagement do not only refer to being represented or not represented in a collective database; they also refer to democratic issue formulation within the urban context. The real value of civic apps such as participatory urban observatories is that they can allow residents to voice their concerns and aspirations for the city rather than only reporting operational problems (de Mesquita et al., 2018). In line with this statement, Mattern (2021) suggests that they do not necessarily have to be 'instrumentally utilitarian' to give valuable insights into the experience of people in the city. She argues that observatories can also be overwhelming in complexity and design, where people get lost and deep-dive into a niche subject rather than providing a snap-shot overview. In all their messiness and complexity, these observatories most likely do a better job of representing the city than a stylised and reductionist view does (Mattern, 2021). They help us experience the diversity in knowledge that can inform urban governance.

Finally, the third pillar of the data justice framework is non-discrimination. In operationalising non-discrimination, Taylor (2017) states that people should have the power to identify and challenge biases within the data and use them to prevent discrimination. This attends to structural inequalities that are reproduced in the data, such as the unequal representation of marginalised people and the types of knowledge presented in the observatory. Moreover, it urges us to look beyond the initial interface of the observatories and consider their features and how they are embedded in the city's larger social and political networks (Masiero & Das, 2019). Justice in knowledge generation requires going further than visualising structural inequalities and actively seeking to work against them (Milan & Treré, 2019).

In addition, to challenge biases, the processes of data collection, selection, curation, communication, and use should be transparent. This entails that data, algorithms, and code should be open.

Identifying and challenging biases in observatories also means challenging the ontology presented in the observatory and pluralising it to embrace the multiplicity in ways we can understand the city (Milan & Treré, 2019). Creating spaces for equal knowledge exchange between epistemic communities and centring plurality and collaboration is especially important, as colonial patterns in knowledge production manifest themselves in a variety of ways (Jimenez, Delgado, et al., 2022).

In operationalising Taylor's (2017) data justice framework to review participatory urban observatories, we noticed how many of the defined dimensions are dependent on two or three of the main pillars. Therefore, we have re-envisioned the framework (Figure 5.1), still departing from the three pillars of data justice framework developed by Taylor (2017, p.9) but taking into account how transparency and participation in data practices, collaborative issue formulation, and the pluralisation of ontologies only happen within the intersections of visibility, engagement, and non-discrimination. The dimensions we formulate as part of the data justice pillars or their intersections serve as benchmarks for evaluating current observatories and developing future observatories in accordance with the principle of data justice.

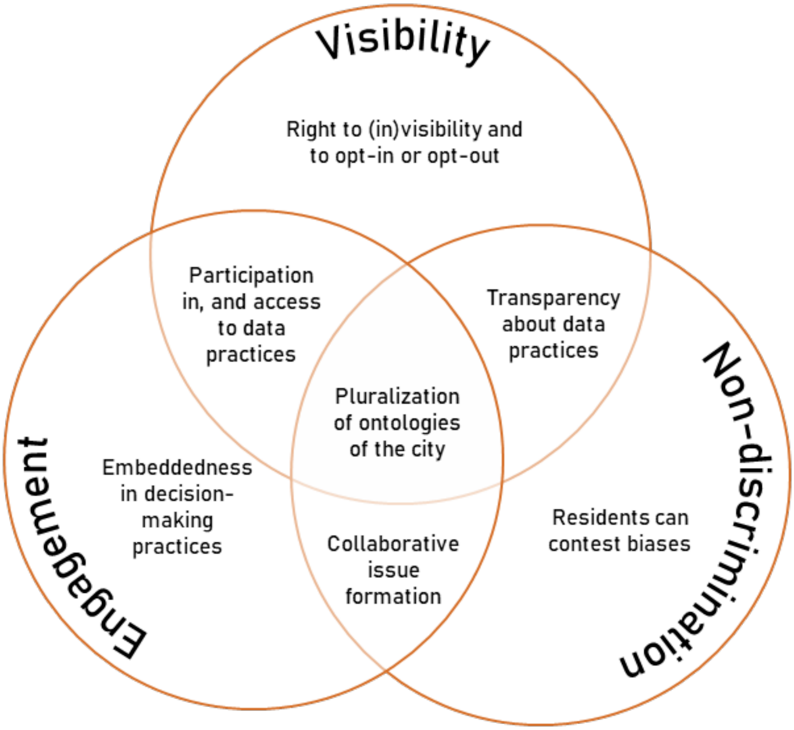

Figure 5.1 Applied data justice framework for participatory urban observatories. Based on the three pillars of the data justice framework developed by Taylor (2017, p. 9).

5.4 Methodology

This review has been conducted to inform the development of *the Observatorio Metropolitano de Agua para Lima-Callao*,[13] a participatory urban observatory that aims to reduce water injustices within the

[13] https://observatoriodelagua.ciudad.org.pe/

metropolitan area of Lima-Callao, Peru (Jimenez, Hoefsloot, et al., 2022). In order to learn from the various kinds of observatories that have been made in the past, their features, and their impact, we systematically reviewed academic and practical cases of participatory observatories for urban governance in general and urban water governance in particular.

The literature review included empirical research published in peer-reviewed papers, conference proceedings, and book chapters on urban dashboards and/or observatories which included a participatory element. Literature was selected using the SCOPUS and Web of Science databases. After a secondary screening of the abstracts focusing on (i) whether or not the papers described empirical research and (ii) the observatories contained a participatory element, a list of 23 papers published between 2001 and 2021 (results returned papers within that period) remained. We conducted additional searches in SciELO and the digital library of the Universidad de Chile to include Spanish language literature. Still, none of the results from these databases matched the subject matter and was selected for the final review. See appendix 5 for the steps taken in selecting the academic case studies, including search terms and a reference list.

In addition to the structured, broad literature review on dashboards and observatories spanning different aspects of urban development, we have reviewed existing and active participatory urban dashboards or observatories. The first part of the review (i.e., the literature) was broad, including dashboards and observatories spanning different aspects of urban development. During this second part, in which we reviewed existing and active platforms, we narrowed the search and specifically focused on participatory observatories or dashboards that, at least in part, focus on water issues in an urban context. We have selected active urban observatories or dashboards for review using the Boolean search function on Google. We used the incognito browser to ensure that our previous browser history did not inform the search results. Due to language constraints, we were restricted in selecting only English and Spanish platforms for this analysis, although we have come across similar platforms in other languages during our search. We have included results from the first 50 results for each search query. After a first screening of the returned results based on whether or not they (i) contained a participatory element, (ii) focused on urban issues, (iii) included topics related to urban water management, and (iv) were still in use at the moment of analysis, we remained with eight platforms. In addition, to this selection, we have included three observatories the authors were familiar with prior to the systematic search. Please see appendix 5 for the steps taken in selecting the practical case studies and the list of observatories finally selected (Figure 5.2).

In line with the literature review, we have specifically considered the self-proclaimed aim of the different platforms, the interactive features they contain, and their scope and contextualisation in our analysis of the platforms. Information for the review was gathered from the observatories' websites. For information regarding the right to (in)visibility, we particularly reviewed the privacy policy of the observatories. Following the data justice framework, our analysis and results are structured along three sections: 5.5.1 access to visibility and participation in data practices, 5.5.2 embeddedness in decision-making as a dimension of engagement, and 5.5.3 on collaboration, plurality, and transparency as dimensions of non-discrimination. We continue this structure in the analysis of the existing platforms in section 5.6.

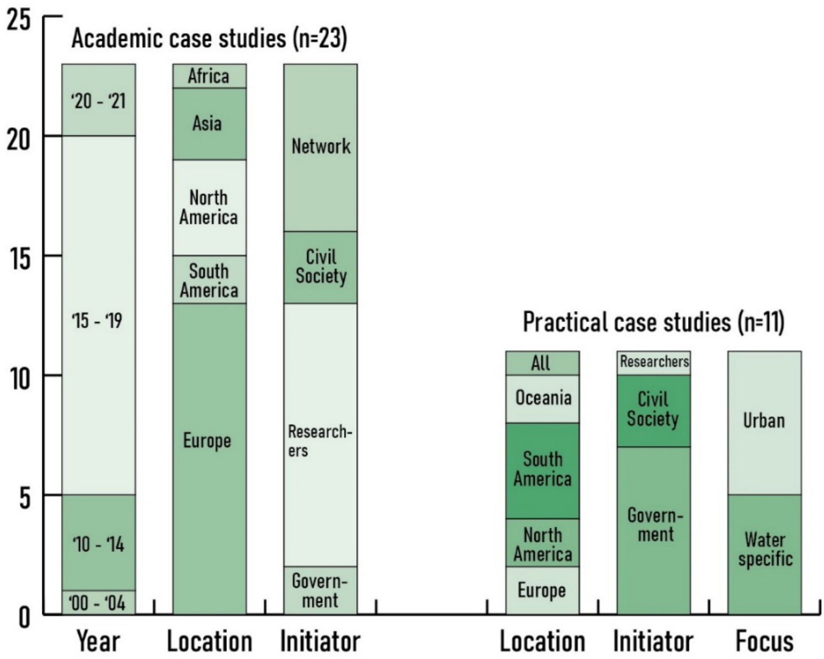

Figure 5.2 Overview of the publication years, case study locations, initiators, and thematic focus in the structural review of the academic literature and the observatories in the field of water. The selection did not contain any articles published between 2005 and 2009.

5.5 Review of literature on participatory urban observatories

5.5.1 Access to visibility and participatory data practices

As we focus on the issues with (in)visibility within the literature reviewed, we find that the observatories have a wide range of tools and methods for providing residents opportunities to participate in the data practices and contribute to visibility-making or guard the right to invisibility. The participatory urban observatories taken into consideration for this review contain a wide variety of data, ranging from volunteered geographic information (VGI), passively collected data from social media or sensors drawing on Internet of Things technology, to data from public registries and community reporting. However, while there are little generalisations we can make about the type and use of data within these different observatories, we can categorise them according to the active or passive roles of users within the system. It is worth noting that participation itself is rarely defined within the studies reviewed. In general, participation refers to any contribution of residents in the data process but does not reflect on whether or not this participation is truly meaningful or if residents' participation is considered mainly an instrument for data collection and validation.

Active participation refers to the engagement of residents in various data practices, ranging from collecting measurements, entering information, and/or validating automatically generated data. For example, in the development of community indicator systems, residents were involved, from formulating the indicators that needed to be measured to setting goals, endpoints, and timelines (Hendrickson, 2010). In other cases, residents help with calibrating automatically-collected earth observation data (See et al., 2016) or are often involved in validating the results of the data collected to make sure that it represents their perception of the city (Ardaya et al., 2019). Acuto et al. (2021) detail how the observatories in Karachi, Bengaluru, Freetown, and Johannesburg focus on building long-lasting and stable relationships between diverse urban groups. In doing so, observatories do not only aim to inform decision-making but also strengthen the research and advocacy capacities of civil society and local communities (Acuto et al., 2021) and serve as platforms to connect data to action (Bixler et al., 2019). For example, in Nova Friburgo, Brazil, the data collected on flood and landslide events were validated by local community groups who also participated in the negotiation of policies for disaster risk response (Ardaya et al., 2019). These observatories require a more active and direct engagement of residents as experts in providing, interpreting, and validating data.

Passive participation refers to cases where residents share data on social media or through sensors connected to the internet and which is automatically collected. Botteldooren et al. (2013) describe this as a 'plug-and-measure' system in which residents can connect their devices like remote sensors within a crowdsourcing platform to share textual, numerical, audio, or visual data such as images or video recordings (Assumpcao et al., 2019; Castell et al., 2015). Ludlow et al. (2017, p. 18) refer to the data passively collected by residents as 'community derived inputs,' emphasising the role of residents as data collectors rather than collaborators in knowledge generation.

The case studies discussed suggest that participatory data practices can lead to higher levels of trust and accountability in the data, the possibility of recording the residents' perceptions of the city, and a better representation of residents in the data. The limitations of participatory data collection discussed are in terms of the 'trade-off' between accuracy and participation. Generally, crowdsourced data used in participatory urban observatories is considered less accurate due to limited or skewed participation, less precision in the adherence to research protocols, or a lack of methodological training (Ardaya et al., 2019; Assumpcao et al., 2019; Botteldooren et al., 2013).

Regarding the issue of limited participation, See et al. (2016) state that the barriers to participation based on education or legal and logical access to technologies should be limited. Particularly in, but not limited to, the Global South, issues related to the unequal access to digital infrastructure to participate in the urban observatories is a concern (Acuto et al., 2021). The

FLAMENCO platform explicitly aims to do so by providing a framework for participatory urban observatories that can be implemented and used by 'ICT-agnostic' people or organisations, meaning that it should be accessible and useable for societal organisations and communities even if they do not have an extensive ICT background (Zaman et al., 2018). Another strategy to increase access to and participation in urban observatories is to diversify how knowledge is shared. We found that in addition to visualising online figures and maps in a web browser or mobile phone application (Ardaya et al., 2019; Botteldooren et al., 2013), various observatories share knowledge about city processes via policy reports distributed online (Acuto et al., 2021) or in workshops and university lectures (de Queiroz Ribeiro & dos Santos, 2001). Some even share knowledge through information plaques within public spaces (Carbonari et al., 2019). Thus, while urban observatories often have the tendency to black box data practices (Mattern, 2021), their participatory counterparts often aim explicitly to increase transparency and access to data.

Nonetheless, Uson et al. (2016) explain that, despite legislation encouraging close collaboration of researchers, policymakers, and residents in defining issues related to urban flood risks, proposing solutions, and making decisions, the population is only considered as a partner to validate the data (based on their local experience), and information is not systematically and effectively shared amongst all actors. Similarly, Ardaya et al. (2019) explain how residents complained that their contribution to the validation of the data about environmental risks was not considered, hollowing out the participatory process. Moreover, while some cases reviewed propose strategies to increase the participation of residents in visibility-making, none of the studies reviewed explicitly discuss how residents can self-determine which data they would like to have recorded within the observatory and how data might be deleted or removed from a database if requested. One of the articles included in this review detailed how observatory admins could protect personal privacy by ensuring that people are not identifiable in the images collected in the observatory (Wannemacher et al., 2018), but this did not include the option to opt-out of the visibility-making practices. Other case studies only described embedded options to remove a data point for the sake of cleaning up or maintaining the database (Guillaume et al., 2016; Ladu, 2020) and not in relation to the right to stay invisible.

Hence, when we look at the literature reviewed through the analytical lens of visibility and access to data, the first pillar of the data justice framework, the review shows how varied the cases are. While some examples appear to use a more goal-driven approach to participation for visibility – increasing visibility through decentralised and participatory data collection – others approach it from a more bottom-up perspective – co-determining what has to be made visible and through which methods. Or in other words, we distinguish between the observatories that approach residents as 'sensors' within the city and observatories that approach residents as 'expert observers.'

5.5.2 Engagement: embeddedness in urban decision-making

Although all observatories reviewed contained or were built on digital information systems, the platforms are embedded within the decision-making in various ways. de Mesquita et al. (2018, p. 192) state observatories can 'enable citizens to express local and communal issues regarding public space to have more potential as they can function as entry points for tailoring policy or urban design on a neighbourhood scale.'

Most participatory urban observatories have in common that knowledge exchange is seen as bi-directional and collaborative (Pihlajaniemi et al., 2017), meaning that the government can learn from residents and vice-versa. Ardaya et al. (2019) emphasise the importance of trust in this learning process. Specifically, they state that if there is mistrust between the actors in the production of participatory knowledge about urban issues, the process loses its legitimacy. From that, we distil that an essential role of the participatory urban observatory is to facilitate that bidirectional learning process by creating spaces in which residents can communicate their knowledge and experience, and governments can provide more insight and transparency over their policies and decision-making processes. However, how this role is operationalised within the participatory urban observatories varies greatly.

Some observatories are specifically localised in the sense that they are made for, and embedded in, the particular context of a specific urban environment. For instance, the observatory for the Italo-Argentinian influence on architectural heritage in Buenos Aires (Carbonari et al., 2019). Others, such as the CITI-Sense-Mob, are developed specifically for a city such as Oslo with a regular and fine-mazed bus transport system and a cycling culture but pursue the more generalisable aim of measuring and monitoring urban air quality (Castell et al., 2015). Similar to other observatories focusing on issues such as noise, air quality, and traffic, these platforms are characterised by their general rather than contextual and sectoral focus and their potential to be implemented in various cities (Botteldooren et al., 2013; Guillaume et al., 2016; See et al., 2016; Sinha et al., 2012). Taking it one step further, the FLAMENCO project is specifically designed as a framework that can be adapted and used in different contexts (Zaman et al., 2018, 2021).

The question that arises here is: how do general observatories contribute to building appropriate and actionable knowledge on urban issues? Bixler et al. (2019) state that for the knowledge collected from observatories to be actionable, it is crucial that they facilitate data collection and knowledge exchange virtually and actively engage with urban actors 'in real life.'

In Rio de Janeiro, the Observatorio was developed as part of more considerable governmental reform and as a tool to facilitate the direct participation of residents in urban planning and reformulate government-citizenship relations after a period of dictatorship (de Queiroz Ribeiro & dos Santos, 2001). Its specific aim was to strengthen residents' participation and democratise information about the urban and infrastructural policy. Similarly, the observatories discussed by Acuto et al. (2021) are positioned within the broader debate on urban planning and policymaking. In their case study research on the use of urban observatories during the Covid-19 crisis, Acuto et al. (2021) illustrate how already existing observatories transitioned into crisis observatories during the covid-19 pandemic. From having a general advisory role, the urban observatories in Johannesburg, Bengaluru, Karachi, and Freetown became key players in generating and mobilising spatial knowledge about the covid crisis. In doing so, they did not only assist local governments by filling gaps in knowledge, e.g., the mapping of pandemic risk factors such as household crowding and shared sanitation, but also by taking over specific governmental roles.

5.5.3 Non-discrimination: collaborative, plural, and transparent

Having discussed how the observatories approach issues related to the access to visibility, engagement, and embeddedness in urban decision-making, we now review how participatory urban observatories can potentially work towards overcoming discrimination within urban knowledge practices by providing space to contest biases and fostering transparency, collaborative issue formation, and plural ontologies. By default, participatory urban observatories contain the normative notion that the city, and urban governance, can be improved by deploying the knowledge of its residents. However, whose knowledge is represented in the observatory and which narratives for the city to come are produced are often not explicitly discussed.

de Mesquita et al. (2018) argue observatories can have dual results. On the one hand, they can increase the efficiency of urban processes by reducing 'bureaucratic fuss' (p. 185). On the other hand, they serve as tools so 'citizens can find out what is happening in their neighbourhood, take ownership and become more actively engaged with local issues and within a community' (p. 186). In line with this statement, we find that we can roughly categorise the reviewed participatory urban observatory into two types: the observatories that aim to monitor urban processes and support effective management and the observatories that aim to generate new perspectives of the city. Regarding the first, the observatories are characterised by a technology-driven approach in which it is argued that, due to the advancement of IoT and geo-technologies, we have new opportunities to monitor urban spaces (Ladu, 2020). For example, the U-TEP project uses geospatial data, mainly earth observation imagery, to facilitate 'effective and efficient urban management' (Esch et al., 2017, p. 1380). Also, the DECUMANUS observatory is presented as a tool that can help monitor and assess land, energy, and citizen health at a much higher resolution than previous systems would allow. This could potentially help residents and urban planners in decision-making (Ludlow et al., 2017). Through their focus on the opportunities of technologies and efficiency, they often reproduce dominant images of the smart, digital, or cyber city.

The second type of observatories, which focuses on generating new perspectives of the city, is characterised by the often explicit aim to enhance residents' authority and autonomy in making their voices heard within urban development processes. For example, Uson et al. (2016, p. 70) state how participatory observatories can 'enhance instances for proposing alternative visions of space, knowledge and the notion of risk' within the city. They emphasise how, instead of focusing on validating knowledge, they aim to give residents the opportunity to deliberate collectively about how to define their own problems, opportunities, and solutions to issues related to urban risk. Similarly, Rio's observatory's main impact lies in how it assisted in the formulation of alternative urban policies in partnership with research institutions, NGOs, and residents (de Mesquita et al., 2018). In doing so, participatory urban observatories can help residents to address local issues, voice their aspirations for their city, mobilise knowledge to tackle challenges within their environment and enable residents to influence urban development by collecting and datafying the public perception (de Mesquita et al., 2018; Wannemacher et al., 2018).

In addition to the opportunity to pluralise narratives, we find that some observatories also facilitate the contestation of biases in the data they create or are used as tools to contest the biases in knowledge external to the observatory. As detailed earlier, this can be done by inviting residents to validate or contest the data collected on the platform based on their on-the-ground expertise (Assumpcao et al., 2019; Esch et al., 2017; See et al., 2016). In addition, some observatories explicitly profile themselves as a tool to critique current indicators for urban processes (Hendrickson, 2010), contest already existing maps and navigation routes (de Mesquita et al., 2018), or diversify the ways we value and report the significance of cultural heritage with the city (Carbonari et al., 2019).

Transparency in terms of why, what, and how data are generated through the observatories is a prerequisite for being able to critically investigate the knowledge shared via these platforms. Hence, it is a precondition for both pluralising ontologies and being able to contest the biases in the data. Several observatories reviewed explicitly mentioned their aim of increasing transparency in policy development and implementation and public administration by facilitating the exchange of information between governments, organisations, and residents (Acuto et al., 2021; Brown-Luthango et al., 2013; Estuar et al., 2017; Ladu, 2020). Other observatories contribute to transparency implicitly by making the data more accessible for different actors and participatory monitoring of urban processes (Bixler et al., 2019; Esch et al., 2017; Guillaume et al., 2016). However, it is important to note that the aim of increasing transparency in the public administration of urban processes does not automatically correspond with the observatories being transparent about their own data practices. While the case studies in the academic literature provided clear methodological sections, it was not detailed how this information was communicated with the users of the observatories and how the observatories themselves guarantee transparency in data practices.

5.6 Analysis of participatory urban observatories used in practice

The review of the academic literature gives us an overview of the broad range of approaches in the design and application of participatory urban observatories and leads us to the categorisation of characteristics of the data justice dimensions, as seen in Table 5.1. Nevertheless, the analysis of academic cases does not allow us to review how the observatories are experienced from the user perspective, nor does it give us much insight as to how the dimensions of the applied data justice framework can be translated into practice. In this section, we review a selection of participatory urban observatories to better understand these aspects.

