Thesis submitted in fulfilment of the requirements for the award of the degree of Doctor of Engineering Sciences (Doctor in de ingenieurswetenschappen)

The Human Face of Water

Understanding the Socioecological Complexity in the Integrated Water Resource Management Paradigm

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February 2022

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By

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This thesis is dedicated to Julia Agramont,

beautiful minds inspire others.


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List of Abbreviations

DPSIR	Drivers- Pressure-State-Impact-Response
WHO	World Health Organization
IWRM	Integrated Water Resources Management
KRB	Katari River Basin
KRBIP	Katari River Basin Interinstitutional Platform
MWE	Ministry of Water and Environment
TBAA	Titicaca Binational Autonomous Authority

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Chapter 1

Introduction

Partially based on: Agramont, A., van Cauwenbergh, N., van Griesven, A., & Craps, M. (2022). Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins: case study of the Katari River Basin, Bolivia. Water International, 47(1), 8–29. https://doi.org/10.1080/02508060.2021.1997021

Agramont, A., Craps, M., Balderrama, M., & Huysmans, M. (2019). Transdisciplinary Learning Communities to Involve Vulnerable Social Groups in Solving Complex Water-Related Problems in Bolivia. Water, 11(2), 385. https://doi.org/10.3390/w11020385.

Agramont, A., Peres-Cajías, G., Villafuerte, L. Van Cauwenbergh, N., Craps, M., & van Griensven, A. Framing water policies, a transdisciplinary study of collaborative governance. The Katari River Basin Case (Bolivia). To be submitted to: Water Alternatives.

This introductory chapter presents an overview of the work presented in this thesis. We initially discuss the global water context and introduce the concept of Integrated Water Resource Management. Then the shifts on water planning and water governance linked to the Integrated Water Resources Management approach are presented. After, the Drivers-Pressure-State-Impact-Response framework, the transdisciplinary learning community approach, and framing water policy developments are introduced. Finally, the main research objective and research questions are presented.

1.1 Context

The global water crisis is impacting society, the environment, and the economy worldwide. More than 700 children under age 5 die every day due to the lack of improved water, sanitation, and hygiene services (UNICEF, 