Table 5.1 Categorisation of participatory urban observatories (POU) resulting from the review of cases in academic literature

Dimensions	Characteris-tics	Elaboration	References
Access to visibility	Citizen as sensor	Passive citizen participation through crowdsourced data collection. E.g., the use of sensors embedded in household or mobile devices used by residents.	(Assumpcao et al., 2019; Botteldooren et al., 2013; Castell et al., 2015; Ludlow et al., 2017)
	Citizen as expert observer	Active participation of residents in defining what needs to be observed and in the interpretation, use, or validation of the information collected.	(Ardaya et al., 2019; Bixler et al., 2019; Carbonari et al., 2019; de Mesquita et al., 2018; Hendrickson, 2010; See et al., 2016)
Right to (in)visibility and to opt-in or opt-out	Explicit	PUO explicitly mentions how residents can opt-out, be invisible, or only have some of their data shared.	None
	Not mentioned	PUO does not explicitly state how to opt-out	All
Issue Formulat-ion	Top-down	Issues addressed in the observatory are predetermined by the initiator.	(Acuto et al., 2021; Bixler et al., 2019; Botteldooren et al., 2013; Brown-Luthango et al., 2013; de Queiroz Ribeiro & dos Santos Jr., 2001)
	Collaborative	Issues addressed in the observatory are defined in collaboration between different actors.	(de Mesquita et al., 2018; Hendrickson, 2010; Zaman et al., 2021)
Embed-deness in decision-making	Embedded	POU is embedded within the broader debate on urban planning and policymaking.	(Acuto et al., 2021; Bixler et al., 2019; de Queiroz Ribeiro & dos Santos Jr., 2001; Hendrickson, 2010)
	External	POU collects data that can potentially help residents and governments in informed decision-making.	(Botteldooren et al., 2013; Castell et al., 2015; Guillaume et al., 2016; Ladu, 2020; Ludlow et al., 2017; See et al., 2016; Sinha et al., 2012; Zaman et al., 2018, 2021)

Continuation of Table 5.1

Contest biases	Facilitated	POU has built-in methods for residents to report and contest internal and external biases. E.g., a workshop or online form.	(Acuto et al., 2021; Assumpcao et al., 2019; Carbonari et al., 2019; de Mesquita et al., 2018; Esch et al., 2017; Hendrickson, 2010)
	Not facilitated	There is no explicit method that allows for the reporting and contestation of biases.	All others
Transparency	Outward	POU focuses on increasing transparency in public administration and decision-making	(Acuto et al., 2021; Bixler et al., 2019; Esch et al., 2017; Estuar et al., 2017; Guillaume et al., 2016)
	Internal	PUO focuses on transparency about its data practices.	(de Mesquita et al., 2018; Sinha et al., 2012; Zaman et al., 2021)
Pluralising ontologies of the city	Pluralises urban narratives	POU facilitates residents to express their understanding, experience, and narratives of the city.	(Carbonari et al., 2019; de Mesquita et al., 2018; de Queiroz Ribeiro & dos Santos Jr., 2001; Uson et al., 2016; Wannemacher et al., 2018)
	Dominant urban narratives	POU departs from and presents a clear narrative understanding of the city. E.g., the 'smart city' or the 'right to the city.'	(Esch et al., 2017; Ladu, 2020; Ludlow et al., 2017)

Specifically, as we are – eventually – interested in the potential use of participatory urban observatories for water access, the observatories analysed self-described as urban dashboards or observatories and engaged with – at least partially – issues related to urban water governance or management. For example, the city of Evanston's (USA) open data portal is a government-led data platform in which residents can consult and download data on a wide range of topics, including issues such as housing, urban ecology, transport, infrastructure and urban (water) risks. Similarly, the platforms This is not an Atlas[14] and *Observatorio del Derecho a la Vivienda*[15] (Observatory of the Right to Housing) share and collect information about urban transformation and the right to the city at large, including issues related to water governance.

For most of the platforms reviewed, the urban observatories serve as tools to establish communication and interaction between the water authorities and residents and increase public participation in the design and assessment of public policies to align with the ambition to promote *collaborative* and *transparent* governance. This can either be approached from the perspective of government organisations such as municipalities or water service providers[16]. For example, in Sevilla, Spain, the local water authority has initiated an *Observatorio de Agua Sevilla*[17] (Sevilla Water Observatory). In addition to creating a digital platform, the Observatorio de Agua Sevilla has invited a group of organisations, ranging from private companies to civil society organisations, environmental groups, and neighbourhood representatives, to participate in round table discussions about water governance in the region. Their website states that the observatory has specifically been created because of a belief that residents' participation is vital to legitimise decision-making processes and the design and adoption of public policies. These platforms are directly *embedded* in urban decision-making and facilitate residents' *engagement*. The 'external' observatories, such as the *Observatorio Urbano* (Urban Observatory) of the Peruvian NGO Desco[18], are generally initiated by civil society and have the ambition to influence public decision-making but operate as external, critical entities towards the government.

[14] https://notanatlas.org/maps/collaborative-cartography-in-defense-of-the-commons/
[15] http://www.observatoriodevivienda.org/
[16] http://www.ideam.gov.co/web/ocga/inicio
[17] https://www.emasesa.com/conocenos/observatorio-del-agua/
[18] https://observatoriourbano.org.pe/

Three observatories explicitly indicated how users could practice their *right to (in)visibility* by providing information about how personal data can be rectified or erased. Practically, the EU and Australia-based observatories do so by referring users to legal frameworks that offer data protection or privacy rights (e.g., the EU General Data Protection Regulation or the Australian Privacy Principles). Two observatories did refer to the right to privacy but did not provide any further information about how data can be deleted or altered. The other observatories did not provide any information about privacy and data policies within the platform.

In addition to gathering information and establishing communication between the water authorities and residents, the observatories are used as tools to inform residents about challenges in urban and resource governance and the responsibilities residents have. See, for example, Connect Coliban[19] and the Unity Water Community Hub[20], two platforms initiated by water service providers in Australia. The Unity Water Community Hub serves as a platform to involve residents in various projects ranging from a people's panel where residents can inform Unity Water by answering a bi-annual survey. In addition, they aim to educate consumers about water security, responsible water consumption, and water management in irrigation and infrastructure. Similarly, Connect Coliban, the community platform of the water provider in the northern part of Victoria, Australia, has set up citizen science initiatives to monitor the condition of the waterways and estuaries in the region. They use different strategies for community engagement, including visits to the towns, citizen science projects, surveys, and online educational games about tap water.

Three of the 11 observatories stand out with regard to their efforts to increase *transparency*. The Observatorio del Agua Sevilla, City of

[19] https://connect.coliban.com.au/projects
[20] https://communityhub.unitywater.com/

Evanston's Open Data Portal[21], and Decide Madrid[22] (Madrid Decides) all aim to contribute to outward transparency by *increasing access* to government data and granting insight into public decision-making. In addition, these platforms work towards internal transparency through their openness about their data practices, even providing an API for developers to access the data and code. The latter two also invite developers to access the platform and share their assessment of the observatory's architecture. In addition, Connect Coliban, Decide Madrid, and the City of Evenstrom's Open Data Portal contained a digital form through which users were invited to provide feedback, suggestions, or critique to the observatory. Thereby facilitating the *contestation of internal biases*.

Finally, we identified six observatories working towards the *pluralisation of ontologies* about the city and water infrastructure. These platforms take diverging approaches to go beyond informing residents and increasing transparency, and creating spaces for people to voice their visions, opinions, or aspirations for the city. For example, the Observatorio del Derecho a la Vivienda focuses on urban issues in Mexico and seeks to systematise the collection and analysis of information about adequate housing across municipalities to facilitate reflection and dialogue on the matter. Additionally, Decide Madrid states explicitly that its aim is to build, through participation, dialogue, and inclusion, a better, more democratic, and plural city that seeks the shared commitment of a project of a city that improves the life and well-being of its residents. Amongst the civil society, research, or collaboratively initiated platforms, This is not an Atlas collects and shares a wide range of counter-maps, drawing on critical and participatory methods, to portray alternative experiences of space and serve as tools to communicate needs and challenge hegemonic prepositions about cities. The

[21] https://data.cityofevanston.org/
[22] https://decide.madrid.es/

Observatorio del Agua Mendoza[23] (Mendoza Water Observatory) explicitly states as their objectives that they want to promote the active participation of residents, paying particular attention to the participation of women, improve communication between residents and the water authority, help planning processes and management, directly and indirectly, related to water, and gather ideas for the continuous improvement of water resource management. And finally, going one step further, the *Observatorio del Derecho a la Ciudad*[24] (Observatory for the Right to the City) organises public assemblies during which input is gathered for policy briefs and general demonstrations to express residents' discontent with current policies. Their digital platform – the website – functions as a tool to share information and mobilise residents to participate in physical gatherings and marches on the streets of Buenos Aires.

Overall, as illustrated in Figure 5.3, we find that when reviewing the participatory urban observatories in practice, Decide Madrid stands out in the sense that residents participate in visibility-making as experts, it is explicit about the user's rights to (in)visibility, fosters collaborative issue formulation, is embedded in decision-making practices, facilitates the contestation of biases, is transparent, and contributes towards pluralising the ontologies of the city.

[23] https://www.observatorioaguamza.com/es
[24] https://observatoriociudad.org/

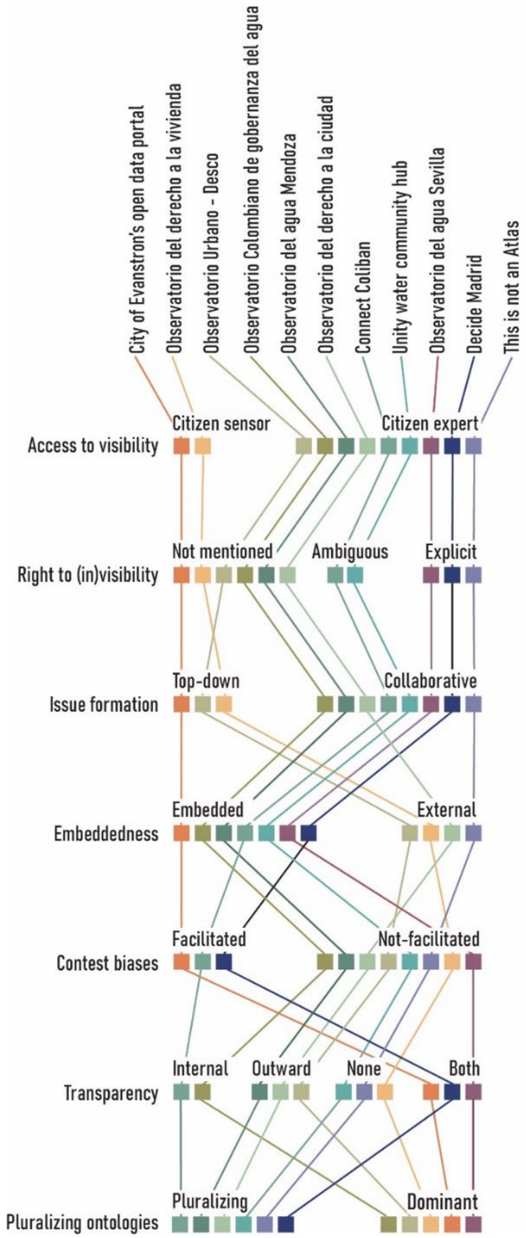

Figure 5.3 Analysis of urban water observatories from practice. Graph design inspired by de Mesquita et al. (2018).

5.7 Towards design principles for just participatory urban observatories for water governance

Both the analysis of the academic literature and the assessment of participatory observatories in the field of urban water management showcase the diversity of approaches to the development and design of participatory urban observatories. Applying Taylor's (2017) data justice framework and reviewing the participatory urban observatories based on the pillars (in)visibility, engagement, and non-discrimination helps in eliciting principles for the future development of similar observatories for public infrastructure governance in cities (Table 5.2). Combining the theory-informed data justice framework with a review of participatory urban observatories currently in use helped formulate more meaningful and applicable principles. Although purposefully formulated broadly to be applicable for a wide range of urban issues, we are particularly interested in thinking through how these principles can help design participatory urban observatories that bring to the surface issues that otherwise go unseen, help formulate shared solutions for water insecurity, while preserving ontological pluralism with regard to water.

First, regarding the issues of (in)visibility making and residents' active participation, it is important to consider how the knowledge residents have regarding water management by way of daily life can be translated into an observatory. Specifically, our analysis shows we must think of how the policy actions related to the water infrastructure and the distribution of water in the city can be articulated with residents who seek water justice and have been critical in the development and management of the system for a long time. However, it is important to consider how to record the stories and needs of residents and organisations, specifically since ‘voices from the neighbourhood’ might be difficult or impossible to record in indexes or maps. As shown by several case studies reviewed, this can be addressed by diversifying the data collection visualisation and sharing approaches in line with the needs and abilities of residents.

Table 5.2 Data justice informed principles for designing participatory urban observatories (PUO).

	Data justice dimension	Design principles
1	Right to (in)visibility and to opt-in or opt-out	PUO explicitly mentions how residents can opt-out, be (in)visible, or only have some of their data shared. Specific attention should be granted to visibilising the experiences and perspectives of marginalised communities.
2	Participation in and access to data practices	Residents are approached as expert observers within the city, stimulating their active participation in all stages of developing a PUO: from defining what needs to be observed to the interpretation, use, or validation of the information collected.
3	Embeddedness in decision-making practices	PUO fosters relationships and communication between actors and feeds into public planning and decision-making processes.
4	Issue formation	PUO works towards empowering residents to voice their aspirations for their city and mobilise knowledge to tackle challenges within their environment and urban governance.
5	Contestation of biases	PUO facilitates the contestation of internal and external biases.
6	Transparency about data practices	In addition to contributing to administrative transparency, PUO is transparent with regard to the definition and selection of indicators, and the generation, processing, and use of data. Ideally, this translates into opening the data, algorithms, and codes of the platforms.
7	Pluralisation of ontologies of the city	PUO facilitates the expression of plural ways of understanding and knowing the city and is part of a dialogue about the city.

As we reviewed the application of participatory observatories in urban settings, it is important to note that, in cities, the limitations regarding access to digital infrastructures such as mobile devices and the internet are significantly lower than in rural communities (ITU, 2021). As a result, the results from our analysis are also limited to this context. When exploring the application of participatory observatories in rural settings, other standards for participation and access may apply.

Second, urban observatories are part of larger spatial data infrastructures and should be embedded in governance and management processes (Kitchin et al., 2015). Our analysis shows how the anticipated impact of the reviewed observatories generally lies in the potential to create new partnerships and open up routes of communication between government actors and residents. Following examples of the civil society and collaborative platforms that we reviewed (Bixler et al., 2019; Brown-Luthango et al., 2013; Castell et al., 2015; Hendrickson, 2010; Pihlajaniemi et al., 2017), this means working in collaboration with organisations that have been involved in community work and building on the existing structures in the city. Additionally, this implies that observatories need to consider the socio, political and geographical context to which the technology is introduced.

Third, if we trust participatory observatories to contribute to data justice, they need to open up to everyone: groups with different skills, capacities, and backgrounds should be able to participate in data practices, issue formation, and check internal and external biases. It is not just important for people to have access to participatory observatories, but that the systems are in place for them to be able to use them in ways that fit their needs considering accessibility, availability, awareness, agency, and affordability (Roberts & Hernandez, 2019). Applied to the case of urban water governance, this means that also people who are not customers of the formal water system and thus fall outside of the SCADA system should be actively included in these processes. Incidentally, this requires transparency about data practices and the architecture of the observatory.

Finally, while many observatories described in the literature and practices allow for higher levels of engagement and create spaces for residents to express their ideas about how urban infrastructure should develop, only very few of the platforms reviewed aim to, and potentially succeed in, upending the dominant ontologies of the city. Others rarely exceed the dominant indicators of infrastructure management, such as efficiency and accountability. Inspired by the observatories Observatorio del Agua Mendoza, Decide Madrid, and This is not an Atlas, which stand out in their effort to challenge hegemonic thinking and invite plural imaginaries for water governance or the city at large, we argue participatory urban observatories should go beyond the goal of improving resource preservation and the more just distribution of water within the city to enhancing the accountability of decision-making and planning processes. Steps to be taken are increasing transparency, encouraging participatory governance through residents' empowerment and engagement, and facilitating plural ways of understanding and knowing water and the city. This implies that the participatory urban observatory, if contributing to responsible and just infrastructures, should be part of an ongoing and two-way dialogue about the city and public values (Baibarac-Duignan & de Lange, 2021), which departs from an equal collaboration between epistemic communities (Jimenez, Delgado, et al., 2022). In this dialogue, observatories can serve as a space where knowledge is constructed, challenged, negotiated, validated, and consulted (Miranda Sara & Baud, 2014).

The principles in table 5.2 help us design systems that serve to visualise water flows and allow residents to increase visibility while maintaining control, address grievances, reduce inequalities, and suggest alternative approaches and ontologies for water governance. If participatory urban observatories want to contribute to the ambitions of a just city and create a space for residents to engage with and contribute to the governance of urban infrastructures, they will need to be designed according to the principles of data justice. However, future research should consider how we can design urban observatories that recognise the knowledge of marginalised communities and more-than-human entities.

While the design principles depart from the aim to contribute to bridging the divide between data justice in theory and practice, translating the principles into an artefact will require reviewing their value and applicability to the specific context for which the observatory is designed. For those designing participatory urban observatories, this points toward the importance of contextualisation and critically considering the design principles in relation to governmental and infrastructural conditions that promote or obstruct participation and peoples' capabilities.

Specifically, with regard to design principles 2 and 3, it entails evaluating how meaningful participation and engagement can be facilitated in the socio-political and geographical context of implementation. Our analysis of case studies has focused predominantly on countries with (relative) strong democratic institutions. As these conditions vary widely across the globe, a specific issue that should be considered is the local expression of citizenship and the opportunities and risks related to active involvement in issue formulation and governance.

5.8 Conclusions

In this article, we reviewed the design of participatory urban observatories in academic literature and practice and their implementation in urban governance. Although these issues have been previously explored with regard to the usability of dashboards for different types of residents (Young et al., 2021), their participatory functionalities (Lock et al., 2020), and various design features (Barns, 2018; Young & Kitchin, 2020), we contribute to these discussions in two ways. First, we applied Taylor's (2017) data justice framework in practice to evaluate participatory urban observatories. This not only guides the review of participatory urban observatories and how they follow the principles of (in)visibility, engagement, and non-discrimination. It also helps understand the overlap between the three pillars of data justice. As illustrated in Figure 5.1, the creation of an urban observatory that contributes to participation, collaboration, transparency, and plural ontologies of the city is only possible if all three pillars of data justice are adhered to. Secondly, we translate the data justice framework into principles for the design of just urban observatories in the domain of water governance. Participatory urban observatories do not necessarily provide full coverage or 'objective data' but can play a role in communicating the experiences and views of residents currently not represented in digital data and facilitate collective knowledge creation, negotiation, validation, and contestation. This is valuable in the context of the datafication of urban infrastructural governance and, particularly, the use of SCADA systems for water governance in cities.

The principles presented in this paper draw from both theory and practice and highlight the importance of creating smart city interventions collaboratively to avoid reproducing unjust systems and to imagine new ways of enacting a more just city that recognises plurality in ontologies and imaginaries of the city (Milan & Treré, 2019). It is important to emphasise that, while just participatory urban observatories can potentially function as infrastructure to facilitate these steps, they are implemented in the wider political-economic landscape and do not remove power asymmetries between actors (e.g., government, NGOs, and citizens). Therefore, in designing participatory urban observatories, we should continuously examine power relations and question the technology's contribution to development.

Chapter 6:

The *Observatorio Metropolitano de Agua para Lima-Callao*: a digital platform for water and data justice

Abstract:

This paper details the development and design of the *Observatorio Metropolitano de Agua para Lima-Callao* (the metropolitan water observatory for Lima-Callao, MWO). The MWO is a digital, collaboratively developed observatory that aims to collect and share data about water access and infrastructuring practices within the metropolitan city of Lima-Callao, Peru. The purpose of developing the MWO has been to contribute to a fairer distribution of water resources amongst urban residents by creating an *espacio de concertación* and collect and diffuse data on access to and quantity and quality of water for human consumption. By combining collaborative design approaches with the theory-informed data justice principles, we have developed a prototype of the MWO. The prototype and lessons learnt in its development offer generalisable guidance on how to design digital platforms according to the principles of data justice in practice.

This chapter is a combined version of the following two publications:

Hoefsloot, F. I., Jimenez, A., Miranda Sara, L., Estacio Flores, L., Martinez, J., & Pfeffer, K. (2022). The *Observatorio Metropolitano de Agua para Lima-Callao*: a digital platform for water and data justice. In *IFIP WG9.4 Conference proceedings*, peer-reviewed

Jimenez, A; Hoefsloot, F.I; Miranda Sara, L (2022). The coproduction of the Metropolitan Water Observatory (MWO) platform, *KNOW Working Paper Series*, No. 8, London, United Kingdom, ISSN 2632-7562

6.1 Introduction

In this chapter, we detail the design of the *Observatorio Metropolitano de Agua para Lima-Callao* (the metropolitan water observatory for Lima-Callao), hereafter referred to as MWO. The MWO is a digital, collaboratively developed observatory that aims to collect and share data about water access and infrastructuring practices within the metropolitan area of Lima-Callao in Peru. The purpose of developing the MWO has been to contribute to a fairer distribution of water resources amongst urban residents by exploring the potential of collecting and diffusing data on the access to, quantity, and quality of water for human consumption in Lima and Callao.

Over the past years, SEDAPAL, Lima's water company, has implemented a supervision, control, and data acquisition system (SCADA) to manage the water flows within the city. The use of digital technologies for water management and the focus on data-driven decision-making has been of value for SEDAPAL in managing the water distribution system in Lima. With the help of this digital infrastructure, SEDAPAL has reduced non-revenue water significantly, improved the billing system for residents, and can respond faster to breakdowns or leakages in the system (SEDAPAL, 2015). This is vital in a city of over 11 million people built in the desert.

However, previous research has shown how the datafication of Lima's water infrastructure, understood as the quantification of flows within the water distribution system, reproduces structural inequalities within the water infrastructure, contributes to the further peripheralisation of the non-digital city, and only partially accounts for other epistemologies, and water governance approaches (Hoefsloot, Martinez, et al., 2022; Hoefsloot, Richter, et al., 2022). Built to increase efficiency through the monitoring and supervision of water infrastructure, the SCADA system represents an economical approach to water as a scarce resource, rather than reflecting other conceptualisations of water as life or water as spiritual that co-exist in Lima and Peru as a whole (Calderón, 2000; Miranda Sara, 2021).

Within these conditions, an important portion of Lima's residents is not only structurally underserviced but also structurally underrepresented in the data about the water distribution in Lima due to a lack of registration or the absence of a water meter. These gaps in the data have significant consequences for urban water consumers. Unregistered water consumers generally have less security in terms of the quantity, quality, reliability, and continuity of the water service and, if registered but unmetered, are rationed by the water provider. While SEDAPAL used several tools to accommodate the data collection on unplanned urbanisation and clandestine water infrastructures, such as drones and geo-radar (Hoefsloot, Richter, et al., 2022), to date, no tool facilitates the collection of data in collaboration with, and from the perspective of, the water consumers. Therefore, the central question explored in this research and the development of the MWO is: how can we design a digital platform that incorporates plural perspectives regarding water management to contribute data on water access, help raise awareness of existing inequalities, and contribute to fairer policymaking?

Addressing the unequal distribution of water in Lima requires a water justice approach. Water justice is a global water crisis response based on the principles of fairness, equity, and participation (Sultana, 2018). This approach responds to mainstream approaches to water scarcity, which are frequently based on market-driven approaches and technological solutions (Miranda Sara & Baud, 2021; Zwarteveen & Boelens, 2014). In urban areas, water justice acknowledges how marginalised groups are further disenfranchised by water scarcity and inequitable redistribution (Sultana, 2018). The lack of access to water contributes to increased vulnerability to climate change, extreme weather events, and political unrest, particularly affecting the most vulnerable groups of the population. Thus, water scarcity not only has detrimental health impacts but also becomes a structural factor that shapes urban inequality and people's resilience toward disruptions. It entails a relational, situated, and context-sensitive approach that necessitates acknowledging that water scarcity is more a problem of unequal distribution and power relations than a natural problem exacerbated by climate change and overpopulation (Sultana, 2018). A water justice lens reminds us that efficiency and sustainability-focused strategies can sometimes inadvertently lead to dispossession and displacement (Zwarteveen & Boelens, 2014).

Water is an 'intrinsically contested resource' (Zwarteveen & Boelens, 2014, p. 149) that requires acknowledging the multiple perspectives that shape redistribution, recognition, and participation. In this regard, we follow Zwarteveen and Boelens (2014) and examine water justice from two perspectives that are frequently presented as being in tension: the urgency of finding solutions to metropolitan water scarcity and the fair process of ensuring that everyone's perspectives are considered and included (Kumar et al., 2021; Miranda Sara & Baud, 2014). For this to happen, we first need to acknowledge that current water distribution regimes fail to capture plural perspectives and experiences (Zwarteveen & Boelens, 2014).

The MWO is envisioned as a bottom-up and participatory counterpart of SEDAPAL's SCADA system. Our goal is not to introduce a new digital tool for capturing 'objective' knowledge from a specific perspective. Rather, we propose the development of a participatory and co-produced platform that provides alternative discourses and conceptualisations of the water distribution system, including people and experiences currently overlooked in formal, government-led digital systems.

This chapter continues with a discussion of the theoretical perspectives regarding participatory urban observatories in relation to design science and data justice. In section 6.3, we detail our collaborative design process before outlining how the insights from resident consultations have informed the requirements for the functionalities of the MWO. After presenting and discussing the design of the MWO in section 6.4, we conclude the chapter with reflections on the lessons learnt and limitations of the design of the MWO in section 6.5.

6.2 Developing citizens' observatories

The MWO falls within a broader tradition of citizens' observatories and participatory urban dashboards, which aim to generate and exchange knowledge about cities or aspects of cities worldwide. These tools, which often take the shape of digital, geospatial information systems for collecting and sharing urban data, range in scope, levels of participation, interface, and contextualisation. They can address place-specific issues unique to a particular urban context, such as the observatory for the Italo-Argentinian influence on architectural heritage in Buenos Aires (Carbonari et al., 2019). Other urban observatories focus more comprehensively on urban governance and management or spotlight a particular infrastructure or urban phenomena (e.g., sound, air quality, housing stock) across cities (Botteldooren et al., 2013; Brown-Luthango et al., 2013; Castell et al., 2015). Similarly, there is a wide range of ways to involve urban residents in the data practices of an urban observatory. Citizens can contribute passively through volunteered geographical information from sensors embedded in household appliances or mobile phone devices. In other cases, citizens take up a more active role by co-defining what needs to be observed and interpreting, validating, and using the data collected (Dickey et al., 2021; Young & Kitchin, 2020). Yet, most citizens' observatories and participatory dashboards share the common goals of wanting to increase transparency in policymaking by facilitating the exchange of information between stakeholders, mobilising knowledge to tackle challenges in urban governance, and empowering citizens to voice their aspirations for their city (de Mesquita et al., 2018).

Mattern (2021) and Couldry and Mejias (2021) explain how developing critical and experimental observatories, or dashboards can be fruitful despite the fact that many digital technologies that emerged during neoliberalism reproduce the long-term asymmetries in knowledge production along the lines of coloniality and capitalism. The contribution of critical and experimental platforms may not lie directly in the accuracy of the data generated but rather in showing the messiness and complexity of the city and visualising a perspective on the city that is often unrepresented (Mattern, 2021).

We do not deny that creating a digital infrastructure to engage with digital infrastructure critically is paradoxical. Our research is inspired by experiments in 'statactivism,' which mobilise statistics' power for emancipation (Bruno et al., 2014), and critical data sciences, which specifically generate and reappropriate demographic data to make visible and support feminist (D'Ignazio & Klein, 2020) and decolonial struggles (Ricaurte, 2019). These movements use data, indicators, and coded categories – compelling tools of the modernist state – to alter policy discourse and challenge the perceived neutrality of comparative statistics (Bruno et al., 2014). Creating a platform teaches us about the limitations of the current data infrastructure. It is crucial to develop new sociotechnological artefacts that can assist in imagining alternative narratives of data technology (Couldry & Mejias, 2021) and further theory about the role of datafication on water access.

There are many methods and approaches for designing citizens' observatories, usually following design science, collaborative design approaches, human-centred design, or emerging out of activism. This research adopted a collaborative process that follows similar principles as design science applied in action research and information technology for development (ICT4D). Originally stemming from engineering disciplines, design science research approaches the development of an artefact as the outcome of a research project, as well as the methodology to theorise about the environment in which the artefact is intervening (Gregor & Hevner, 2013). Design science research departs from the premises that the process of design teaches us about the technological rules embedded in the artefact, how theoretical approaches are operationalised in practice, and in doing so, contributes to developing a comprehensive body of knowledge and useful design principles. While traditionally, design science research engages primarily with innovative solutions for business challenges, it has also been applied in cases that concern socio-economic problems and seeks to contribute to technological interventions for human development (Islam & Grönlund, 2012; Sein et al., 2011). In aligning design science approaches with action research or ICT4D, Sein et al. (2011) and Islam and Grönlund (2012) show that the process of constructing an artefact is iterative. Rather than approaching the design process as a set of separated steps in sequence, the experience with design science research for action or development emphasises how the artefact developed is 'contextually situated and sociotechnically enabled' (Islam & Grönlund, 2012, p. 140).

Our starting point for the design stages of the research is data justice. We depart from this central value because water justice calls for a 're-politicisation' of urban water governance in which not only the unequal distribution of water is made visible but also the inequalities in political and economic power to influence water policies (Hartwig et al., 2021). Hence, data on water should also be sensitive to and represent how people relate to water and participate in its governance.

We follow Taylor's (2017, p. 1) definition of data justice as the 'fairness in the way people are made visible, represented and treated as a result of their production of digital data.' Specifically, Taylor (2017) and Kitchin and Lauriault (2018) emphasise that data need to be approached from a relational perspective, acknowledging how data infrastructures are part of the larger political, social and physical landscape and are inscribed by politics, power, and interests. In addition to explicitly paying attention to tensions and the lack of transparency in data practices (Heeks & Shekhar, 2019), data justice requires fostering democratic dialogue and civic engagement (Baibarac-Duignan & de Lange, 2021). It follows that the MWO does not strive towards 'objective knowledge or a fully digital representation of the formal and informal water distribution system. Instead, it aims to engage critically with the current hegemonic representation of Lima's water infrastructure and establish itself as an *espacio de concertación* (Miranda Sara & Baud, 2014) or 'data subaltern' (Heeks & Renken, 2018) to help communicate the experiences and views of residents currently overlooked. In doing so, the MWO builds on volunteered geographical information (Elwood, 2008). The following sections of this chapter will detail our collaborative design approach in developing the MWO and explain how the data justice design principles have been translated into the platform's design.

6.3 Methodology

In the development of the MWO, we bring together two knowledge bases. The first is from residents and experts in the field of water management through a collaborative design process. The second is the data justice design principles formulated after reviewing participatory urban dashboards and observatories in academic literature and practice (Hoefsloot, Jimenez, et al., 2022). The design principles depart from the three elements of Taylor's (2017) data justice framework: (in)visibility, engagement, and non-discrimination. The design principles capture the generic characteristics the artefact should have through which the project objectives are met and dictate its technical features (Chanson et al., 2019); in our case, the project objectives are water and data justice. This offers several implications for the development of participatory observatories, their institutionalisation, and the features they should contain.

The dimensions of the data justice referring to issue formulation, the embeddedness of the MWO in decision-making practices, the contestation of biases, and the pluralisation of ontologies of the city, are not as much part of the design of the MWO as they are integral to the collaborative process of developing the platform. Therefore, the development of the MWO, guided by the aim to critically engage with and challenge the current representation of the water distribution system in data, has started with the collaborative formulation of the main issues and context of use that should be addressed. In the continuous conversation with the residents and civil society organisations we collaborate with, we aimed to leave room for contesting the biases in the development of the platform and the data collection practices. Additionally, with the current prototype of the MWO, we aim to establish further partnerships with government and non-governmental institutions in the field of water management in Lima to embed the platform within their decision-making practices and align it with planning frameworks.

In line with the principles of design science as applied in action research and ICT4D, we structure the methodological approach into four stages: (i) problem formulation, (ii) building, intervention, and evaluation, (iii) reflection and learning, and (iv) formalisation of learning (Sein et al., 2011).

As we are yet to launch the MWO in Lima and Callao, we can only describe the first two stages in this chapter. The final two stages, both essential elements of design science (Gregor & Hevner, 2013), focus on the evaluation of the adherence to the principles, on the contribution to theorising about design principles for data justice, and on abstracting what we have learned in order to understand water governance in Lima and Callao. These two stages will be the focus of future work.

The collaborative design process took place between December 2019 and December 2021 (see Figure 6.1). The first stage is primarily characterised by exploring the issues to be addressed in the MWO and building relationships (steps 1 and 2). This stage in the research aimed to gain an in-depth understanding of the challenges Lima's residents face regarding water security. We chose focus groups as they allow for collaborative brainstorming and to gather a broad range of perspectives. Through these focus groups, we aimed to identify the different types of knowledge already in use, how this knowledge is shared, and what the current knowledge gaps are.

We collaborated with residents from three districts representing different socio-economic realities in Lima: Jose Carlos Mariátegui, Barrios Altos, and Miraflores. José Carlos Mariátegui is a recently constructed peri-urban neighbourhood characterised by high degrees of poverty, vulnerability, and fragmented service provision (Jaime et al., 2021). Residents often engage in collaborative work for community development and to bridge gaps in the provision of infrastructural services. Concerning water infrastructure this entails that much of the water infrastructure is still self-built and relies on the continuous labour of residents to operate, manage, and maintain the system.

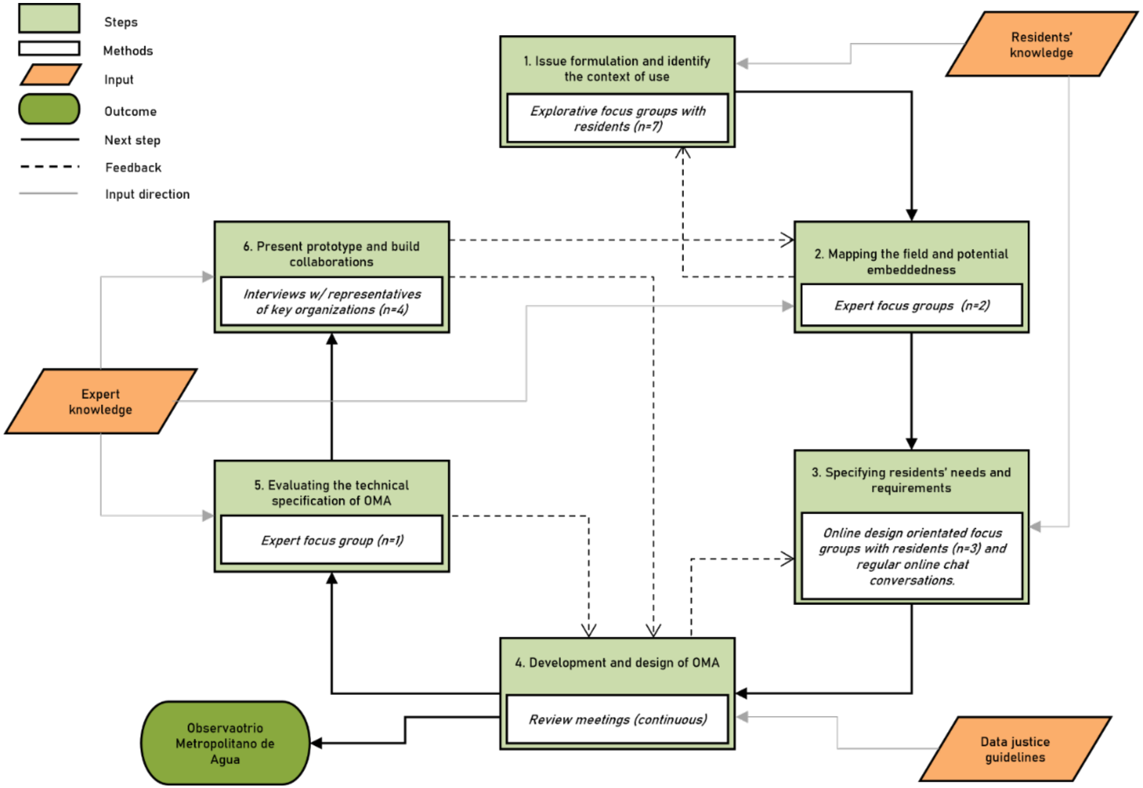

Figure 6.1 Workflow and methods followed in the development of the MWO. The feedback loops indicate the various iterations of each of the steps taken. Graph design inspired by (Aguilar et al., 2021)

The second neighbourhood, Barrios Altos, is part of Lima's historical and commercial centre and houses the city's main commercial markets. A large part of the population in Barrios Altos earns less than minimal income and lives in precarious housing (Jaime & Bernales, 2021). Although the majority of the households are connected to the formal water infrastructure, their connections are unreliable due to an overburdening of the system, frequent rupture due to a lack of maintenance, public investments, and a high degree of clandestine connections (Jaime & Bernales, 2021).

Thirdly, Miraflores is generally defined by its up-scale housing and as the city's touristic centre. In Miraflores, water service provision, access, and security are generally high. Nevertheless, Miraflores' residents often have constructed backup systems in case of maintenance work or an emergency interrupting the water delivery. For example, residents assemble water storage systems by installing tanks on the roof of their houses or apartment buildings, storing water in jerrycans, or, in a few cases, constructing a connection to subsurface wells. Together, these three areas represent Lima's diversity regarding socio-economic living conditions and diverging degrees of geographical and political centrality.

In total, seven in-person focus groups were held before the Covid-19 pandemic: two rounds of focus groups with residents of each district and an additional focus group with youth (see appendix 3 for focus group guides). The first round of focus groups aimed at identifying and describing the main challenges related to water access as experienced by residents. In the second round of focus groups, we discussed the roles of various actors in the water distribution system, the infrastructure's materiality, and potential interventions. As the perspective of the youth was unrepresented in the general focus groups, we organised an additional conversation inviting people under the age of 30 from all three neighbourhoods to attend and participate in a conversation regarding water access and the material and institutional infrastructure. All focus groups were audio-recorded and transcribed. The results of the focus groups were thematically analysed. A two-page report was written, which summarised the discussion in each focus group. These reports were shared with the participants and used as input for steps 3 and 4 in the collaborative design of the MWO.

Finally, as part of identifying what the main objective for the MWO should be and how it is positioned in the broader water sector of Lima, we organised two expert meetings, one with engineers and researchers from SEDAPAL and one with representatives of civil society organisations, research, and government. These expert meetings aimed to establish relations with relevant actors in the field and helped pinpoint what the MWO can contribute to their ongoing work in the field of water management. The issues raised by the participants and experts informed the focus of the MWO and helped define the main features and indicators that had to be included in the design.

The second stage (steps 3 and 4, Figure 6.1) focused on the formulation of the user's needs from the perspective of the residents, translating these insights into the design and development of the digital platform, and moved towards evaluating the prototype and exploring the options to embed it institutionally within the water sector in Lima. Due to Covid-19 lockdowns, this stage was conducted online using WhatsApp groups and Zoom. Particularly during the first months of the pandemic, we noticed that WhatsApp groups became popular and effective in mobilising communities for environmental goals in Lima. Our considerations for using a particular software or platform have primarily been accessibility and ease for all participants. There was a large disparity amongst the groups regarding access to and experience with online conferencing tools across age and socio-economic conditions. Since many residents in Jose Carlos Mariátegui and Barrios Altos only have easy access to the internet via their smartphones, we needed a platform that was accessible on those devices and which would not use too much mobile data. Additionally, there was a variance in the participants' digital literacy depending on their educational background and age. This excluded the use of collaborative design software such as Trello, Miro, or Mural.

To mitigate privacy risks, we made sure that all participants were informed regarding the information they would be sharing with others before partaking in the WhatsApp focus groups by calling everyone individually to explain the implications and rules of conduct for participating in this conversation. We specifically encouraged participants to share their ideas and information in ways they felt were most comfortable. All contributions were welcomed, including written text, voice messages, videos, and photos.

Additionally, we organised a call with participants from the three groups where we evaluated existing urban observatory designs, identified strengths and weaknesses, and established which features should be most important in the format of the MWO. In doing so, the residents were able to contribute to formulating requirements for the design of the MWO. We organised the recommendations from the conversations with participants from the three districts for the platform's functionalities and design into a table and classified them based on their importance in achieving the MWO's goals and their feasibility.

The third stage (steps 5 and 6, Figure 6.1) involved organising meetings with governmental and civil society stakeholders to present the initial prototype of the MWO and receive feedback on the effectiveness of its design and features. This allowed us to ask questions about the advantages and disadvantages of a platform like this and better understand what key factors contribute to water inequalities in Lima and how they can be fixed. In this stage, we organised three meetings with representatives from three government institutions working on water issues. These meetings were held with the entire MWO team, including the platform's developer.

6.4 The design of the Observatorio Metropolitano de Agua

In this section, we discuss how the data justice design principles for Participatory Urban Observatories (PUO), specifically the right to invisibility, participation in and access to data practices, the contestation of biases, and the transparency about data practices, have been implemented in the collaborative design of the MWO.

6.4.1 From user needs to prototype

The conversations with residents pointed us to the large diversity in the experiences with the water distribution system - the physical infrastructure and the institutional system – and the participants' perceived influence on these dimensions. In José Carlos Mariátegui and Barrios Altos, where residents are highly involved in the construction and operation of the water systems in the area (Hoefsloot et al., 2020), participants mainly focused on the issues hampering their daily water security. For example, participants expressed a need for easier application processes, formalising their water systems, transparency over metering and billing practices, and accurate information about breakage or construction work on the pipes.

In Miraflores, the conversations focused on the macro-scale challenges faced by the water sector. The most significant issues concerning Lima's current and future water resources expressed were the uncertain effects of climate change on the water sources and reserves; the lack of knowledge and transparency about the quality of water in the city; the knowledge of the residents of Lima concerning responsible water consumption; and the perceived prevalence of corruption in Peru and it's water sector.

The meetings with governmental and civil society stakeholders were beneficial in understanding how the MWO can assist their organisations in their work. Two of them explicitly stated their desire to support the MWO and collaborate with us. They see the MWO as a user-friendly platform that will provide citizens with relevant information that is simple to access and understand. They were especially interested in sharing information with the MWO that would normally be difficult to communicate due to their complicated and formal websites. They also saw potential issues with the MWO, particularly regarding potential misconceptions about the platform's role in taking over some of the work these organisations are doing. Furthermore, one of the representatives expressed concern about the implications of the data showing clear inequalities and how this could lead to even more social outrage in a city/country already struggling with various political and social crises.

Through these conversations, we aimed at enabling *espacios de concertación*, which involve 'the validation (or contestation) of the knowledge of a variety of participating actors, and a highly sensitive and complex process of dialogue-negotiation-*concertación*-conflict management and consensus-building (or not)' (Miranda Sara & Baud, 2014, p. 506). The results of these conversations served as a starting point for conceptualising what the MWO should become, what features it should have, and what goal it should serve (Table 6.1).

Table 6.1 Summary of the requirements for the functionalities for the MWO, drawing from the online focus groups with residents. Table adapted from Jimenez, Hoefsloot, et al. (2022).

Knowledge exchange	Visualisation and interface	Network building	Data requirements
• Function to upload data on household water access. • Function to download the (geo)data collected in the MWO in different formats. • Forum or chat function. • Integration of social media platforms.	• An interactive map of Lima's water system. • Tables and figures that are easy to understand. • The MWO should be a web application accessible on smartphones.	• Mapping civil society and community organisations working on water issues in the Metropolitan region. • Work together with SEDAPAL and the regional water authority.	• Suggested indicators focused on water access, coverage, quality, and sustainability. • Collect experiences, testimonies, and visual data regarding water access.

6.4.2 Integrating design justice principles

Having established the main features and design requirements based on the conversations with residents and experts in the field, we continued the design of the MWO following the design principles derived from Taylor's (2017) data justice framework. Table 6.2 summarises the data justice design principles and their implementation in the MWO. As indicated in Figure 6.1, we are currently in the phase of presenting the prototype of the MWO to experts on water management or digital platforms and establishing routes for further collaborations with key actors in Lima's water management.

6.4.2.1 Right to (in)visibility

In relation to the principle of the right to (in)visibility, there are some critical considerations in the data input form and in how we have translated the principle into the design of the MWO that we would like to highlight here.

Table 6.2 Implementation of data justice design principles (as formulated by Hoefsloot, Jimenez, et al. (2022) and based on Taylor's (2017) data justice framework) in the Observatorio Metropolitano de Agua.

Data justice dimensions	Design principles	Implementation in MWO	Example of implementation
1. Right to (in)visibility and opt-in or opt-out of the data	Participatory Urban Observatories (PUOs) should explicitly mention how residents can opt-out, be (in)visible, or only have some of their data shared. Specific attention should be given to visibilising marginalised communities' experiences and perspectives.	The MWO is designed to be accessible and usable for people without advanced digital skills and people living in informality.	In addition to textual and numerical data, users can share pictures of the water infrastructure to diversify ways of visibilising their experience. Users can send a request to have their submitted data removed or revised. We guarantee location privacy by adding 'noise.'
2. Participation in and access to data practices	Citizens should be approached as expert observers within the city, stimulating their active participation in defining what needs to be observed and interpreting, using, or validating the information collected.	Residents can share and download data and knowledge in multiple features and formats, allowing for diversity in ways knowledge can be shared, altered, or challenged.	The MWO includes various data sharing methods, e.g., the data input form, the chat function, uploading photos, or using dedicated hashtags on social media. Data can be downloaded in Geo-JSON, Excel, and PDF.
3. Embedded in decision-making practices	PUO should foster relationships and communication between actors and inform public planning and decision-making processes.	The MWO is a collaborative project between civil society and research.	We are currently formulating further partnerships with governmental institutions to embed the MWO in decision-making practices.

Continuation of Table 6.2.

4. Issue formation	PUO should work towards empowering citizens to voice their aspirations for their city and mobilise knowledge to tackle challenges within their environment and urban governance.	Residents were consulted in all stages of development for issue formation. We are working towards supporting citizens' capacity to use the MWO data for development.	Citizens' input has directly informed the questions in the data input form. We provide guidelines for using the data for advocacy and will organise a knowledge-sharing workshop.
5. Contestation of biases	Participatory urban observatories should facilitate the contestation of internal and external biases.	Externally, the MWO focuses on the biases and injustices in the water distribution system. Internally, we collaborate with various stakeholders to detect biases.	Users can access and use the data for analysis or advocacy. The collaborative approach and features like the chat function allow discussing biases within the MWO.
6. Transparency about data practices	In addition to contributing to administrative transparency, participatory urban observatories should be transparent concerning data generation, processing, and use. Ideally, this translated into opening the platforms' data, algorithms, and codes.	The MWO is built on open-source software. The data collected is openly accessible. The source code of the MWO will be shared in a secure repository under a creative commons licence after finishing the development.	We use GeoServer, PostGIS, Openlayers and Open Street Maps as the main building blocks for the MWO.
7. Pluralisation of ontologies of the city	PUO should facilitate the expression of plural ways of understanding and knowing the city.	The MWO is developed to critically engage with Lima's hegemonic datascape of the water distribution system.	The MWO works toward diversifying the knowledge about water distribution by using indicators developed by citizens, focusing on representing their needs.

First, the right to (in)visibility refers to the ability of residents to determine what data they would like to include in the MWO database. The MWO accommodates this by offering various ways of sharing information. First, residents can start by filling in the data input form. In addition to closed questions regarding, among others, the residents' access to water, the continuity of the service, and its organisation, the questionnaire also includes an open question where residents can share any further information or suggestions for improving the water distribution system and upload a photo of and elements of their water infrastructure, for example, auto-constructed water storage systems. The questions in the data input form were formulated in collaboration with participants and reflect that people get water in various forms. To be able to allow for a collection of a more diverse set of experiences, we developed different questions depending on where and how respondents get water. The list of questions automatically adjusts depending on the answer selected.

Secondly, residents can share information and experiences directly and openly in the chat forum. This forum is accessible to all people who register with the MWO. A registration function was necessary to block bots from taking over the chat function. Nevertheless, we have made it possible to register with a name or pseudonym and password, not requiring an email address or any other personal information, to protect users' privacy and lessen participation barriers. Third, the right to invisibility is adhered to by offering residents the option to delete data they have shared at any prior moment.

6.4.2.2 Participation, access, and transparency to data practices

The MWO aims to increase the voice of people as experts within their communities, particularly to make the MWO accessible to all residents of Lima. For residents who receive water via various infrastructures, including informal systems, this has implications for how we collect and protect their information. First, to include residents who do not have a formal residence or registered address, there is an option to geo-locate their house in two ways. They can allow the application to access and record their geo-location, enter their street name, or place a point on the map themselves. This will enable residents living in unmapped areas of the city to record their data. Providing this type of personal data is optional; users have to actively volunteer their geographical information in the data input form.

Second, for all residents, but in particular, for residents who might depend on clandestine water connections, it is paramount that their privacy is protected. Hence, aside from the location data, no personal data (data that can be traced to a natural person) is requested. Additionally, the locational privacy of the people who share their data is guaranteed by adding 'noise' to the geo-localisation of the data points entered (Chatzikokolakis et al., 2015a).

Each georeferenced data point is randomly distributed within a 20 – 300 metres[25] wide buffer circling the original location (see Figure 6.2). Since this noise is added automatically while entering the data, and the original

[25] The buffer zone of 20 to 300 meters is based on research from Chatzikokolakis et al., (2015b) which suggests this range should provide sufficient geo-indistinguishability within an urban environment. However, considering the differences in urban density amongst the various districts of Lima, we will have to assess, in collaboration with residents, whether or not this range provides sufficient privacy for all residents while keeping in mind the quality and accuracy of the data.

location is never stored in the database, it is impossible to trace the exact location of the respondent. Hence, the addition of noise entails increasing the inaccuracy of the data to achieve a certain level of locational privacy.

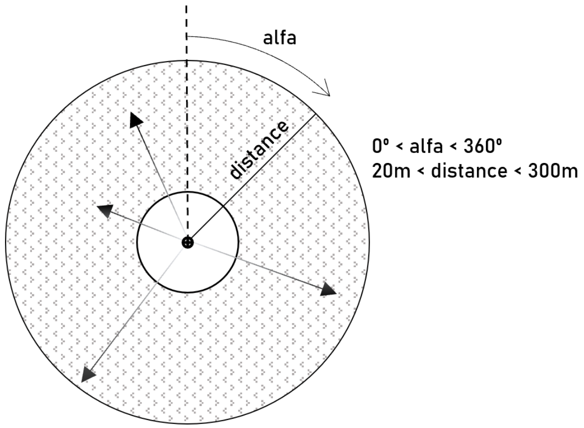

Figure 6.2 Schematic representation of the 'noise' added to the data coordinates to protect residents' location privacy via geo-indistinguishability (Chatzikokolakis et al., 2015a). The original geo-location is randomly distributed within the buffer zone.

Additionally, regarding access, we have designed the MWO, keeping in mind the requirements of residents who are not digital-savvy or have limited internet access. The direct implications this had for the design are: (i) the MWO is accessible via a browser rather than an app since this requires less storage on a device, (ii) the MWO is responsive and accessible via desktop as well as mobile phone, (iii) we have included guidelines and plain text explanations on all tabs and pages of the MWO, guiding the users about the use and application of the observatory, and (iv) the data from the MWO can be downloaded in different formats (geo-JSON, excel, and PDF) along with the requirements of a specific user.

In line with the ambition to increase transparency and openness in the collection and use of data about water distribution in Lima, the MWO has been designed to adhere to the principles of open science (Unesco, 2021). In addition to the open data practices, this entails that the MWO is built on open-source products (including geo- and database servers), and the source code of the MWO will be made open after the launch of the platform.

6.4.3 The prototype of the *Observatorio Metropolitano de Agua*

The prototype of the MWO, i.e., a dedicated web application, includes an interactive map, layer management, a form for data input from residents, a forum for interaction between users, and social media integrations. Figure 6.3 shows the MWO interface layout where the interactive map with data from the 2017 census is presented. Users can expand the map to cover the full-screen width, zoom in and out, (de)active or adjust the transparency of various data layers, switch between base maps, and click on data points for more information. A legend, scale bar, and source information box are included at the bottom of the map.

6.5 Concluding remarks and next steps

This chapter documents the conceptualisation, development, and partial evaluation of a participatory urban observatory for monitoring water access in the metropolitan area of Lima-Callao, Peru. By combining a collaborative design approach following the principles of design science with the theory-informed data justice principles, we have been able to develop a prototype of the MWO that aims to incorporate plural perspectives regarding water management to contribute data on water access, helps raise awareness of existing inequalities, and contributes to fairer policymaking in Lima. By doing so, the MWO seeks to challenge the hegemonic representation of

Lima's water infrastructure and help communicate the experiences and views of residents currently overlooked.

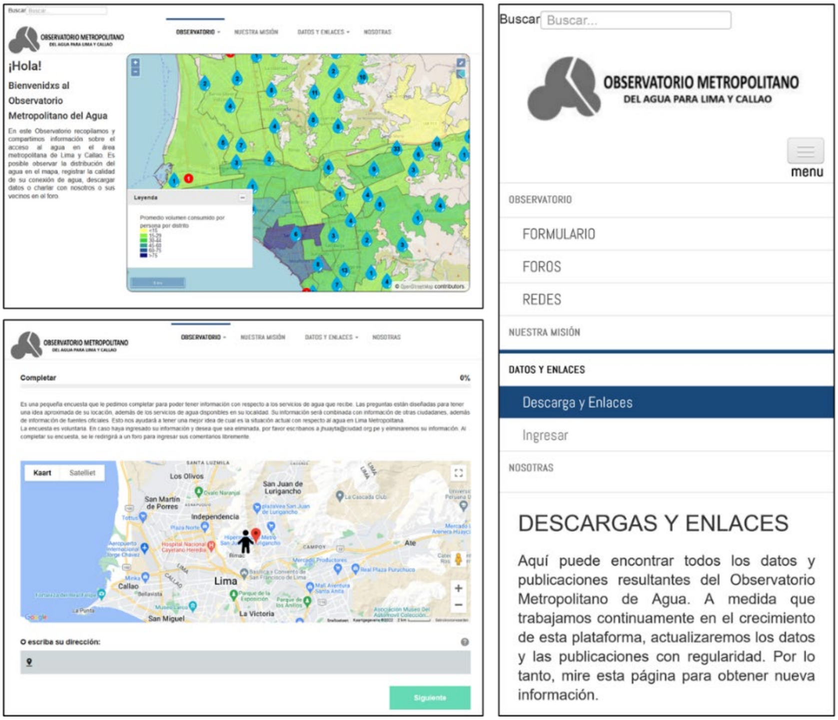

Figure 6.3 Screenshot of the MWO prototype. Top left screenshot shows the homepage with the map presenting data in a desktop browser. Bottom left screenshot shows the data input form in a desktop browser. The right screenshot shows the menu and data download page in a mobile phone browser. The platform can be accessed here: https://observatoriodelagua.ciudad.org.pe/index.php

In addition, the project of the MWO teaches us how to design digital platforms according to the principles of data justice in practice. Recent research has shown how participatory urban observatories can contribute to increasing transparency in data generation and policymaking by facilitating the exchange and mobilisation of knowledge (de Mesquita et al., 2018), yet face the risk of reproducing historical inequalities in collective knowledge production for the city (Mattern, 2021). Departing from the value of data justice and following the earlier defined design principles helps structure the design process and outcome according to the pillars of (in)visibility, engagement, and non-discrimination (Taylor, 2017).

As we have now completed the design of the prototype of the MWO, it is important to reflect on the limitations of our approach up to now. The MWO, as an artefact, took shape from the interaction between researchers, activists, residents, and governmental organisations. Collaborative design is a complicated and sensitive process, particularly with residents with diverging backgrounds and capabilities. This process was partially disrupted due to the onset of the Covid-19 pandemic and the resulting meeting and mobility restrictions. As a result, residents' participation in the second stage of this research was constrained to a consulting role rather than co-producers, and the final design stage was not as collaborative as we had initially planned.

Secondly, for the MWO to reach its intended objectives and contribute to more just water governance in Lima, the database must be monitored and maintained, there should be a broad uptake of the platform, and it should become embedded in the institutional framework of water governance in Lima. While we have partially made room for this by making the MWO open-source and establishing connections with institutional partners, the sustainability of the platform needs to be prioritised in the future. It follows that the next steps in the project are (1) to continue piloting and evaluating the platform amongst the communities and civil society, and government actors we have been collaborating with and (2) to launch the MWO and promote its use in the metropolitan city as a whole.

The reflection and learning phase (stage iii) will mainly concern the accordance of the MWO with the criteria set: does it contribute data on water access according to the principles of data and water justice? For evaluating the MWO as ICT4D design science, Islam and Grönlund (2012) propose asking the following questions: does the artefact research this goal? And what points to the fact that the goal is or is not complied with? The first question addresses the utility of the artefact. The second question guides us towards theorising about how we can design data just platforms. To date, we have been able to present and test the prototype with representatives of key institutions in the field of water management in Lima. To address these two questions for future evaluation, the next phase in the development of the MWO will consist of testing the observatory amongst the residents we have collaborated with and assessing to what extent it contributes to data and water justice.

Additionally, for the MWO to have transformative potential, even if incremental (Heeks & Shekhar, 2019), it is key that the observatory becomes embedded in decision-making and planning practices. We found that government representatives may consider the MWO as a challenge to their work, which may result in less impact. So, we need to pay special attention to how our discussions with them can be conducive to the process of collaboration and engagement while at the same time staying close to citizens' perspectives. Sein et al. (2011) emphasise the importance of considering the artefact as emergent out of the organisational network and argue that to evaluate the contribution and utility of the tool in relation to the already existing SCADA system used in the water distribution system of Lima-Callao, we need to pay attention to its institutionalisation within the network. For this, we will need to seek long-term collaborations in which the MWO functions as an *espacio de concertación* (Miranda Sara & Baud, 2014). We hope that water consumers from various districts in Lima can adopt the MWO and that, by involving actors such as SEDAPAL, residents, and civil society groups, it also becomes a space of sustained dialogue, negotiation, and policy change.

Chapter 7:

Conclusions

7.1 Knowledge infrastructures for just urban water governance

Innovations in digital water management, such as using sensors, SCADA, GIS, and digitised water services, have become commonplace technologies for cities to tackle water governance and management challenges. While this topic has gained attention in academic literature, most scholarly work has focused on the economic or operational value attributed to digital technologies for water management, the risks of datafication for surveillance and privacy concerns, or how digital technologies can change managerial structures in the water distribution system (Amankwaa et al., 2021). There is a need to analyse the implications of the digital transition in urban water governance from a relational perspective - acknowledging its social and material elements - and explore more just and collaborative pathways for future developments (Luque-Ayala & Marvin, 2015).

Therefore, this dissertation has sought to establish how knowledge infrastructures can support just urban water governance. To answer this question, it was necessary to look beyond the knowledge and water infrastructure themselves and consider them in relation to the broader knowledge systems, urban development, regional geography, and societal structures. In this thesis, knowledge infrastructure refers to the sociotechnical system for generating, distributing, mobilising and contesting knowledge. Just water governance is understood as the collective of administrative, material, political, and social systems that work towards a just allocation of water, as well as the recognition of the social, political, and epistemological dimensions of water (Zwarteveen & Boelens, 2014).

The multi-scalar and multi-perspective set-up of this research allowed for thinking about and analysing the infrastructure through different perspectives and grappling with heterogeneity. As illustrated through the juxtapositions between the water producer and the differentiated water consumers, 'expert-amateurs' and 'smart citizens,' and the rural and urban knowledge systems, the diverse everyday practices of infrastructuring do not easily lend themselves to generalisations. Comparing and contrasting different points of view on the water and knowledge infrastructure, placing knowledge systems side-by-side, and researching the city across geographies are useful because it helps understand the diverse situated experiences within the city (Niranjana, 2022).

This thesis has put forward the argument that to support just urban water governance, knowledge infrastructures should centre the knowledge and experiences of residents and foster plurality and self-determination in data practices. Chapters 2 and 3 have shown how digital infrastructures used in Lima's water distribution system are built on historical inequalities, invisibilise the experiences, labour, and knowledge of people on the periphery, and reproduce unjust structures in water governance. Chapter 4 analysed the hybridisation of knowledge systems as a potential transformative pathway to more just water governance and argued this is only possible when all knowledge is considered emergent from particular worldviews, values, epistemologies, structures and regions.

In chapters 5 and 6, the focus transitioned from seeking to understand and describe the implications of datafication in urban infrastructure to developing a tool that aims to contribute to a fairer distribution of water resources among urban residents by exploring the potential of collecting and disseminating data regarding water access in *Observatorio Metropolitano de Agua para Lima-Callao* (Metropolitan Water Observatory for Lima-Callao, MWO). By making inequalities visible through the *Observatorio Metropolitano de Agua* and implementing an outreach campaign, we aim to create a space to critically engage with the current water data to influence action for a just water distribution system. In that sense, inspired by bell hooks (1991), this research aimed to contribute to theory as a practice of 'liberatory activism'. Meaning that theory and methods are used to expand our thinking in support of justice approaches and assist in the struggle to oppose classism, racism, and sexism. It is directed to assisting residents who live in situations of injustice to bring about change. Central therein are the testimonies of Lima's residents and the collective effort to make everyday experiences with the water and digital infrastructure visible.

In this final chapter, I return to the three sub-questions outlined in the introduction. I will first address each of the sub-research questions separately before reflecting on the main contributions to theory and returning to the central research question – how knowledge infrastructures can support just urban water governance - in section 7.2. The final parts of this thesis are dedicated to discussing the key contributions to practice (7.3) and opportunities for future research (7.4).

7.1.1 How do current data infrastructures challenge or reproduce unequal structures in Lima's water governance?

Mattern (2021), in her book 'A City is not a Computer', describes the creation of the city and acts of infrastructuring as a process of grafting: the age-old horticulture technique in which one part of a plant is joined to the stem or root of another. Together, they grow into hybrids but with still distinguishable origins. Mattern's metaphor of grafting is useful in thinking about the relationship between the digital and water infrastructure in Lima and understanding how unjust structures in Lima's water governance are challenged or reproduced in the current knowledge infrastructure as it emphasises how infrastructure has roots in and mediates the strengths and limitations of the installed base (Star & Ruhleder, 1996).

The joint between the water and digital infrastructure in Lima shows similar properties to the joint of a graft. Digital technologies are installed on the water infrastructure to make it sturdier, easier to manage or grow faster. The use of digital technologies for water management and the focus on data-driven decision-making have helped SEDAPAL to manage the water flows within the city, reduce the loss of water due to leakages and breakdown, and deliver potable water to Lima's formal residents. In short, it has made the water infrastructure more efficient and less vulnerable.

However, grafting also tends to be a tricky and finicky process, and there are many reasons why a graft may go wrong. For example, when the two entities are not fully compatible, the rootstock is not healthy, or the grafted scion does not align properly with the stem.

Similarly, this research has shown how the digital infrastructure is not fully compatible with the structure of Lima's water distribution system, reproduces its unjust structures, and does not properly align. The lack of compatibility is illustrated in the way water meters assume individual domicile water connections, while *quintas* and multi-story buildings often depend on collective water connections. Or, as argued in chapter 3, how the digital infrastructure does not register and mobilise the experience and knowledge of residents in Lima.

These irregularities in compatibility between the digital and water infrastructures reveal normative assumptions built into the digital system. Built from the view of SEDAPAL and at the scale of the metropolitan city, the digital infrastructure grafted onto the water infrastructure legitimises the choices about what is worth recording in the data (Jasanoff, 2017) and, indirectly, what counts as good water management, infrastructure expansion, or forms of water consumption.

Additionally, the digital infrastructure tends to reproduce the unjust structures of the water infrastructure, similar to how a grafted tree may take over unhealthy characteristics of the rootstock. Chapter 2 laid out how digital monitoring may improve water distribution within the formal infrastructure while simultaneously increasing the differentiation between water consumers and delegitimising people's access to water without an in-home connection. These apparent differences between water consumers reappear continuously in the urban landscape and the narratives about water consumption in the city. For example, every year during the hottest summer months, small inflatable pools start popping up in the streets. Specifically, in the poorer communities of Callao, this is a popular summer pastime. However, every year in the newspapers of Lima and Callao, the users of these pools are critiqued for their excessive water use during the already water-scarce summer months, the fact that they occupy public space, and the risks of mosquitoes carrying diseases such as dengue and chikungunya. It is important not to downplay these issues, particularly the health risks related to still, warm water in the city, but these annual discussions make painfully visible how the urban poor are disproportionately surveilled and publicly critiqued for their water consumption habits. In contrast, the urban rich tend to consume far larger amounts of water[26] without facing similar public scrutiny (Ioris, 2016).

This tendency to attribute blame to the urban poor resonates in the language of the policymakers when they say the urban poor should not have chosen to build their homes on the steep hills surrounding the city, when it is said that people 'lack education and culture' for responsible water consumption

[26] Also illustrated in figure 1.1 in the introduction chapter: the aerial photo depicting the Lima's urban inequality.

(chapter 3), and in the use of geo-technologies such as the geo-radar to police auto-constructed water connections (chapter 2). The findings of chapters 2 and 3 show how the increased use of digital technologies to mediate the relationship between SEDAPAL and residents favours digitally enabled participation while overlooking the contributions of auto-constructing residents who breach the water access gap in underserviced neighbourhoods. By doing so, the digitalisation reproduces the unjust structures of the water distribution system through digital technologies that reinforce the framing of people who do not have an official water connection as illicit and problematic.

Lastly, the digital infrastructure does not align properly with the region's plural knowledge systems and water governance approaches, nor with the diverse experiences with the water infrastructure in the city. The datafication of the water infrastructure is not only the codification of how much water is received, consumed, or lost but also the creation of knowledge about people, places, and issues. Yet, the use of digital infrastructure in Lima's water management, despite its potential, still means making some issues visible and, in effect, making others invisible. Data-driven water governance, which focuses on quantifiable information and increasing efficiency, reduces water to its properties that can be quantified and tends to overlook labour and expertise from residents who work within the water infrastructure to overcome the service gap (Criqui, 2020). Their consumption and efforts are recorded in the many databases of the water system as illicit rather than victims of a poorly functioning infrastructure.

In sum, thinking about the development of infrastructure as grafting presents digital infrastructure as embedded and structuring the larger fabric of the city. The city is no tabula rasa, and infrastructure is not built on a blank slate. While the data infrastructure grafted on the water infrastructure may increase efficiency and reduce vulnerabilities, it also reproduces unjust structures in the system through a lack of compatibility, inequalities in the installed base, and malalignment with the plural conceptualisations of water in the region.

7.1.2 How do different actors and knowledge systems contribute to water governance in the region and Lima?

Researching the city through infrastructure, or actually, as infrastructuring, makes it possible to understand the interactions between the material and the social elements, which give ground for cities to emerge in all their uniqueness and complexity. Once we learn these characteristics of infrastructuring in relation to the city, we can see how people are part of and active agents in shaping, constructing, maintaining and decomposing the city. It allows us to think about the city beyond this dualism, the distinction between social and matter, and start paying attention to all the possibilities in the system, which is in continuous construction and collapse, formation and deformation, and open to incremental change.

Moreover, seeing infrastructure as relational conceptualises the city and urban infrastructure as in constant formation, never static. Infrastructure promises flow, connection, unity, and consolidation of the city. It operates through a performative idea that permits the city to exist in an imaginary of coherence. At least, as experienced from the inside, where infrastructure is often not noticed until a moment of breakdown. From the outside or from the margins of the networks where its service and power are weak or non-existent, this experience is radically different. There, infrastructure can be violent and exclusionary in the boundaries that it creates and the access it hampers.

Throughout this research, the perspective of Lima's residents has been important to gain insight into the everyday ways in which they experience and partially overcome the injustices in the water distribution system. We consider the water management and governance practices of marginalised residents such as in José Carlos Mariátegui and Barrios Altos and rural communities like San Pedro de Casta as forms of intervention and transformation of the established structures. As described in chapters 3 and 4, these interventions work with, or contest, the script of the water infrastructure, legitimise alternative approaches and empower residents to meet their needs in ways they consider best.

This study contributes to further understanding how different actors and knowledge systems contribute to urban water governance in two important ways. First, it has analysed how residents not only feature in building and managing the material infrastructure through auto-construction (Holston, 1991), but also the digital infrastructure and the knowledge infrastructure. Rather than only focusing on the contributions of 'smart citizens' (Vanolo, 2016), we have paid attention to the ways in which expert-amateurs shape the digital infrastructure by adopting, adjusting, or rejecting digital technologies.

In particular, chapters 3 and 4 illustrate from various regimes of sights and scales how urban and rural residents and professionals in the water sector are actively engaged in the process of infrastructuring. Through the conversations with residents in Barrios Altos and José Carlos Mariátegui, we have seen that coping with the service gap in the infrastructure requires skills, knowledge, and collaboration within the community. From San Pedro de Casta, we see how Andean communities have been mobilising their knowledge and infrastructuring practices to challenge the dominant knowledge system in Lima's water governance.

However, it is important to acknowledge how the possibilities for people to engage and build systems according to their own needs and knowledge is born out of necessity while simultaneously constrained by material, political, and historical path dependencies. Normative frameworks embedded in the infrastructure - such as the hierarchical differentiation between water consumers or the conceptualisation of water as a market resource rather than a commons, which are backed up by sanctions on clandestine water systems and indicators such as non-revenue water - limit the opportunities to restructure and rethink the infrastructure from the perspective of the diverse consumers. For example, chapter 3 showed how the top-down digital infrastructure shapes the agency and everyday experiences of urban residents to favour the digital, formal citizen. Likewise, in chapter 4, we found that the hybridisation of the Andean and modern-scientific knowledge systems is skewed toward the dominant ways of knowing and only includes other types of knowledge after they have been translated into the modern-scientific knowledge system. This duality between the necessity and constraints influences the strategies developed by non-dominant actors to create room for manoeuvre within the system.

Emphasising this is important because in developing information systems such as the SCADA and defining which elements of the water are made relevant through data production, engineers are often not explicit about their ontological claims and how, in their daily work, they favour certain values, actors, and ways of knowing over others. While some elements of water justice are increasingly captured through the legibility-making practices described in chapter 2, these databases mainly further the fragmentation of the conceptualisation of water and isolate other types of knowledges and approaches to urban water governance.

On the other hand, legibility has an important function for accountability (Offenhuber, 2017). Specifically, in the contemporary city, characterised by complex public-private governance and ownership structures, data can help trace actions and responsibilities and help inform policy decisions. The attention to ‘smart citizens’ or citizen-centred smart cities (Calzada, 2018;

Vanolo, 2016) indicates how urban residents have become a central part of thinking about, and developing, the smart city. Citizens feature as active agents in the smart city by using digital tools for public engagement and accountability holdings and their datafied movement through and consumption of the city. This observation aligns with Pfeffer (2018), who states that digital technologies can create opportunities for residents, as knowledge actors, to contribute to understanding urban infrastructure and, untimely, the city at large.

This observation also informed the development of the *Observatorio Metropolitano de Agua*. The development of the *Observatorio Metropolitano de Agua* illustrates how digital infrastructure, when designed in collaboration with residents and following data justice principles, can potentially serve as a tool for residents to help to transform the system to meet their needs. Within the digital infrastructure, 'smart citizens' participate as important nodes in the infrastructure by generating data and validating knowledge claims. The 'expert-amateurs' – a concept used in chapter 3 referring to urban residents with tacit knowledge of the water infrastructure but broadened here to include rural and indigenous experts on water governance - while situated on the side-line of the digital infrastructure, in turn, challenge the norms embedded in the technology, readjust it according to what they see fit, and self-govern the water distribution within their communities. Contrary to conceptualisations of citizens' participation in urban development and governance departing from top-down, organised, and consensus-oriented interactions, these types of participation or involvement are bottom-up, sometimes subversive, examples of auto-construction (Holston, 1991, 2009; Watson, 2009).

7.1.3 How can we design knowledge infrastructures that contribute to just water governance?

Throughout this thesis, I have argued and demonstrated how knowledge infrastructures, the city, and water are closely related. First, knowledge infrastructures mediate the access to water and structure the relationship between water consumers and the state. Second, knowledge infrastructures are informed by our epistemological approach to water and the values we centre in governance.

In the first empirical chapters of this thesis (2, 3, and 4), I was concerned with trying to understand these interactions and how they help explain the urban water governance system. In the final two empirical chapters (5 and 6), I go beyond the goal of understanding the urban water governance and knowledge infrastructure to developing an intervention to shape the water governance system from the requirements and needs of society itself. Those chapters address the third research question: How can we design knowledge infrastructures that contribute to just water governance in Lima?

In the design and development of the *Observatorio Metropolitano de Agua*, we approached this question from both theory and practice. Starting from data justice as a core value, we propose seven design principles to which knowledge infrastructures - in our case, participatory urban dashboards - should adhere. The principles we formulated call attention to the issues of privacy, discrimination, and access, consider the importance of approaching knowledge infrastructures within the social, political, and material context in which they are implemented, and centre the agency and needs of residents in the creation and mobilisation of digital knowledge infrastructures (chapter 5).

Simultaneously, the development of the *Observatorio Metropolitano de Agua* was, in essence, the materialisation of the conversations we were having, and will continue to have, within the transdisciplinary project team and with residents of Lima and experts in the field of water governance. Initiated by Foro Ciudades para la Vida, an NGO which had been involved in and committed to sustainable urban development in Peru for a long time, the *Observatorio Metropolitano de Agua* is very much a grassroots data initiative built on the alliance between different types of knowers.

Therefore, I want to discuss the *Observatorio Metropolitano de Agua* and its contribution to exploring how we can design knowledge infrastructures that contribute to just water governance as an ongoing conversation between theory and practice. This is informed by design science approaches in action research and information technology for development (ICT4D), which emphasise the iterative process of designing information technologies in order to contribute to the dual goals of knowledge generation and creating a useful technological artefact (Islam & Grönlund, 2012; Sein et al., 2011). It is important to note that this conversation is not finished. Since the *Observatorio Metropolitano de Agua* is currently still in the prototype phase and we have not launched it yet, it has not been possible to evaluate its utility in practice.

Yet, the *Observatorio Metropolitano de Agua* project has brought forth findings relevant to design science and theorising about the relationship between data justice and water justice. First, the process up to now shows how designing according to the principles of data justice has implications for the process as well as the outcome. Data justice, and its commitment to visibility and anti-discrimination, requires engaging with plural perspectives and values right from the initiation of the project all the way through to the use of the artefact. Accordingly, in the development of the *Observatorio Metropolitano de Agua*, the conceptual distinction between 'expert-amateurs' and 'smart citizens' as described in chapter 3 has been backgrounded as the platform aims to overcome these distinctions in participation and influence based on knowledge and centrality in the system.

This points to another vital aspect in the development of digital infrastructures for water justice, as learned through the development of the *Observatorio Metropolitano de Agua*: we need to give voice to the experiences of people to understand the (in)justice of the water distribution system.

As described in the first paragraphs of this thesis, it is hardly unusual for Lima’s residents to get up in arms about new developments in urban water governance. The current state of water governance in Lima antagonises many; the seemingly lacking ability to address structural injustices in the water distribution system means that policy and technological interventions in the system are met with a degree of distrust by citizens. As presented in chapters 3 and 4, those reliant on clandestine water connections might oppose the digital infrastructure completely, while others find ways to work with or around them, trying to mobilise the technologies to visibilise their experienced inequalities.

With the *Observatorio Metropolitano de Agua*, we attempt to offer an alternative imagination of knowledge infrastructure as a bottom-up development that functions by its residents’ agency. In this infrastructure, residents can give direction to future design, use, and application of knowledge in urban governance. We are essentially grafting another element onto Lima's water and digital infrastructure, which makes the digital infrastructure decentralised and communal, and highlights the expertise of residents. We hope that by democratising digital technologies and envisioning and materialising critical technologies for urban futures, we will be able to mitigate unintended consequences and contribute to the collective interest of society.

Returning to the sub-question, I argue that the knowledge infrastructures designed for just water governance should engage with, and be based on, the experiences, needs, and plural knowledges of diverse residents at all stages of development. This argument has roots in the work of Shklar (1990) and Zwarteveen and Boelens (2014), who argue that theories about justice, be it in general or specifically focused on water, should pay more attention to citizens' experiences of injustice. Specifically, with the acknowledgement that the data infrastructure is part of a larger hydrosocial system where competing interests are at play, we need to assess the fairness of and access to the participation in knowledge generation and mobilisation. Centring residents' experiences of injustice in the formulation of the data justice design principles thus becomes a powerful tool to bring the water distribution system into conversation with the voice of residents (chapter 5).

7.2 Main contributions to theory

Classic urban studies either tended to look at the city as a conglomerate of material objects or as sites of peculiar social innovation and economic development. But infrastructure shows how the city is both and neither (Amin & Thrift, 2017). There are elements of the city that can be touched, built, or broken down. But the city is hardly a material object. A city without people, plants, animals, and ideas is just ruins. On the other hand, the city can also not be captured by looking only at people. Urban life is made possible through the background, embodied, hermeneutic, and alterity mediation of technologies (Verbeek, 2008) that form the context in which we live, and shape how we see, assess, and interact with the city. As a result, society and people can be perceived as infrastructural phenomena, or at least very much like it. This has been a major shift in thinking about the city and how it is (re)structured (Graham & Marvin, 2022).

Taking infrastructure as a conceptual departure point, this research brings together various disciplines, methods, and perspectives in a unique way to narrate the story of datafication in Lima's water distribution system, the ways that residents contribute through labour and knowledge, and how we can create more just digital tools that contribute to water justice. In important ways, this research contributes to and intersects with theoretical debates from various fields.

First, this thesis puts forward an approach that goes beyond narrow modernist goals for the smart city and instead adopts a relational approach that allows a rethinking of infrastructure that accounts for its social and political lives. Throughout this thesis, I have urged readers to think about water and digital infrastructures beyond their material features and consider people, landscapes, and knowledge as part of the infrastructural systems. While looking through different perspectives and drawing on various bodies of literature at multiple scales, all the empirical chapters of this thesis share a commitment to understanding technology, data, knowledge, water, or the everyday city from a relational perspective. This is noticeable in the use of the concepts such as 'hydrosocial territory' and 'hydrosocial geography' in chapters 2 and 4, emphasising how society, water, and the landscape co-constitute each other (Boelens et al., 2016; Flaminio et al., 2022; Wesselink et al., 2017); in how data has been conceptualised as both outcome and starting point for different and sometimes divergent assemblages which categorise and structure urban processes (Kitchin & Lauriault, 2018); and in our analysis of knowledge infrastructures as emergent from dynamic relationships within a system of knowledge claims, values and standards, epistemologies, structures, and the region (Muñoz-Erickson et al., 2017; Wijsman & Feagan, 2019).

Moreover, this dissertation shows how this relational approach is not only useful for the analysis of the knowledge infrastructure in Lima's water governance but also can be usefully applied in informing design practices. Given the continuous development of digital knowledge infrastructures for urban governance, one of the most important contributions of this research to previous work on urban infrastructure from a sociotechnical perspective (e.g., Amin & Thrift, 2017; Anand, 2017; Salamanca, 2015; Simone, 2004, 2015) is that we work towards bridging the gap between theory and practice through the conceptualisation and design of a participatory urban observatory.

There is value in creating and theorising at the same time. As explained by Milan and Treré (2019), the parallel acts of exploring alternative data imaginaries and creating alternative data practices can be valuable exercises for thinking about data justice in design and the ways we might be able to overcome the injustices in the system. The *Observatorio Metropolitano de Agua* fits within this tradition. In creating an artefact, we are required to decide who should participate in the design and use. What features should it have? What purpose does it serve? And how will people interact with it? (Young & Kitchin, 2020). This invites us to reflect on how values are inscribed in the technology, forces us to place the developed technological artefact within its sociotechnical assemblage, and gives insights into what theory might mean for society.

By presenting an alternative data practice which centres justice rather than efficiency or control, the *Observatorio Metropolitano de Agua* brings to the fore the biases and embedded values in SEDAPAL's data practices. Most importantly, it illustrates how knowledge and data regarding water can be conceptualised and scrutinised in different ways. It follows that designing knowledge infrastructures that contribute to just water governance, particularly in a context of societal, climate, and material transformations, requires a transdisciplinary approach and novel alliances between infrastructuring actors. The *Observatorio Metropolitano de Agua* is an intervention that aims to contest the current data practices and empower those who are working towards overcoming injustices in the field of water governance. This speaks to critical strands of data studies and scholarship on digitalisation which pursue the dual aims of contributing to knowledge and dismantling unjust orders in society (e.g., D'Ignazio & Klein, 2020; Eubanks, 2018).

Second, this thesis illustrated the need to approach the 'smart city' as the everyday city rather than an exceptional category. In various ways, this thesis has pointed out how people create the digital infrastructure, how it impacts the organisation of daily urban life, and is emergent from local knowledge and governance configurations.

The insight that the smart city is mundane has bearings for the ways we approach the cases we research. Echoing Datta (2018) and Luque-Ayala and Marvin (2015), I argue we need to concentrate on the 'local smart city' and focus on the urban spaces that are being structured by digital technologies. Similarly, Niranjana (2022, p. 15) calls for 'becoming minor' in theory and research. This attends to the need to consider the case and space-specific variations of global transitions such as urban digitalisation.

The choice of Lima as a case study site and working together with a diverse set of residents in designing the *Observatorio Metropolitano de Agua* goes to the heart of such calls. The empirical findings of the process of datafication in a city in the Global South are highly relevant for present-day core theoretical debates in urban studies, which have for a long time built their theories from insights from North-Atlantic cities. The set-up of this thesis, being multi-scalar and covering privileged and marginalised communities, allowed for thinking about the city from the inside as well as elsewhere – the Andes, José Carlos Mariátegui – and grappling with urban heterogeneity (Niranjana, 2022). Therefore, as a case study, it contributes to the diversity of cases discussed in the literature on smart urbanism and gives insight into the many different expressions and experiences of becoming 'smart' within one city.

Conceptually, this research provides tools for a better grasp of the disparities in the effects of datafication in everyday urban life. For instance, returning to the work of Scott (1999) and conceptualising datafication as layered legibility-making practices helped us understand how data affect the sociotechnical system in unequal ways: structured and unstructured data from multiple sources reduce on-the-ground complexity by creating manageable and strategic categories and lead to various degrees of (il)legibility (chapter 2).

To understand the implications of these created differentiations, critical feminist and decolonial research on urban infrastructure and digital technologies have been important. Specifically, feminist and decolonial work on urban infrastructure tends to highlight the importance of everyday urban life as a window into the distinctive ways that the city shapes urban lives (Sultana, 2020; Truelove & Ruszczyk, 2022). Regarding digitalisation and datafication, incorporating insights from feminist and decolonial scholarship helps to understand how the unequal outcomes of the processes of data creation, management, and mobilisation are tied to the structural and historical marginalisation and wider urban inequalities based on race, gender, and class (Eubanks, 2018; Ricaurte, 2019). This work draws on both bodies of literature to analyse the intersection between the digital, the urban, and the social. By doing so, it advances earlier work on smart urbanism by providing empirical evidence of how the local smart city is constructed on a daily basis and contributes to understanding how digitalisation plays out in a deeply unequal urban context.

Additionally, the collaborative, bottom-up development of the *Observatorio Metropolitano de Agua* shows how digital knowledge infrastructures can be civil society-led, diverse, and small, as opposed to the dominant image of corporate-led, homogenising, and big (Taylor & Broeders, 2015). From the perspective of everyday life of Lima's residents, it is possible to see how the impact of the digital infrastructure is double-edged: it can undercut the common aspirations of improving the water distribution system and, at the same time, allow us to see people's knowledge, labour, and capacity for organisation to better water governance. These findings underscore the value of making bottom-up infrastructuring practices the focal point, locating residents' agency and capabilities at the centre of the debate on the digitalisation of the city (Milan & Treré, 2019), and explore how a decolonial approach to innovation may result in digital infrastructures which are better aligned with social concerns (Jimenez, Delgado, et al., 2022).

Third, the findings of this dissertation call into question how we conceive and theorise knowledge infrastructures and the relationship between digitalisation in water governance. Water governance and management, if informed by holistic approaches to water justice (Zwarteveen & Boelens, 2014), struggle with a fundamental data issue. Current data for water governance overwhelmingly focus on water's utilitarian properties and the operation of the water distribution system. SEDAPAL, like many other utility service providers worldwide, has shown a strong desire to use digital infrastructures, particularly geo-technologies, to improve service provision by increasing operational efficiency. However, such a drive for digitalisation is often based on the shaky logic that higher efficiency will also lead to a fairer distribution of urban resources (Datta, 2018; Kitchin et al., 2015). Engaging with the knowledge of residents from Lima and San Pedro de Casta showed how data in water governance is not only a tool for water management or a means to record an empirical observation: it is an ontological framing of water and our relationship to our material environment.

The central issue is how to balance and engage with widely diverging conceptualisations of fundamental concepts, such as 'water' and 'knowledge,' in the development of digital technologies to be able to use them as a tool for integration rather than differentiation. While we attempted this in the *Observatorio Metropolitano de Agua*, we did not succeed completely. The scope of the observatory – being the metropolitan city – and its emphasis on generating numerical data in order to engage with policymakers automatically positions it within the modern-scientific knowledge system and its related utilitarian definition of water as a resource for people.

This is a challenge we have noted not only in our work but in the literature on water governance in general. We increasingly see the concept of 'digital water' used in academic research to refer to the ways in which water is datafied and managed through digital technologies (Amankwaa et al., 2021). At the same time, there is a growth of attention for ancestral, indigenous, and nature-based approaches to water governance which present plural ontologies about water (Hartwig et al., 2021; Vera Delgado & Zwarteveen, 2008; Viaene, 2021; Wilson & Inkster, 2018). Very rarely do these two bodies of literature speak to each other, something we have attempted to do in this research. Only by combining an urban focus with a regional focus did it become possible to understand Lima's digital infrastructure for water management within the plural knowledge systems of the region.

Nevertheless, pluralising the cultural and political understandings of water and knowledge embedded in infrastructure proves to be difficult, abiding work. While chapter 4 described how there might be options for hybridisation in knowledge systems for water governance, it also showed how this interaction is skewed towards the dominant actors and ways of knowing.

It is unlikely that technological development will slow down to fully accommodate other narratives and visions for the future of water in Lima. In the meantime, we need to continue exploring ways to overcome the juxtaposition between water and data justice. Zwarteveen and Boelens' (2014) framework for water justice, which grants equal importance to distribution and acknowledgement of knowledge systems, may form a good starting point. If water justice can only be achieved when plural conceptualisations of water are respected and listened to, we need to steer our digital systems and their inscribed ontologies to recognise the value of other ways of knowing. It is through the pluralisation of knowledge that the symbolic boundaries drawn up between the city and landscape, urban and rural, scientific and indigenous, and producer and consumer seem to be slightly redrawn.

Returning to the main research question of this dissertation – how can knowledge infrastructures support just urban water governance – I argue that the knowledge infrastructures created for Lima's water infrastructure should re-focus on justice and centre people as experts, users, and beneficiaries. The context of Lima, and Latin America in general, shows that people are willing to contribute and collaborate. This entails that it has to represent the daily experiences of urban and rural residents and offer opportunities to make their voices heard while acknowledging them as local experts. To do so, and for datafication to contribute to water justice, it should follow the principles of data justice, meaning that people have autonomy and self-determination in sharing data, the digital infrastructure is embedded in public decision-making, and contributes to overcoming structural inequalities in the sociotechnical system (Eubanks, 2018; Taylor, 2017). I hope that the data justice design principles in chapter 5 serve as a starting point for developing knowledge infrastructures that involve citizens in the technologised city of tomorrow. While being an integral part of the water distribution system, their knowledge rarely surfaces in policy, planning, or mainstream narratives about the future of Lima's water system.

The following recommendations for practice may help redirect the development of digital infrastructures to focus first on values, with a vision and plan starting from local needs.

7.3 Recommendations for practice

The first recommendation for practice relates to the importance of pluralisation. This research has illustrated how the narrow definition of knowledge and knowers used in modern-scientific approaches to water governance is short-sighted towards the value and contribution of tacit and indigenous forms of knowledge and knowers in Lima and the region. Scott (1999) explains how state-led legibility-making practices tend to increase order and control while excluding non-codified knowledge and other forms of organisation of people and resources. It not only results in politics of categorisation, as is shown in chapter 2, but also reduces the exchange of creative, pragmatic, and effective ideas to address shortcomings in water service provision. By limiting the space for plural knowledges and knowers, SEDAPAL is doing itself a disservice.

Knowledge infrastructures should support the generation, exchange and mobilisation of diverse sets of knowledge from diverse types of knowers rather than homogenising the knowledge landscape. The hybridisation of the modern-scientific knowledge system and Andean knowledge system, as analysed in chapter 4, serves as an imperfect example of how plural perspectives on water challenges and plural anticipations for the city can be brought together to face current and future challenges regarding water security in Lima.

To facilitate a more collective and democratic process of knowledge generation for urban water governance, the work of Miranda Sara (2021) may serve as inspiration. Miranda Sara (2021) argues that we need to understand Lima's water governance as a process of *concertación*. As a concept, *concertación* is original to Peruvian governance culture and refers to the cyclical and 'highly sensitive and complex process of dialogue–negotiation–*concertación*–conflict management and consensus-building (or not)' amongst stakeholders (Miranda Sara & Baud, 2014, p. 506). Embracing this complex and deliberative process as opposed to pursuing more technocratic approaches opens up space for dialogue about fundamental conceptualisations of water, knowledge, and good governance. In her research, Miranda Sara (2021) applies this to analyse and facilitate the formulation of different scenarios for Lima's water governance in the future. In the development of the *Observatorio Metropolitano de Agua*, we built on this work. While Miranda Sara analysed this process from an institutional perspective, we aimed to create a digital knowledge infrastructure which can serve as an *espacio de concertación* and visibilise and exchange knowledge between stakeholders, adding to the practical and empirical contributions of this research.

However, the '(or not)' in Miranda Sara and Baud's (2014) definition of *concertación* is important and carries a lot of weight. Opting for dissensus rather than consensus by stepping out of the dominant methods, debates, and technologies for inclusive collaboration can be a powerful approach for communities and civil society organisations to break with pre-defined roles and potentially redistribute power in the negotiation over the smart city (Kaika, 2017).

The second recommendation for practice relates to how digitalisation currently unfolds within Lima's urban water distribution system. This thesis provides substantial evidence that the current digitalisation in urban water governance takes shape along conventional lines: it differentiates between water consumers, leads to the further peripheralisation of the non-digital citizen, and overlooks the many ways in which urban residents contribute to water management and governance. It follows that this path of digitalisation will not solve the structural inequalities in Lima's water distribution system.

A different approach is needed to facilitate a change of this kind. Aligned with earlier writings on this topic (Criqui, 2020) and acknowledging Lima's legacy of incremental urbanisation and auto-construction (Turner 1968; Fernandez Maldonado, 2015), I argue that we need water governance policies and technologies that embrace the pragmatic and decentralised approaches of Lima's expert-amateurs in constructing and managing neighbourhood water distribution systems and depart from the value of water justice. This can be done top-down, from the perspective of the state, or bottom-up, driven by civil society. In both cases, it is important that the digital technologies used to govern the 'smart city' are built to respond better to human needs.

To be able to do so, we need to centre people as experts, users, and beneficiaries in our design practices. This work was the first to combine water and data justice in formulating design principles for participatory urban observatories (chapter 5). By putting forward a novel approach to designing digital tools for participation in urban infrastructural governance, it contributes to advancing approaches for governments and citizens alike to develop knowledge infrastructures that contribute to just water governance (chapter 6). We hope this inspires the development of knowledge infrastructures that bring together an assemblage of tools to accommodate the different voices and purposes in urban governance.

7.4 Opportunities for future research

As no research is ever complete, this section ends by reflecting on some of the questions that remain. What has become clear over the course of this research is how infrastructure is everywhere but has no clear unit or scale. It is unlikely that infrastructures exist within a traditionally territorial boundary in an administrative or geographical sense. Rather, infrastructural configurations will always cross spatial and temporal scales. Researching it from the catchment area, the metropolitan city, and the neighbourhood gives us some grip on the role of spatial scale within the water and knowledge infrastructure. However, the issue of temporal scales remains. While we have touched upon the future anticipated in the infrastructure in chapter 4 when analysing how different knowledge systems are hybridised, we are left asking: what timescales are embedded and anticipated in the infrastructure? How is the idea of the future materialised in the city? And most importantly, whose future is the city built for?

Researchers such as Bell (2015, 2022) and Anand (2017) partially engage with these questions by looking at the past to unpack how past notions of the city and how it should develop are materialised in the water infrastructure in Lima and Mumbai today. Building on that research and analysing how future imaginaries - as collectively held, institutionalised, and publicly performed visions of the future - inform infrastructuring practices today will not only help see how the future city surfaces in the present infrastructure but might also identify pathways for change and intervention in urban planning.

This raises two further interrelated questions regarding the limitations of this research and recommendations for future inquiry. How can we give more direction to the (future) use, design, and application of geospatial technologies in public governance and space, so they contribute to more just urban futures? And whose knowledge and experiences should be included in developing future urban infrastructure?

Concerning the first question, and in thinking through how to move from analysis to action, we turned to data justice as a departure point. Our decision to focus on quantitative data and data justice in the *Observatorio Metropolitano de Agua* was partly informed by the fact that data is considered a powerful asset within the fragmented yet entangled institutional network that is Lima's water sector (Filippi et al., 2014; Miranda Sara, 2021). But this is only one possible direction. It is also possible to start from the perspectives of human interaction design, value-sensitive design, speculative design, or many more approaches that centre human and societal needs in the process of designing digital technologies. Taking inspiration from these other approaches might create more space to share and debate ideas in ways that stimulate coming to a shared understanding and sense of community.

Additionally, we have focussed strongly on how data (in)visibilises, structures, and can be made more transparent. However, we have not yet focussed on people's capacities to mobilise data and digital technologies to improve the water infrastructure according to their needs and ambitions. This should and will be the focus of the next steps of the *Observatorio Metropolitano de Agua* project. Not only is it relevant to understand the utility of the *Observatorio Metropolitano de Agua*, but we should also pay attention to issues related to people's access and capabilities to use digital technologies and data. Taking a capabilities approach might offer a starting point to thinking about issues related to the digital divide more explicitly.

Regarding the second question, throughout this thesis, I have centred urban and, to a lesser extent, rural residents in thinking about the knowledge infrastructures created. I argue this is an important and valuable pivot from centring governments and utility companies as done before. Nevertheless, this does entail that the role of institutions in urban planning and water governance has not been fully addressed in this thesis. While this is partly touched upon by Miranda Sara (2021) and Ioris (2012b, 2016), who have analysed how Lima's water injustices are the legacy of institutional reforms and unequal power dynamics in urban planning, there remains an avenue for future research to understand how just knowledge infrastructures are embedded within political and economic institutions, or become institutionalised, to support just urban water governance. Political ecology, as a theoretical lens for analysing complex, urban-social-natural configurations as emergent from deeply unequal pre-existing conditions, may offer a useful starting point to explicitly link socionatural relations to environmental change, political inequalities, and the capitalist development in the city (Heynen, Kaika, and Swyngedouw, 2006).

Finally, this research has sought to include and represent the perspectives of various actors in the process of infrastructuring. Nevertheless, it has taken an anthropocentric approach while we live in a more-than-human world. Following the pathway set out by indigenous and decolonial thinkers in water governance (Hartwig et al., 2021; Viaene, 2021; Wilson & Inkster, 2018), the next important step would be stepping away from the human-centred and embracing more eco-centric approaches in the development of just knowledge infrastructures for water governance.

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Appendix 1: Data overview

Expert Interviews				
	N.	Organisation	Position	Informed
FEB/ MAR '19	1	Independent researcher	Urban governance expert	Ch. 2
	2	PUCP	Humanities, section geography	Background
	3	IFEA	Researcher	Background
	4	SEDAPAL	GIS specialist	Ch. 2
	5	SEDAPAL	GIS specialist	Ch. 2
	6	SEDAPAL	SCADA engineer	Ch. 2
	7	SEDAPAL	Data scientist	Ch. 2
	8	SEDAPAL	Data scientist	Ch. 2
	9	Foro Ciudades para la Vida	Researcher and activist	Background
	10	Embassy of the Netherlands	Economic department	Background
SEP/ FEB '20	11	PUCP	Developmental economics	Background
	12	PUCP	Anthropology / Political Economy	Background
	13	CENCA	Project lead	Ch. 2 & 3

	14	Sembrando Agua	Community leader	Ch. 4
	15	Municipality San Pedro de Casta	Municipality San Pedro de Casta	Ch. 4
	16	San Pedro de Casta	Cattle rearing committee in San Pedro de Casta	Ch. 4
	17	CCA / Expo Agua	Director	Ch. 4
	18	Siemens	Water & Wastewater engineer	Background
	19	CENCA	Researcher on quality of life	Ch. 3
	20	SEDAPAL	Commercial Analyst	Ch. 2 & 3
	21	SEDAPAL	Social Project Management	Ch. 2 & 3
	22	SEDAPAL	Social Project Management	Ch. 2 & 3
	23	SEDAPAL	Social Project Management	Ch. 2 & 3
	24	Red Energías Renovables	Director	Background
	25	Municipality of Comas	Environmental management	Background
	26	AQUA-C / Universidad agraria La Molina	Researcher integrated (holistic) water management	Ch. 4
	27	CONSYSS	Construction, maintenance and repair of water infrastructure	Ch. 2 & 3
	28	Municipality of Barranco	Environmental management	Background

DEC '21	29	SEDAPAL	Research and development	Ch. 4 & 6
	30	Municipality of Lima	Environmental strategy and climate change	Ch. 4 & 6
	31	Colegio de Ingenieros del Perú	Director	Ch. 6

Interviews with residents					
	N.	Gender	District	Position	Informed
SEP/ MAR '20	1	M	Pachacutec	*Dirigente* of one of the communities in Pachacutec	Ch. 3
	2	F	Pachacutec	*Dirigente* of one of the communities Humanos in Pachacutec	Ch. 3
	3	M	Pachacutec	Community representative for all the produce markets in Pachacutec	Background
	4	F	Barrios Altos	*Dirigente* of one of the communities in Barrios Altos	Ch. 3 & 6
	5	F	Villa Maria del Triunfo	Resident	Ch. 3 & 6
	6	M	San Juan de Lurigancho	Resident	Ch. 3 & 6
	7	F	Barranco	Resident	Ch. 3 & 6
	8	M	Miraflores	Resident	Ch. 3 & 6
	9	F	Independencia	Resident	Ch. 3 & 6

	10	F	San Juan de Lurigancho	Resident	Ch. 3 & 6
	11	F	Miraflores y Los Olivos	Resident	Ch. 3 & 6
	12	F	Villa Maria del Triunfo	Resident	Ch. 3 & 6
	13	F	Villa Maria del Triunfo	Resident	Ch. 3 & 6
	14	F	San Juan de Lurigancho	Resident	Ch. 3 & 6
	15	F	San Juan de Lurigancho	Resident	Ch. 3 & 6
	16	F	San Juan de Lurigancho	*Dirigente* of one of the communities in San Juan de Lurigancho	Ch. 3 & 6
	17	F	Villa Maria del Triunfo	Resident	Ch. 3 & 6
	18	F	Barrios Altos	Resident	Ch. 3 & 6
	19	M	Villa Maria del Triunfo	Resident / politician	Ch. 3 & 6

Focus Groups					
	N.	Location	Description	People attending	Informed
Feb Mar '19	1	J.C. Mariátegui, San Juan de Lurigancho	Focus group part of KNOW - focus on neighbourhood needs	15 residents and community leaders of the neighbourhood	Ch. 2

SEP MAR '20	2	Barrios Altos, Cercado de Lima	Focus group on water stories	Five residents of different parts of the city centre	Ch. 3 & 6
	3	J.C. Mariátegui, San Juan de Lurigancho	Focus group on water stories	15-20 residents of different neighbourhoods of Mariátegui	Ch. 3 & 6
	4	Miraflores	Focus group on water stories	8 residents of Miraflores	Ch. 3 & 6
	5	Collegio de Ingenieros, Miraflores	Conversation with experts on water in different fields	Six experts from academia, civil society, and water authorities	Ch. 2, 3, 4, & 6
	6	Sedapal, La Atarjea	Conversation with engineers of Sedapal	Five engineers of the department of investigation and department of *control de fugas* of Sedapal	Ch. 2, 3, 4, & 6
	7	J.C. Mariátegui, San Juan de Lurigancho	Focus group on interventions and influence	Seven residents of different neighbourhoods of Mariátegui	Ch. 3 & 6
	8	Barrios Altos, Cercado de Lima	Focus group on interventions and influence	Three residents of different neighbourhoods in Barrios Altos	Ch. 3 & 6
	9	Foro Ciudades para la Vida, Miraflores	Focus group with youth of Lima	Three young residents of different districts (Los Olivos, Santa Anita and Miraflores)	Ch. 6
	10	Miraflores	Focus group on interventions and influence	Six residents of different parts of Miraflores	Ch. 3 & 6
JAN JUN	11	Online (WhatsApp)	Re-initiate design process MWO	Three parallel WhatsApp conversations with	Ch. 6

'21				residents from the three key sites.	
	12	Online (Zoom)	Focus group: setting design features	Three residents of San Juan de Lurigancho	Ch. 6
	13	Online (Zoom)	Focus group: setting design features	Three residents of Barrios Altos	Ch. 6
	14	Online (Zoom)	Focus group: setting design features	Six residents of Miraflores	Ch. 6

Activities					
	N.	Location	Organisation	Description	Informed
FEB/ MAR '19	1	Tour to La Atarjea	SEDAPAL	Tour through the water treatment plant.	Ch. 2 & 4
	2	Transect walk Mariátegui Project KNOW	PUCP / KNOW	Transect walk through JC Mariátegui and explanation by CENCA.	Ch. 2 & 3
	3	Transect walk Barrios Altos Project KNOW	PUCP / KNOW	Transect walk through Barrios Altos, focus on the commercial centre.	Ch. 2 & 3
	4	International Water Day	SEDAPAL / World Bank	Conference with keynote presentations and speeches on the current and future water challenges.	Ch. 2 & 4
SEP/ MAR '20	5	Visit to San Pedro de Casta	PUCP MSc Water Management	Visiting San Pedro de Casta and learning about the Amunas project.	Ch. 4

	6	Community Meeting Mariátegui	CENCA	Meeting with the directors of the neighbourhoods to discuss the progress of projects.	Ch. 2 & 3
	7	Expo Agua 2019	Expo Agua	Conference with engineering companies and governmental organisations in the field of water.	Ch. 2 & 4
	8	Taller Municipalidades y Adaptacion a Cambio Climatico	Foro Ciudades para la Vida	Workshop for municipality representatives to formulate climate change adaptation policy.	Ch. 4
	9	Consultary meeting PLANMET	PLANMET	Meeting of the consultary council to discuss the metropolitan plan for Lima-Callao.	Ch. 4
	10	Foro Urbano	Foro Urbano	Citizens forum on the collective right to the city.	Ch. 2
	11	Community work with Atrapaniebes	Los Sin Agua	Joined the community in working on the installations to catch atmospheric water through nets.	Background
	12	Walk through in Ventanilla / Pachacutec	non	Joined municipality workers in visiting community leaders in Pachacutec to discuss land title formalisation.	Background
	15	Second trip to San Pedro de Casta	non	Tour to the amunas in the upper catchment of the Rimac.	Ch. 4

	16	Meeting PLANMET	PLANMET	Third meeting attended of the stakeholder group of the PLANMET.	Ch. 2 & 4
	17	Visit to the neighbourhood Malambo, Barranco	Municipality of Barranco	Transect walk through the neighbourhood of Malambo and conversation of women of the area.	Background
	18	Expo Agua 2020	Online	Conference with engineering companies and governmental organisations in the field of water.	Ch. 4

Appendix 2: Interview Guides

General Introduction:

Thank you very much for wanting to talk to me. Before we start the interview, I just wanted to discuss a few formalities with you. First of all, are you okay with the interview being recorded for research purposes? Secondly, do you consent that what you say can be used in a research publication anonymously? If you have any questions or change your mind, you can always contact me!	Muchas gracias por querer hablar conmigo. Antes de comenzar con la entrevista, solo quería discutir algunas formalidades con usted. En primer lugar, ¿está de acuerdo con que la entrevista se grabe con fines de investigación? En segundo lugar, ¿das tu consentimiento para que lo que dices se pueda usar en una publicación de investigación de forma anónima? Si tiene alguna pregunta o cambia de opinión, ¡siempre puede contactarme!

Questions for citizens in informal neighbourhoods:

English	Spanish
Could you tell me a bit of your background story? For example, when and why did you move to this area? How has the area developed since you have lived here? How do you get your water for daily use?	¿Podrías contarme un poco de tu historia de fondo? Por ejemplo, ¿cuándo y por qué te mudaste a esta área? ¿Cómo se ha desarrollado el área desde que has vivido aquí? ¿Cómo obtiene sus servicios básicos como agua, alcantarillado y electricidad?

Could you explain to me the process of getting water in your home and your neighbourhood?	¿Podría explicarme el proceso de obtener estos servicios en su hogar y en su vecindario?
Do you have an official land title?	¿Tienes un título de propiedad oficial?
(if yes)	*(en caso afirmativo)*
How did you manage to get this?	¿Cómo lograste conseguir esto?
Why did you want to be registered?	¿Por qué querías estar registrado?
What do you expect from being registered as a citizen of your district?	¿Qué esperas de estar registrado como ciudadano de tu distrito?
(if no)	*(si no)*
Why don't you have a land title?	¿Por qué no tienes un título de propiedad?
Are you in the process of getting a land title or not?	¿Estás en el proceso de obtener un título de propiedad o no?
Would you want to be registered, or do you prefer not to be registered?	¿Desea estar registrado o prefiere no estar registrado?
What do you expect from registration?	¿Qué esperas de ser registrado?
(About infrastructures)	*(Sobre infraestructuras)*
What type of water infrastructures have been built in the neighbourhood? For example, pipes, water reservoirs or wells?	¿Qué tipo de infraestructuras se han construido en este vecindario? Por ejemplo: tuberías, reservorios de agua o pozos?
Under which authorities have the infrastructure been built and operated?	¿Bajo qué autoridades se ha construido y operado la infraestructura?
What have been significant changes in the infrastructure over time? What has triggered these changes?	¿Cuáles han sido los cambios significativos en la infraestructura a lo largo del tiempo? ¿Qué ha provocado estos cambios?
What have been the consequences of these changes?	¿Cuáles han sido las consecuencias de estos cambios?

How has this influenced the distribution and division of water in the neighbourhood? Are there any plans that have not been successful? What made them unsuccessful? *(If they have running water in their home)* For a couple of years, Sedapal has been installing meters in the water infrastructure. Do you have a meter in your house to measure water consumption? *(If yes, then...)* When has this been installed? Do you know why this has been installed? How do you feel about this change in how the water is measured? Are there benefits to having a household meter? Are there downsides to having a household meter? *(If they don't have a household water consumption meter)* Do you know why there is no meter installed in your household? What do you think about the fact that there is no meter installed?	¿Cómo ha influido esto en la distribución y división del agua en el vecindario? ¿Hay algún plan que no haya tenido éxito? ¿Qué los hizo fracasar? *(Si tienen agua corriente en su casa)* Desde hace un par de años, Sedapal ha estado instalando medidores en la infraestructura del agua. ¿Tiene un medidor en su casa para medir el consumo de agua? *(Si es así, entonces ...)* ¿Cuándo se ha instalado esto? ¿Sabes por qué se ha instalado esto? ¿Cómo te sientes acerca de este cambio en la forma en que se mide el agua? ¿Hay beneficios por tener un medidor doméstico? ¿Hay inconvenientes para tener un medidor doméstico? *(Si no tienen un medidor de consumo de agua doméstico)* ¿Sabes por qué no hay medidor instalado en tu hogar? ¿Qué opinas sobre el hecho de que no hay medidor instalado? ¿Qué le parece este cambio en la forma en que se mide el consumo de agua?

How do you feel about this change in how water consumption is measured? Are there benefits to having a household meter? Are there downsides to having a household meter? Under what circumstances would you want to have a meter installed? What do you expect from a meter? *End of the interview:* Do you have anything else you would want share? Or do you have any questions for me? Is it okay if I call or email you in case if I have some follow up questions?	¿Hay beneficios por tener un medidor doméstico? ¿Hay inconvenientes para tener un medidor doméstico? ¿En qué circunstancias le gustaría tener un medidor instalado? ¿Qué esperas de un medidor? *Fin de la entrevista:* ¿Tienes algo más que quieras compartir? ¿O tienes alguna pregunta para mí? ¿Está bien si te llamo o te envío un correo electrónico en caso de que tenga algunas preguntas de seguimiento?

Appendix 3: Focus group guides

Focus group guide – round 1

Central questions[27] for the focus group:

- What are the main issues residents in each neighbourhood are facing with regard to water access?
- How do people deal with challenges regarding water access in their daily life?
- What do people see as potential interventions/solutions to these challenges?
- What are the potential indicators for water access we should consider?

Agenda:

00.00 – 00.15	Registration
00.15 – 00.30	Introduction to research and aim of focus group
00.30 – 01.00	Theme 1: Access to water resources
01.00 – 01.30	Theme 2: Information and potential tools
01.30 – 01.45	Closing
01.45 – 02.00	Drinks

Discussion guide:

[27] All questions were translated to and asked in Spanish.

Theme	Description
Knowledge for water management – Personal water stories	Discuss the experiences of demanding, controlling, monitoring and maintaining water resources in their households or neighbourhoods. What are their main challenges with regard to these issues? The main focus should be on the types of knowledge and information they use in their daily water management. Before the start of the meeting, we can ask one person if they are willing to start the conversation and share their 'water story.' This could, for example, be about the process of getting a water connection to their home or the way they manage and monitor the water consumption in their households. The objective of the personal stories would be to identify similar experiences and common challenges. The results of this discussion can be analysed through a 'problem tree' framework.
Thinking about information and tools that help	After discussing the past and current experiences in the form of the 'water stories,' we ask which information or tools would have helped in applying for a water connection or can help today in their household or neighbourhood water management. What information or tools would make it easier to demand, control, monitor and maintain their water resources? What information did you miss, or are you missing? What could be the role of information/data in improving access to, and quantity of, water for household consumption? If you could advise a friend on how to demand and manage water resources, what would you tell them? What knowledge that you have based on your experience would you like to share with others?
Defining indicators	What would we have to record if we gather information or data about the experiences of demanding, controlling, monitoring, and maintaining water resources? How can we measure water access and consumption? What are the indicators for water access and consumption? Which information do you think is important to gather with respect to the distribution of water and water access in Lima/Callao? What kind of information or tool would be the most useful for you?

Focus group guide – round 2

Central questions[28] for the focus group:

- How would a data-based system work if it were meant to encourage poor and working-class people to meet their needs in their own ways?
- How can we design the system so that it works for you specifically?
- What is the room of influence that you have on the (re)design of the system?
- And what knowledge or tools would help you in realising this transformation?

Agenda:

00.00 – 00.15	Refreshing information about the last meeting
00.15 – 00.30	Finish mapping the neighbourhood
00.30 – 01.00	Theme 1: Focus on the physical infrastructure
01.00 – 01.30	Theme 2: Focus on the institutions
01.30 – 01.45	Final round
01.45 – 02.00	Closing

Discussion guide:

Theme	Description
Introduction and practicalities	During the past focus group meeting, we took the time to talk about the different individual experiences with regard to receiving, using and administering water. During this session, we want to

[28] All questions were translated to and asked in Spanish.

	focus a bit more on the neighbourhood and in relationship to the city. The main question we will be focusing on is: How would we design the system to make it work for you? We will be focusing on three main aspects of the water distribution system, which are the physical infrastructure (so all the water, pipes, meters, pumps, rotoplas, etc.), the institutional system (including Sedapal, the municipalities, but also the community organisations and directivas) and the knowledge (data and daily experience) that we have about the infrastructure. A small warning, since we will be discussing complex issues and we do not have too much time, I will be a bit strict with the time. It would be great if you could help me with this! However, before we move towards thinking about the changes we need, I wanted to return quickly to the previous meeting and check if the conclusion represents well what we have discussed.
Refresher about the past focus group discussion	Have a flip-over sheet with the bullet points of the main conclusions of the past focus group discussion we organised. The main objective of this section is to check if I understood them well in the past focus group and to refresh the minds of the participants about what had already been discussed. Ask them: Did I understand well what has been said during the past conversations? Do you have anything to add? Present a summary of the findings of all three focus groups in Mariátegui, Barrios Altos and Miraflores.
Mapping the neighbourhood	So now we move to thinking about the neighbourhood and what we need to change. First of all, I thought it might be good to focus on the map of the neighbourhood quickly. I have drawn a very basic map of the neighbourhood with what I thought were points of interest. However, what is still missing from the map? Do you want to add something? Until where, more or less, do the pipes of the water infrastructure reach? And which ones have a meter installed? Which neighbourhoods get water from communal taps? Where do the pipes break? Use different colours to indicate different elements. For example, blue to mark where pipes water reaches. Green for the neighbourhoods that get water from the communal taps. Red for pipes that have broken in recently.

Theme 1: Physical infrastructure	So, thinking since we have already talked a bit about the physical infrastructure, I want to ask you, how would you design the physical infrastructure if possible? Ask people to discuss in pairs: What would you like to develop for the neighbourhood? Think about the distribution, the quantity, and the quality. Potentially distribute these topics per pair of people. Do two rounds. This would mean 2 x 10 minutes. 1 minute think, 3 minutes pair, and 4 minutes share. Use the Think, Pair, Share method: Get an idea of each pair. Ask them not to repeat what has already been said to motivate everybody to come up with different ideas. When everybody has shared their ideas, ask if there are still some ideas that have not been mentioned yet. Why are these things important?
Theme 2: Influence of people on infrastructure development	And then ask, As a resident of this neighbourhood, do you have influence over it and why / why not? What is the influence you have on the changes in the infrastructure? What are the issues you cannot change? And who is the person/institution that could make a change? How about, for example, the community leaders (dirigentes) of the neighbourhoods? And what kind of knowledge do we need to get this done? This moves us to think about the institutions and their position as citizens. If you want to increase your influence, what kind of information or tools do you need? What would be the most useful to you?
Final round	So, returning to the question: If we design the physical and institutional system in a way that works for you, how would you design it? The final question would be: To change the physical and institutional system in a way that works better for you, what information and tools do you need?
Closing	Five minutes before the end of time, tell everybody that we have to round it up. Give all the participants the chance to share a final thought. Explain that we will be writing a report again and will share this with them via WhatsApp as soon as it is finished.

Focus group guide – round 3

Central question[29] for the focus group: What functions and features should the *Observatorio Metropolitano de Agua* have?

- Discussing the main objectives of the Observatorio
- What are the functionalities you would like?
- What should the Observatorio look like?

Agenda:

00.00 – 00.15	Introduction
00.15 – 00.30	Refreshing
00.30 – 01.00	Theme 1: Functionalities
01.00 – 01.30	Theme 2: Design features
01.30 – 01.45	Final round
01.45 – 02.00	Closing

Discussion guide:

Theme	Description
Introduction	Introduce the aim of the focus group and introduce ourselves. We ask people to introduce themselves. Ask people to share experiences and ideas about water service delivery in their neighbourhoods. This can be written, or we can ask people to talk.

[29] All questions were translated to and asked in Spanish.

Refresher and identify the main issues	Summarise the main issues shared; what are the common challenges? Is anything missing? Ask people to help brainstorm about what is still missing. How can we break up the main challenges into smaller dimensions? How can we value the quality of each of these dimensions? (For example, when is water provision good? When is it bad?) Can we then make the step in defining indicators for each dimension and determine a certain value range?
Inspiration	Prototyping Share examples of two or three already existing Observatorios and urban dashboards as potential prototypes for the observatory. What do people like? What do they dislike? What is easy to use, and what is difficult? What is relevant to our aim, and what is not relevant? http://emergenteleon.org/mapas/salud/ https://www.observatorioaguamza.com/es http://otuc.cl/nuevo/port_menu.html Ask people to try out the selected platforms and record their first responses/observations. They can share the recordings.
Visualise and design ideas	What should the platform look like according to them? Can they visualise it in some way? Could they sketch their ideas on paper and share a picture in the chat? Can they share links to possible platforms that they use?
Define the features of the Observatory	What would be your main goal for the observatory? How can an observatory like this be helpful for you? What would be the functions that you are interested in? What are your requirements and essential features for the platform? Questions: - What objectives do you think the observatory platform should meet? - Who are the potential users? - If you consider yourself a potential user, how would you like to use it? For example, to be informed / to download information / to add information / to interact with others? - What devices do you think should work on? (cell phone, iPhone, Android, laptop)

	- Would you like it to be an interactive platform? What characteristics do you want it to have? For example, a section with social networks and email allows taking and sharing photos and videos, which can determine the location, analysis, scan codes, etc. - How would you like information to be shared? Would you like access to the raw data? What type of reporting/visualisation would you prefer (tables, maps, written reports)?
Closing	Share the synthesis of the focus group so far. Now that we have a basic structure and design for the observatory, is anything missing? What do they want to add? What is good, and what can be improved? Close the focus groups and send a personal thank you message from us

Appendix 4: Code books

Codebook used in qualitative analysis for chapter 2

This codebook contains the list of codes used for the qualitative analysis of the data, texts, notes, and transcripts in ATLAS.ti™. Please note that some codes have been made prior to the analysis, and others were created during the coding process as new themes emerged. The coding was conducted by the author of this thesis, who also collected the data in the field.

Code	Description
Actors involved	This code should give an overview of the different actors involved in the development of the project.
Data strategy	This code relates to text that describes how data in itself is strategic or how data is used strategically.
Data production	This code is used for text which describes how data about the water infrastructure is produced in Lima.
Data use	This code relates to text that describes how data is used in urban water management. Data sharing amongst institutions is also a part of data use and thus is coded in this code.
Description of SCADA	The text related to this code should explain the design, implementation, and/or functioning of the SCADA system.
Start / End date	The date (year) that the infrastructural project has started and (is supposed to be) finished.
Functioning of system	The text related to this code should explain the design, implementation and/or function of the overall water infrastructure. Specifically, this refers to the water distribution system.
Funding agency	This is the main financer of the infrastructural project.
Hardware of	This code relates to the physical materials used in the

information system	(development) of the digital information system.
Institutional relationships	This code relates to descriptions of how different institutions involved in water management are related to each other / work together.
Justification for solution proposed in project	The text related to this code should answer the question: How is the proposed solution to the stated problem justified in the text? Why do they choose this solution as opposed to others?
Proposed solution to stated problem	The text related to this code should answer: what solution is proposed to solve the problem as stated in the text? For example, the stated problem is that a neighbourhood is not connected to the water pipes. The proposed solution is we need to expand the water pipes to include that neighbourhood.
Sectorisation	This code is related to the text that describes the process of sectorisation of the water infrastructure in Lima.
Stated problem that is to be solved	The text related to this code should answer: what is the problem that is identified in the text that needs to be solved? For example, the stated problem is that a neighbourhood is not connected to the water pipes.
Targeted location of project	Which neighbourhoods of the city does the project focus on/take place?
Urban development process	This code relates to text that describes the urban expansion and growth process in Lima.
Sedapal - Administration	Describes the administration of the water infrastructure by SEDAPAL
Sedapal - Construction	Describes the construction of the water infrastructure by SEDAPAL

Codebook used in qualitative analysis for chapter 3

This codebook contains the list of codes used for the qualitative analysis of the data, texts, notes, and transcripts in ATLAS.ti™. Please note that some codes have been made prior to the analysis, and others were created during the coding process as new themes emerged. The coding was conducted by the author of this thesis, who also collected the data in the field.

Code	**Description**
Auto-administration of water consumption	Refers to the process of auto-administration and governance in water infrastructure.
Auto-construction of water infrastructure	Refers to the process of auto-construction in water infrastructure.
Description of settlement	This code relates to the description of the neighbourhood and building the residents reside.
Description of water infrastructure	Broad code: includes quotes of people describing the water infrastructure in their homes, the water quality, as well as the complete waterscape.
Digital technologies (aside from meter)	This code is used in discussions of the use or implementation of digital technologies in water management that are not the water meter.
General information about living conditions.	This code refers to the description of the general living conditions but not the housing or neighbourhood description.
Habits / cultura / education	This code refers to discussions on the habits, culture, or education related to water consumption.
Perception of community organisation	This code refers to discussions regarding community organisation and collaborative management of water resources.
Perception of Sedapal	This code refers to how SEDAPAL is perceived by residents of the different neighbourhoods.

Perception of state	This code refers to how government entities (municipal or national government) are perceived by residents in different neighbourhoods.
Responsibility of citizens	This code refers to the discussions about what is considered to be the responsibility of citizens in urban water management.
Responsibility of State	This code refers to the discussions about what is considered to be the responsibility of the state in urban water management.
Sedapal - Administration of water consumption	This code refers to citizens' perceptions regarding SEDAPAL's water consumption administration.
Sedapal - construction of water infrastructure	This code refers to the perceptions of citizens regarding SEDAPAL's construction of water infrastructure.
Water meter perception	This code refers to the citizens' perception regarding the water meter.
Water meter use	This code refers to the description of the use and functioning of the water meter.

Codebook used in qualitative analysis for chapter 4

This codebook contains the list of codes used for the qualitative analysis of the data, texts, notes, and transcripts in ATLAS.ti™. The codes are based on the knowledge system analysis framework (Muñoz-Erickson et al., 2017). As noted in section 3 of this research, the coding was conducted by the author of this thesis, who also collected the data in the field.

Code group	Code	Description
Knowledge claim	Statements representing worldview	The worldview is a collection of attitudes, values, stories, and expectations about the world around us, which inform thought and action
	Problem definition	Reflects what is considered to be the main problem that should be addressed.
	Future challenges	This refers to sections of text in which future challenges and planning are discussed. This can include infrastructural plans but also climate change risks.
Values and standards	Argumentation for decision	This refers to the texts that explain why a certain decision has been made.
	Normative principles	Reflects values that suggest which actions are wrong and which are right. Represents what the actor or institution thinks 'should' be the case.
	Standards	Represents the established requirements for the quality of water governance
Epistemologies	Ways for knowing	This refers to the methods or processes through which knowledge is acquired. It can refer to modern-scientific methods, generational experience, or anything in between.
	Definition of knowledge	This should code text that explains which knowledge is considered to be valuable in thinking about water governance
	Reasoning about	Represents the actors' logic or explanation for

	the world	how the world works.
Structures	Relationships between actors	This refers to the texts in which the relationships between actors are described. This can be human/human, human/non-human, or non-human/non-human.
	Actors involved	This code refers to the human and non-human actors that are involved in the knowledge system
Region	Relationship with environment	Represents statements about the relationships of water governance with the natural environment
	Relationship with location	Represents statements about the relation between water governance and the geographic location in which it takes place. This also includes the boundaries of the territory on which the water governance model should focus.
	Water management	Water management refers to the control over the movement of water

Appendix 5: Methods structured literature review

Selection of academic literature

Stage 1- Identification of initial constructs and related terms

Literature was selected using the Boolean search function on SCOPUS, Web of Science, and SciELO. The search function was based on the following concepts (*within rows use OR operator and between rows use AND)*

Constructs	Related terms	Broader terms	Narrow terms
Urban	City		Lima
Dashboard	Observatory	Indicator's systems	Water observatory
Participatory	Inclusive	interactive	

Stage 2- Search for articles in

Web of Science Core Collection (20-05-21)

Sets (all indexes and all years)	Search string	Results
1. In title, abstract or keywords	TOPIC: (observator*) OR TOPIC: (dashboard*) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years	60,624

2. In title, abstract or keywords	TOPIC: (participatory) OR TOPIC: (inclusive) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years	113,574
3. In title, abstract or keywords	TOPIC: (urban) OR TOPIC: (cit*) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years	1,338,802
4. Set 1, 2 and 3	#3 AND #2 AND #1 Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years	38

SCOPUS (20-05-21)

Sets (all indexes and all years)	Search string	Results
1. In title, abstract or keywords	(TITLE-ABS-KEY (observator*) OR TITLE-ABS-KEY (dashboard*))	83,318
2. In title, abstract or keywords	(TITLE-ABS-KEY (participatory) OR TITLE-ABS-KEY (inclusive))	163,842
3. In title, abstract or keywords	(TITLE-ABS-KEY (urban) OR TITLE-ABS-KEY (cit*))	1929,731
4. Set 1, 2 and 3	((TITLE-ABS-KEY (observator*) OR TITLE-ABS-KEY (dashboard*))) AND ((TITLE-ABS-KEY (participatory) OR TITLE-ABS-KEY (inclusive))) AND ((TITLE-ABS-KEY (urban) OR TITLE-ABS-KEY (cit*)))	71

SciELO (20-05-2021)

Sets (all indexes and all years)	Search string	Results

1. Todos los índices	(observatorio*) OR (dashboard*)	955
2. Todos los índices	(participativ*) OR (inclusi*)	24,190
3. Todos los índices	(urban*) OR (ciudad*)	43,874
4. Todos los índices	(ciudad*) OR (urban*) OR (metropolitan*)	48,785
4. Set 1, 2 and 3	#3 AND #2 AND #1	283 (41 in English or Spanish)

We collected all the combined search results (search set 4 in each database), resulting in a total of 150 research papers. Of the results in SCOPUS, Web of Science and SciELO, 33 papers were duplicates. Leaving a combined total of 117 results. After the initial search, we returned to the SciELO database to search on "tablero* de control". This resulted in 20 papers, but none matched the screening criteria.

Stage 3 – Literature screening inclusion criteria based on abstract

After reading the abstracts of the articles, a short list of papers to be included in the review was compiled based on the following criteria. This second round of screening resulted in a list of 27 empirical research papers on participatory observatories in an urban context.

Criteria	Description
Topic	Focus on participatory dashboards or observatories used in an urban context
Period	No restrictions
Abstract	Case studies/empirical research which discusses the design and implementation of a participatory observatory at an urban scale

Type of Research	Peer-reviewed and published articles, book chapters, or conference paper
Language	English or Spanish

After the secondary screening, I have a list of 25 papers that match the criteria. However, none of the papers on the final list came from the SciELO database. Therefore, to try to find more literature published in Spanish, we searched the digital library of the Universidad de Chile. For this database, it was not possible to combine search queries, so we searched for all different combinations separately. Since the database only allowed us to search either on the title (narrow) or in all categories (broad), we opted for the latter. The secondary screening of the results did not result in papers that fit the criteria set.

Biblioteca Digital de la Universidad de Chile (26-05-2021):

Sets (all indexes and all years)	Search string	Results
1. Cualquier campo	(observatorio*) OR (dashboard*)	78.274
2. Cualquier campo	(participativ*) OR (inclusi*)	1.289.302
3. Cualquier campo	(urban*) OR (ciudad*)	1.809.120
4. Set 1, 2 and 3	Not possible	
5. Cualquier campo	“observatorio*” AND “ciudad*” AND “participativ*”	38
6. Cualquier campo	“observatorio*” AND “urban*” AND “participativ*”	32

7. Cualquier campo	“dashboard*” AND “urban*” AND “participativ*”	0
8. Cualquier campo	“observatorio*” AND “ciudad*” AND “participativ*”	1
9. Cualquier campo	“observatorio*” AND “ciudad*” AND “inclusiv*”	68
10. Cualquier campo	“observatorio*” AND “urban*” AND “inclusiv*”	39
11. Cualquier campo	“dashboard*” AND “ciudad*” AND “inclusiv*”	7
12. Cualquier campo	“dashboard*” AND “urban*” AND “inclusiv*”	2

This selection procedure resulted in the following list of articles included for review:

1. Acuto, M., Dickey, A., Butcher, S., & Washbourne, C.-L. (2021). Mobilising urban knowledge in an infodemic: Urban observatories, sustainable development and the COVID-19 crisis. *World Development*, *140*. https://doi.org/10.1016/j.worlddev.2020.105295

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3. Assumpcao, T. H., Jonoski, A., Theona, I., Tsiakos, C., Krommyda, M., Tamascelli, S., ... Popescu, I. (2019). Citizens’ campaigns for environmental water monitoring: Lessons from field experiments.

IEEE Access, *7*, 134601–134620. https://doi.org/10.1109/ACCESS.2019.2939471

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Selection of case studies used in practice for review of existing platforms

Stage 1- Identification and selection of platforms

Platforms will be selected using the Boolean search function on Google (incognito tab) and DuckDuckGo (incognito tab). We have included results from the five first pages of both search engines (the first 50 results for each search engine). The search function was based on the following concepts (*within rows use OR operator and between rows use AND)*

Constructs	Related terms	Broader terms	Narrow terms
Urban	City		Lima
Dashboard	Observatory	Indicator's systems	Water observatory
Participatory	Inclusive	interactive	

Since we specifically searched for functioning platforms and not research publications, we have excluded results that include 'scholar' and 'research'. This removed a lot of results from the top pages that came from Google Scholar or Research Gate.

Sets	Search string	Results (26 July 2021)
Google (incognito tab)	urban AND (observatory OR dashboard) AND water -scholar -research	30.400.000 (0.60 seconds)
Google (incognito tab)	(urban OR city) AND participat* AND (dashboard OR observatory) -scholar -research	14.400 (0.66 seconds)
Google (incognito tab)	(urban OR city) AND (participat* OR inclus*) AND (dashboard OR observatory) -scholar -research	21.300 (0,54 seconds)
Google (incognito tab)	water AND (urban OR city) AND (participat* OR inclus*) AND (dashboard OR observatory) -scholar -research	8 (0,66 seconds)
Google (incognito tab)	water AND (urban OR city) AND participatory AND (dashboard OR observatory) -scholar -research	311.000 (0,72 seconds)

Google (incognito tab)	agua AND urbano AND participacion AND (dashboard OR observatorio) -scholar -research	2.300.000 results (0,48 seconds)
Google (incognito tab)	online AND participatory AND platform AND urban -scholar -research	19.000 results (0,72 seconds)
Google (incognito tab)	online participatory platform urban water -scholar -research -budget	28.100 results (0,47 seconds)

Stage 2: Secondary screening

We screened the first five pages of each of the search queries and selected all the pages that matched the following criteria:

- Language (English or Spanish)
- The platform is (still) functional. Does not have to be updated very recently.
- There has to be a participatory element in the platform. This entails residents provide input in one way or another.
- The platform (partially) focuses on urban issues
- The platform (partially) focuses on issues related to water access, quality, and/or scarcity.
- The platform has to be (partly) digital.

This resulted in the following list:

1. https://data.cityofevanston.org/
2. https://observatoriourbano.org.pe/
3. http://www.ideam.gov.co/web/ocga/comisiones-conjuntas

4. https://observatoriociudad.org/el-gcba-se-declara-incompetente-ante-la-justicia-para-garantizar-el-agua-potable-en-la-totalidad-de-los-hogares-porte%C3%B1os/
5. https://connect.coliban.com.au/projects
6. https://communityhub.unitywater.com/
7. https://www.emasesa.com/conocenos/observatorio-del-agua
8. https://decide.madrid.es/

In addition, we have added the following three observatories to the analysis:

9. http://www.observatoriodevivienda.org/
10. https://www.observatorioaguamza.com/es
11. https://notanatlas.org/maps/collaborative-cartography-in-defense-of-the-commons/

Summary

Innovation in digital water management, such as the use of sensors, supervisory control and data acquisition systems (SCADA), geographic information systems (GIS), and digitised water services, has become commonplace for cities to tackle challenges related to water governance and management. Also in Lima, Peru, datafication - the transformation of something, for instance, social activities, objects and their characteristics, or natural phenomena, into data through diverse actors, methods, and technologies for it to be recorded and analysed (Mayer-Schönberger & Cuckier, 2013) - is frequently attributed a key role in improving urban water governance. Nevertheless, these innovations play out in a context of severe discontent among the city's residents due to the structural inequalities in Lima's water distribution system.

The main aim of this dissertation is, therefore, to understand **how knowledge infrastructures can support just urban water governance** within the context of hydrosocial inequality in Lima, Peru. In order to be able to answer this question, it was necessary to look beyond the digital infrastructure itself and consider it in relation to the broader knowledge systems, urban and regional geography, and societal structures of the city. The research is structured along three sub-questions: (i) how can current data infrastructures challenge or reproduce unequal structures in Lima's water governance? (ii) how do different actors and knowledge systems contribute to water governance in the region and Lima? and (iii) how can we design knowledge infrastructures that contribute to just water governance? The first sub-question is answered through the empirical research in chapters 2 and 3, the second sub-question is answered through chapters 3 and 4, and the third sub-question is answered through chapters 5 and 6.

As the foundation on which the city is built, infrastructure has constantly defined and redefined the development of urban areas and their people. However, contrary to what the word 'structure' implies, urban infrastructure is not static. The moment infrastructure is used, for example, when a water tap is opened, a jack is plugged in, or a road is maintained, new elements are added to the structure of the infra. Urban infrastructure is, therefore, constantly in-the-making. To emphasise this processual character of infrastructure, scholars have used the term 'infrastructuring' (Bowker et al., 2007; Karasti et al., 2016).

Thinking through the concept of infrastructuring opens up analytical space to consider the politics within its everyday practices. Urban residents are embedded in multiple material infrastructures as well as more immaterial forms of infrastructure such as social networks, urban master plans, or discourses about the right to water and citizenship within a particular location (Kathiravelu, 2021). Focusing on the everyday is a move away from trying to locate power and pay more attention to the situated moments wherein infrastructure engages and enacts social relations and the (un)settling of these dynamics. By researching the mundane rather than the monumental, we turn our attention to the people, places, and experiences that are consistently excluded in dominant narratives and promises of infrastructural development.

The main research question is answered through a multi-method, multi-perspective, and multi-scalar approach. While the first empirical sections of the dissertation primarily draw on qualitative modes of inquiry at different scales, the later sections of the thesis employ review methods and collaborative design science to inform the development of a digital artefact. Both the conceptual analysis and the design process helps to inform theory about the potential of knowledge infrastructures to support more just water governance in Lima.

Chapter two analyses the effects of datafication of Lima's water infrastructure as layered legibility-making practices (Scott, 1999) and aims to understand how the relationship between residents and the state is shaped through multiple data sources. We found that in the 'smart city,' where various structured and unstructured sources of data come together and databases are made interoperable, it becomes increasingly important to consider not only the role of a variety of actors beyond the state that are making the city legible (Li, 2005; Taylor & Richter, 2017) but also the links between the variety of data sources. While digital data technologies seek to increase equality and homogenisation, in practice, they seem to introduce new differences, multiple layers or boundaries, and, as such, reproduce the inequality in Lima's water distribution system.

In chapter three, we move from the metropolitan scale analysed in chapter two to the neighbourhood level to understand the diverse ways people relate to digital infrastructure in the city. We ask: how does the digital infrastructure reconfigure the roles within the water distribution system in Lima, now imagined as centralised and digital rather than decentralised and auto-constructed?

Research on the impacts of datafication has generally focused on marginalised communities. While undeniably important, this thesis innovatively researches these relationships across socio-economic class and geographical locales. We conceptualise residents' roles in the knowledge and water infrastructure as either 'expert-amateurs' or 'smart citizens' to analyse how digitalisation redistributes tasks, roles, and responsibilities within the system. The qualification of 'expert' is important in this case since the residents have advanced tacit knowledge about the needs of the community and the design, operation, and administration of the water distribution systems they have developed.

We conclude that it is essential to consider the differences between the digitalisation trajectory in formalised infrastructures and cities compared to auto-constructed spaces. While auto-construction continues to be an important form of infrastructural development in Lima, digitalisation hampers people from finding innovative ways to construct and manage water systems according to their own logic and needs. Specifically considering the underlying socio-economic inequalities in Lima, attention should be paid to developing a system that fosters the participation of all people and avoids the peripheralisation based on knowledge asymmetry.

In chapter four, we zoom out and analyse the different knowledge systems informing water governance approaches in the Rimac catchment area, Lima's main water source. It took a visit to the mountains, and stepping into different theories, to see Lima as part of the Rimac river system, rather than only approaching it as a desert city. Moreover, going beyond the urban discussions on water governance was necessary to think more critically and comprehensively learn about the knowledge that should be included in the development and design of the Observatorio Metropolitano de Agua, a co-designed participatory observatory aiming to visibilise injustices in the water distribution system of Lima and Callao.

Chapter four draws on knowledge system analysis to examine the different water governance models as distinctive manifestations of understanding the socio-ecological changes in Lima's hydrosocial territory. We conclude that it is possible to see how the hybridisation of the modern-scientific knowledge system (MSKS) and the Andean knowledge system (AKS) might represent a new chapter in water governance which is open to diverging perspectives for water governance to address current and future environmental challenges. Yet, at the same time, considering the situatedness of knowledge, it becomes apparent that as knowledge is extracted from its regional context and mobilised to serve other regions and people, this hybridisation is asymmetric and does not work towards overcoming structural inequalities amongst actors and between knowledge systems.

Chapters five and six are dedicated to exploring the potential of participatory urban observatories as knowledge infrastructures for creating collaborative pathways to more just smart urbanism. Chapter five proposes design principles to guide the development of just urban observatories. By doing so, we contribute to bridging the divide between data justice in theory and in practice. Chapter six describes the collaborative design process resulting in a prototype for the Observatorio Metropolitano de Agua para Lima-Callao (Metropolitan Water Observatory for Lima-Callao, MWO). Hence, while chapter four zooms out and places the discussions in Lima within the wider regional and discursive context, the subsequent chapters (five and six) zoom in conceptually on data justice within urban water governance.

In chapter five, we argue that participatory observatories should go beyond the goal of improving resource preservation and the more just distribution of resources within the city to enhancing accountability in decision-making and planning processes by increasing transparency, encouraging participatory governance through residents' empowerment and engagement, and facilitating plural ways of understanding and knowing water and the city.

These principles are applied in the development of the MWO, as described in chapter six. The MWO is a digital, collaboratively developed observatory that aims to collect and share data about water access and infrastructuring practices within the metropolitan city of Lima-Callao. The purpose of developing the MWO has been to contribute to a fairer distribution of water resources amongst urban residents by exploring the potential of collecting and diffusing data on the access to, quantity, and quality of water for human consumption in the metropolitan area and by explicitly integrating 'expert-amateur' knowledge in the development of a new digital infrastructure.

Returning to the main research question of this dissertation – how can knowledge infrastructures support just urban water governance – this dissertation argues that the knowledge infrastructures created for Lima's water infrastructure should re-focus on justice and centre people as experts, users, and beneficiaries. To do so, and for datafication to contribute to water justice, the development of knowledge infrastructures should follow the principles of data justice, meaning that people have autonomy and self-determination in sharing data, the digital infrastructure is embedded in public decision-making, and contributes to overcoming structural inequalities in the sociotechnical system (Eubanks, 2018; Taylor, 2017). The data justice design principles in chapter 5 may serve as a starting point for developing knowledge infrastructures that involve citizens in the technologized city of tomorrow. While being an integral part of the water distribution system, citizens' knowledges rarely surface in policy, planning, or mainstream narratives about the future of Lima's water system.

We hope that by democratising digital technologies and envisioning and materialising critical technologies for urban futures, we will be able to mitigate unintended consequences and contribute to the collective interest of society. This highlights the importance of turning our attention to the relationships between actors, knowledge, and the (im)materiality of infrastructure. Researching the city through infrastructuring makes it possible to understand the interactions between the material and the social elements, which give ground for cities to emerge in all their uniqueness and complexity. Once we learn these characteristics of infrastructuring in relation to the city, we can see how people are part of and active agents in shaping, constructing, maintaining and decomposing the city. It allows us to think about the city beyond this dualism, the distinction between social and matter, and start paying attention to a spectrum of possibilities for incremental change.

Samenvatting

Innovatie in digitaal waterbeheer, zoals het gebruik van sensoren, een supervisie, controle, en data-acquisitiesysteem (SCADA), geografische informatie systemen (GIS) en gedigitaliseerde waterdiensten, is gemeengoed geworden in steden om uitdagingen op het gebied van watermanagement en -beleid aan te pakken. Dataficatie - de transformatie van iets, bijvoorbeeld sociale activiteiten, objecten en hun kenmerken, of natuurlijke fenomenen, in gegevens in data door verschillende actoren, methoden en technologieën om het te registreren en te analyseren (Mayer-Schönberger & Cuckier, 2013) – worden vaak een sleutelrol toegeschreven in het verbeteren van stedelijk waterbeheer. Ook in Lima, Peru. Echter, deze innovaties vinden plaats in een context van structurele ongelijkheden in het waterdistributiesysteem van Lima en grote ontevredenheid hierover.

Daarom heeft dit proefschrift als doel **om te onderzoeken hoe kennisinfrastructuren rechtvaardig stedelijk waterbeheer en-beleid kunnen ondersteunen** in een context van hydrologische ongelijkheid in Lima, Peru. Om deze vraag te kunnen beantwoorden is het nodig om verder te kijken dan de digitale infrastructuur zelf en deze te onderzoeken in relatie tot bredere kennissystemen, de stedelijke en regionale geografie en maatschappelijke structuren. Het onderzoek is gestructureerd langs drie deelvragen: (i) hoe reproduceren of herstructureren de huidige data-infrastructuren ongelijke structuren in het waterbeheer van Lima? (ii) hoe dragen verschillende actoren en kennissystemen bij aan waterbeheer in de regio en Lima? en (iii) hoe kunnen we kennisinfrastructuren ontwerpen die bijdragen aan rechtvaardig waterbeheer? De eerste deelvraag wordt beantwoord door het empirisch onderzoek in de hoofdstukken 2 en 3, de tweede deelvraag wordt beantwoord door de hoofdstukken 3 en 4 en de derde deelvraag wordt beantwoord door de hoofdstukken 5 en 6.

Infrastructuur is het fundament waarop een stad is gebouwd en definieert voortdurend de ontwikkeling van stedelijke gebieden en hun mensen. In tegenstelling tot wat het woord 'structuur' impliceert, is stedelijke infrastructuur niet statisch. Op het moment dat infrastructuur wordt gebruikt - bijvoorbeeld wanneer een waterkraan wordt geopend, een krik wordt aangesloten of een weg wordt onderhouden - worden nieuwe elementen toegevoegd aan de structuur van de infra. Stedelijke infrastructuur is dan ook continu in de maak. Om dit procesmatige karakter van infrastructuur te benadrukken, gebruiken we de term 'infrastructurering' (Bowker et al., 2007; Karasti et al., 2016).

Het concept infrastructurering opent analytische ruimte om het politieke in de dagelijkse praktijk van infrastructuur te onderzoeken. Stadsbewoners zijn ingebed in meerdere materiële en immateriële vormen van infrastructuur, zoals bijvoorbeeld sociale netwerken, een masterplan, discoursen over het recht op water, en officieel burgerschap binnen een bepaalde plaats (Kathiravelu, 2021). Een focus op het alledaagse is een stap weg om macht te lokaliseren en meer aandacht te besteden aan die situaties en momenten waarop infrastructuur sociale relaties beïnvloeden en een nieuwe dynamiek tot stand brengend door de bestaande sociale relaties te bevestigen of juist te ontregelen. Door het alledaagse te onderzoeken in plaats van het monumentale, richten we onze aandacht op de mensen, plaatsen en ervaringen die consequent worden uitgesloten in dominante verhalen en beloftes omtrent infrastructurele ontwikkeling.

Hoofdstuk twee analyseert de effecten van dataficatie van de waterinfrastructuur van Lima als het creëren van gelaagdheid in de leesbaarheid (Scott, 1999) van de stad. In dit hoofdstuk onderzoeken we hoe de relatie tussen inwoners en de staat wordt gevormd door middel van meerdere databronnen. We ontdekten dat in de 'slimme stad', waar verschillende gestructureerde en ongestructureerde databronnen samenkomen en databases interoperabel worden gemaakt, het steeds belangrijker wordt om niet alleen de rol te erkennen van de verscheidenheid aan actoren die bijdragen aan het leesbaar maken van de stad(Li , 2005; Taylor & Richter, 2017), maar ook de verbanden te begrijpen tussen de verscheidenheid aan databronnen en hun interacties.. Terwijl digitale datatechnologieën streven naar meer gelijkheid en homogenisering, leiden ze in de praktijk tot nieuwe verschillen, introduceren ze meerdere lagen of grenzen en reproduceren ze zodanig de aard van ongelijkheid in het waterdistributiesysteem van Lima.

In hoofdstuk drie gaan we van de metropool die in hoofdstuk twee is geanalyseerd naar het niveau van de wijk om de verschillende manieren waarop mensen omgaan met digitale infrastructuur in de stad. We vragen: hoe herdefinieert de digitale infrastructuur de rollen binnen het waterdistributiesysteem in Lima, dat nu wordt voorgesteld als gecentraliseerd en digitaal, in plaats van gedecentraliseerd en zelf gebouwd?

Onderzoek naar de effecten van dataficatie is over het algemeen gericht op gemarginaliseerde gemeenschappen. Hoewel onmiskenbaar belangrijk, onderzoekt dit proefschrift op innovatieve wijze deze relaties tussen verschillende sociaaleconomische klassen en geografische locaties. We conceptualiseren de rol van bewoners in de kennis- en waterinfrastructuur als 'expert-amateurs' of 'slimme burgers' om te analyseren hoe digitalisering taken, rollen en verantwoordelijkheden binnen het systeem herverdeelt. De kwalificatie van 'expert' is in dit geval belangrijk omdat de bewoners geavanceerde ervaringsdeskundigheid hebben over de behoeften van de gemeenschap en het ontwerp, de werking en het beheer van de waterdistributiesystemen die ze hebben ontwikkeld.

We concluderen dat het essentieel is om rekening te houden met de verschillen tussen het digitaliseringstraject in geformaliseerde infrastructuren in steden, in vergelijking met zelfbouw wijken. Hoewel zelfbouw een belangrijke vorm van infrastructurele ontwikkeling in Lima blijft, belemmert digitalisering mensen om innovatieve manieren te vinden om watersystemen te bouwen en te beheren volgens hun eigen logica en behoeften. Gezien de onderliggende sociaaleconomische ongelijkheden in Lima moet aandacht worden besteed aan de ontwikkeling van een systeem dat de participatie van alle mensen bevordert en de uitsluiting op basis van kennisasymmetrie vermijdt.

In hoofdstuk vier zoomen we uit en analyseren we de verschillende kennissystemen die ten grondslag liggen aan de benaderingen van waterbeheer in het stroomgebied van Rimac, de belangrijkste waterbron van Lima. Het vergde een bezoek aan de bergen om Lima te zien als onderdeel van het Rimac stroomgebied in plaats van een stad in de woestijn. Bovendien was het nodig om breder te lezen dan de literatuur over stedelijk waterbeheer om kritischer en vollediger na te denken over de kennis die moet worden opgenomen in de ontwikkeling en het ontwerp van het *Observatorio Metropolitano de Agua*, een collaboratief ontworpen participatief observatorium met als doel om onrechtvaardigheden zichtbaar te maken in het waterdistributiesysteem van de metropool regio Lima en Callao.

Hoofdstuk vier is gebaseerd op kennissysteemanalyse om de verschillende benaderingen voor waterbeheer te onderzoeken als resultaat van uiteenlopend begrip van de sociaalecologische veranderingen in het hydrosociale territorium van Lima. We concluderen dat het mogelijk is om te zien hoe de hybridisatie van het modern-wetenschappelijke kennissysteem (MSKS) en het Andeskennissysteem (AKS) een nieuw hoofdstuk in waterbeheer en beleid zou kunnen vertegenwoordigen dat openstaat voor uiteenlopende perspectieven voor waterbeheer en beleid om huidige en toekomstige klimaatproblematiek aan te pakken. Maar tegelijkertijd, gezien kennis altijd voorkomt uit een systeem, wordt het duidelijk dat wanneer kennis uit zijn regionale context wordt gehaald en gemobiliseerd om andere regio's en mensen te dienen, deze hybridisatie asymmetrisch is en niet werkt aan het overwinnen van structurele ongelijkheden tussen actoren en kennissystemen.

Hoofdstukken vijf en zes zijn gewijd aan het verkennen van het potentieel van participatieve stedelijke observatoria als kennisinfrastructuren voor het creëren van gezamenlijke paden naar een meer rechtvaardige ontwikkeling van de slimme stad. Hoofdstuk vijf stelt ontwerpprincipes voor om stedelijke observatoria te ontwerpen die bijdragen aan datarechtvaardigheid. Hoofdstuk zes beschrijft het gezamenlijke ontwerpproces van een prototype voor het *Observatorio Metropolitano de Agua para Lima-Callao* (Water Observatorium voor de metropool regio Lima-Callao, MWO). Dus, terwijl hoofdstuk vier uitzoomt en de discussies in Lima in de bredere regionale en discursieve context plaatst, zoomen de daaropvolgende hoofdstukken (vijf en zes) conceptueel in op datarechtvaardigheid binnen stedelijk waterbeheer.

In hoofdstuk vijf stellen we dat participatieve observatoria niet allen als doel hebben om het behoud en de verdeling van hulpbronnen binnen de stad te bevorderen, maar ook zouden moeten bijdragen om de verantwoording in besluitvormings- en planningsprocessen te vergroten door meer transparantie, het aanmoedigen van participatief bestuur door middel van empowerment en betrokkenheid van bewoners, en het faciliteren van pluralisme in het beheer van water en de stad.

Deze uitgangspunten worden toegepast bij de totstandkoming van de MWO zoals beschreven in hoofdstuk zes. De MWO is een digitaal, collaboratief ontworpen observatorium dat tot doel heeft data te verzamelen en te delen over toegang tot water en infrastructurele praktijken in de metropool regio Lima-Callao. Het doel van de ontwikkeling van de MWO was om bij te dragen aan een eerlijkere verdeling van watervoorraden onder stadsbewoners door de mogelijkheden te onderzoeken van het verzamelen en verspreiden van gegevens over de toegang tot, kwantiteit en kwaliteit van water voor menselijke consumptie in het grootstedelijk gebied en door expliciet het integreren van 'expert-amateur' kennis bij de ontwikkeling van een nieuwe digitale infrastructuur.

Terugkomend op de hoofdonderzoeksvraag – hoe kunnen kennisinfrastructuren rechtvaardig stedelijk waterbeheer ondersteunen – stelt dit proefschrift dat de kennisinfrastructuren die voor de waterinfrastructuur van Lima zijn gecreëerd, zich opnieuw moeten richten op justitie en mensen centraal moeten stellen als experts, gebruikers en begunstigden. Om dit te doen, en om te zorgen dat dataficering bijdraagt aan "waterrechtvaardigheid", moet de ontwikkeling van kennisinfrastructuren de principes van "datarechtvaardigheid" volgen, wat betekent dat mensen autonomie en zelfbeschikking hebben bij het delen van data, de digitale infrastructuur is ingebed in de publieke besluitvorming en dat de digitale infrastructuur bijdraagt aan het overkomen van structurele ongelijkheden in het sociaal-technische systeem (Eubanks, 2018; Taylor, 2017). De ontwerpprincipes voor datarechtvaardigheid in hoofdstuk 5 kunnen als uitgangspunt dienen voor het ontwikkelen van kennisinfrastructuren die burgers betrekken bij de getechnologiseerde stad van morgen. Hoewel burgers een integraal onderdeel zijn van het waterdistributiesysteem, komt hun kennis zelden naar voren in beleids-, plannings- of reguliere verhalen over de toekomst van het watersysteem van Lima.

We hopen dat we door het democratiseren van digitale technologieën en het ontwikkelen van kritische technologieën voor de steden van de toekomst, in staat zullen zijn om negatieve neveneffecten van digitalisering te verminderen en bij te dragen aan het collectieve belang van de samenleving. Hiervoor is aandacht voor de relaties tussen actoren, kennis en de (in)materialiteit van infrastructuur essentieel. Door de stad te onderzoeken door middel van infrastructuur is het mogelijk om de interactie tussen de materiële en de sociale elementen te begrijpen die resulteren in unieke en complexe steden. Als we deze kenmerken van infrastructuur in relatie tot de stad beter leren kennen, kunnen we zien hoe mensen deel uitmaken van de stad en deze actief vormgeven, bouwen, onderhouden en afbreken. Het stelt ons in staat om over de stad na te denken voorbij het dualisme tussen mens en materie, en aandacht te schenken aan een spectrum van mogelijkheden voor stapsgewijze verandering.

Resumen

La innovación en la gestión digital del agua, referida a aquella que incorpora, por ejemplo, el uso de sensores, Sistemas Digitales de Manejo y Procesamiento de datos (SCADA), Sistemas de Información Geográfica (SIG), entre otros, se ha convertido en un punto común desde el que diversas ciudades abordan desafíos relacionados con la gobernanza y la gestión del agua. Este es el caso también de Lima, Perú, donde a la "datificación" - la transformación de algo, por ejemplo, actividades sociales, objetos y sus características, o fenómenos naturales, en datos a través de diversos actores, métodos y tecnologías para ser registrados y analizados (Mayer-Schönberger & Cuckier , 2013) - se le suele atribuir un papel clave en mejorar la gestión del agua en la ciudad. Sin embargo, la implementación de dicho sistemas se lleva a cabo en un contexto de profundo descontento entre los habitantes de la ciudad debido a las desigualdades estructurales en el sistema de distribución de agua de Lima.

Debido a lo anterior, la presente investigación tiene como objetivo comprender cómo las infraestructuras del conocimiento pueden apoyar a una gobernanza justa del agua urbana en el contexto de la desigualdad hidrosocial en Lima, Perú. Para poder responder a esta pregunta, era necesario mirar más allá de la propia infraestructura digital e investigarla en relación con los sistemas de conocimiento más amplios, con la geografía urbana y regional y con las estructuras sociales de la ciudad. De esta manera, investigo en tres subproyectos (i) ¿cómo las infraestructuras de datos actuales desafían o reproducen estructuras de desigualdad en la gobernanza del agua de Lima? (ii) ¿cómo los diferentes actores y sistemas de conocimiento contribuyen a la gobernanza del agua en la región y Lima? y (iii) ¿cómo se pueden diseñar infraestructuras de conocimiento que contribuyan a una gobernanza justa del agua? La primera pregunta se responde a través de la investigación empírica en los capítulos 2 y 3, la

segunda pregunta se responde a través de los capítulos 3 y 4, y la tercera pregunta se responde a través de los capítulos 5 y 6.

Es importante considerar la infraestructura ha definido y redefinido constantemente el desarrollo de las áreas urbanas y su gente, funcionando como base sobre la que se construye la ciudad. Sin embargo, contrariamente a lo que implica la palabra 'estructura', la infraestructura urbana no es estática; en el momento en que se utiliza la infraestructura, por ejemplo, cuando se abre un grifo de agua, se enchufa un dispositivo a la red eléctrica, o se mantiene una carretera, se agregan nuevos elementos a la estructura de la infraestructura. Por lo tanto, la infraestructura urbana está constantemente en construcción. Para enfatizar este carácter procesual de la infraestructura, los académicos han utilizado el término "infraestructurando" ("infrastructuring" en su versión original en Inglés) (Bowker et al., 2007; Karasti et al., 2016).

Pensar a través del concepto de infraestructura abre un espacio analítico para considerar la política dentro de sus prácticas cotidianas. Los residentes urbanos están integrados en múltiples infraestructuras materiales, así como en formas de infraestructura más inmateriales tales como redes sociales, planes maestros urbanos o discursos sobre el derecho al agua y la ciudadanía dentro de un lugar en particular (Kathiravelu, 2021). Centrarse en en las acciones del día a día es alejarse de tratar de ubicar el poder y prestar más atención a los momentos situados en los que la infraestructura se involucra y promulga las relaciones sociales y el (des)establecimiento de estas dinámicas. Al investigar lo cotidiano en lugar de lo monumental en esta investigación, dirigimos nuestra atención a las personas, los lugares y las experiencias que se excluyen constantemente de las narrativas dominantes y las promesas del desarrollo de infraestructura.

Esta investigación se desarrollo con un enfoque multi-método, multi-perspectivo y multiescalar. Esto se puede evidenciar en el hecho que mientras las primeras secciones empíricas de la presente disertación evidencian el uso de métodos de investigación cualitativos a diferentes escalas, las últimas secciones de este documento muestran la implementación de métodos de revisión y diseño colaborativo para informar el desarrollo de un artefacto digital. Tanto el análisis conceptual que se llevó a cabo como el proceso de diseño ayudan a informar la teoría sobre el potencial de las infraestructuras de conocimiento para apoyar una gobernanza más justa del agua en Lima.

El siguiente capítulo de esta disertación (cap. 2), analiza los efectos de la datificación de la infraestructura hídrica de Lima como práctica de entendimiento de la legibilidad a través de capas ("layered legibility-making" en su versión en inglés) (Scott, 1999). El objetivo de dicho capítulo es comprender cómo se forma la relación entre los residentes y el Estado a través de múltiples fuentes de datos. Descubrimos así que en la 'ciudad inteligente', donde varias fuentes y bases de datos estructuradas y no estructuradas se unen y se vuelven interoperables, es cada vez más importante considerar no solo el rol de una variedad de actores más allá del Estado que están haciendo legible la ciudad (Li , 2005; Taylor & Richter, 2017), sino también los vínculos entre la variedad de fuentes de datos. Si bien las tecnologías de datos digitales buscan aumentar la igualdad y la homogeneización, en la práctica parecen introducir nuevas diferencias, múltiples capas o límites y, como tal, terminan reproduciendo la desigualdad en el sistema de distribución de agua de Lima.

En el capítulo tres, nos enfocamos en la escala metropolitana al nivel de barrio presentada en el capítulo dos.. Nuestro objetivo era comprender las diversas formas en que las personas se relacionan con la infraestructura digital en la ciudad. De esta manera, nos preguntamos: ¿cómo reconfigura la infraestructura digital los roles dentro del sistema de distribución de agua en

Lima, ahora imaginado como centralizado y digital, en lugar de descentralizado y autoconstruído?

Es importante considerar que, hasta ahora, la mayoría de las investigaciones sobre los impactos de la datificación generalmente se ha centrado en las comunidades marginadas. Sin embargo, aunque este tema es importante, el trabajo de investigación que se presenta en esta tesis investiga de manera innovadora estas relaciones entre clases socioeconómicas y ubicaciones geográficas. Siendo así, entendemos a los residentes como "expertos-aficionados" o "ciudadanos inteligentes" para analizar cómo la digitalización redistribuye tareas, roles y responsabilidades dentro del sistema. La calificación de "experto" es importante en este caso, ya que, los vecinos tienen un conocimiento tácito avanzado sobre las necesidades de la comunidad y el diseño, operación y administración de los sistemas de distribución de agua que ellos han desarrollado.

En este capítulo, concluimos que es fundamental considerar las diferencias entre la trayectoria de la digitalización de las infraestructuras en las ciudades formalizadas en comparación con los espacios autoconstruidos de las mismas. Si bien la autoconstrucción sigue siendo una forma importante de desarrollo de infraestructura en Lima, la digitalización impide que las personas encuentren formas innovadoras de construir y administrar sistemas de agua de acuerdo con sus propias lógicas y necesidades. Considerando específicamente las desigualdades socioeconómicas subyacentes en Lima, se debe prestar atención al desarrollo de un sistema que fomente la participación de todas las personas y evite la periferización debido a la asimetría del conocimiento.

En el capítulo cuatro nos centramos en analizar los diferentes sistemas de conocimiento que informan los enfoques de gobernanza del agua en el área de captación del Rimac, la principal fuente de agua de Lima. Se necesitó una visita a las montañas y entrar en diferentes teorías para ver a Lima como parte de la cuenca del río Rímac, en lugar de solo acercarse a ella como una ciudad del desierto. Además, fue necesario ir más allá de las discusiones urbanas sobre la gobernanza del agua para pensar de manera más crítica y comprensiva sobre el conocimiento que debe incluirse en el desarrollo y diseño del Observatorio Metropolitano de Agua, un observatorio participativo colaborativamente diseñado que tiene como objetivo visibilizar las injusticias en el sistema de distribución de agua de Lima y Callao.

De esta manera, este capítulo muestra los resultados de examinar los diferentes modelos de gobernanza del agua como manifestaciones distintivas de la comprensión de los cambios socio-ecológicos en el territorio hidrosocial de Lima. Hemos investigado esto a través del análisis de sistemas del conocimiento ("knowledge system analysis" (Muñoz-Erickson et al., 2017) en su versión en inglés). Concluimos que es posible ver cómo la hibridación del sistema de conocimiento científico moderno (MSKS en sus siglas en inglés) y el sistema de conocimiento Andino (AKS en sus siglas en inglés) podría representar un nuevo capítulo en la gobernanza del agua, actual y futura, abierto a perspectivas divergentes . Sin embargo, se hizo evidente que a medida que el conocimiento se extrae de su contexto regional y se moviliza para servir a otras regiones y personas, la hibridación de conocimientos se torna asimétrica. Debido a esto, la hibridación como fue explorada no funciona para superar las desigualdades estructurales entre actores y entre sistemas de conocimientos.

Posteriormente, en los capítulos cinco y seis exploramos el potencial de los observatorios urbanos participativos como infraestructuras de conocimientos donde se crean vías de colaboración hacia un urbanismo inteligente más justo. Específicamente, en el capítulo cinco proponemos principios de diseño que guíen el desarrollo de los observatorios urbanos justos, contribuyendo así, a cerrar la brecha entre la justicia de datos en teoría y en su práctica. En el capítulo seis describimos el proceso de diseño colaborativo que resultó en un prototipo para el Observatorio Metropolitano de Agua para Lima-Callao (Observatorio Metropolitano de Agua para Lima-Callao, MWO). Así, mientras que en el capítulo cuatro las discusiones en Lima se ubican dentro del contexto regional y discursivo más amplio, en los capítulos siguientes (cinco y seis) las reflexiones se acercan conceptualmente a la justicia de datos para el caso de la gobernanza urbana del agua.

De esta manera, en el capítulo cinco argumentamos que los observatorios participativos deben ir más allá del objetivo de mejorar la preservación de los recursos y la distribución más justa de estos dentro de la ciudad para mejorar la rendición de cuentas en los procesos de planificación y la toma de decisiones aumentando la transparencia. El avanzar en estos procesos fomenta la gobernanza participativa a través del empoderamiento y compromiso de los residentes y facilita la promoción y activa participación de ciudadanos y las formas plurales de entender y conocer el agua y la ciudad.

Estos principios se aplican en el desarrollo de la MWO como se describe en el capítulo seis. El MWO es un observatorio digital desarrollado de manera colaborativa para contribuir a una distribución más justa de los recursos hídricos entre los residentes urbanos de la ciudad metropolitana Lima-Callao explorando el potencial de recopilar y difundir datos sobre el acceso, la cantidad y la calidad del agua para consumo humano en el área metropolitana y explícitamente integrando el conocimiento 'experto-aficionado' en el desarrollo de una nueva infraestructura digital.

A lo largo de los capítulos de este trabajo de investigación respondemos a su pregunta principal de ¿cómo pueden las infraestructuras de conocimiento apoyar la gobernabilidad urbana del agua?. Basado en los hallazgos y reflexiones a los que llegamos, sostengo que las infraestructuras de conocimiento creadas para la infraestructura del agua de Lima deben volver a enfocarse en la justicia y centrar a las personas como expertos, usuarios y beneficiarios. Para hacerlo, y para que la datificación contribuya a la justicia hídrica, el desarrollo de infraestructuras de conocimiento puede seguir los principios de la justicia de datos; lo anterior significa que las personas tienen autonomía y autodeterminación para compartir datos, la infraestructura digital está integrada en la toma de decisiones públicas y así contribuye a superar las desigualdades estructurales del sistema sociotécnico (Eubanks, 2018; Taylor, 2017). Los principios de diseño derivados de la justicia de datos presentados en el capítulo 5 pueden servir como punto de partida para desarrollar infraestructuras de conocimiento que involucren a los ciudadanos en la ciudad tecnologizada del mañana. Si bien elles son una parte integral del sistema de distribución de agua, sus conocimientos rara vez son activamente tenidos en cuenta en las políticas públicas, los procesos de planificación urbana o las narrativas principales sobre el futuro del sistema de agua de Lima.

Así, esperamos que al democratizar las tecnologías digitales y al visualizar y materializar tecnologías críticas para los futuros urbanos, podamos mitigar las consecuencias no deseadas y contribuir al interés colectivo de la sociedad. Resaltamos la importancia de volver nuestra atención a las relaciones entre los actores, el conocimiento y la (in)materialidad de la infraestructura; investigar la ciudad a través de la infraestructura permite comprender las interacciones entre los elementos materiales y sociales que dan pie a que las ciudades emerjan en toda su singularidad y complejidad. Cuando hacemos estas exploraciones y una vez que conocemos estas características de la infraestructura en relación con la ciudad, podemos ver cómo las personas son parte y agentes activos en la configuración, construcción, mantenimiento y descomposición de la ciudad. Finalmente, tener las anteriores consideraciones y actuar acorde a ellas, nos permite

pensar la ciudad más allá del dualismo referente a la distinción entre su parte social y la materia y comenzar a prestar atención a un espectro de posibilidades de cambio incremental.

Author biography

Fenna Imara Hoefsloot received her BSc from the University of Amsterdam in Future Planet Studies with a major in Human Geography in 2015 and her MSc (cum laude) in International Development Studies in 2017. Before starting her doctoral work at the Department of Urban and Regional Planning and Geo-Information Management, University of Twente, she worked at the University of Amsterdam as a lecturer at the Institute for Interdisciplinary Studies.

Her research focuses on how knowledge infrastructures can support just urban water governance. Specifically, her PhD research took a relational and multi-scalar approach to analyse how digital infrastructures reproduce or restructure inequalities in the water distribution system of Lima, Peru. As part of her PhD research, Fenna was part of the collaborative design of a participatory urban observatory with experts in the field of water management and residents from diverse socioeconomic backgrounds and geographic positions in the city. This participatory tool aims to visibilise inequalities regarding water access and contribute to a fairer distribution of water resources amongst urban residents.

In addition to her research, Fenna has co-hosted Dialogical Spaces, a podcast critically discussing diversity and inclusion in research, education, and practice. She is a member of the external advisory board for the Institute for Interdisciplinary Studies at the University of Amsterdam, was part of the SENSE committee for research assessment, and served as chair for pITCom, the representative body for PhDs at the Faculty of Geo-information sciences and Earth Observation (ITC). At the University of Twente, she contributed to the development of an interdisciplinary course on global climate challenges and local action and co-supervised MSc students in their project work and thesis.

Digital knowledge infrastructures have become commonplace technologies for cities to tackle challenges related to water governance and management. This thesis analyses these dynamics within the context of the wider hydrosocial inequalities in Lima, Peru, and asks: How can knowledge infrastructures support just urban water governance? This question is answered using a multi-method and multi-scalar approach. It draws on the qualitative modes of inquiry at different scales, review methods, and collaborative design to inform the development of a digital artifact. In doing so, this research moves from conceptual analysis to design science as applied in action research to theorize about the potential of knowledge infrastructures to support more just water governance in Lima.

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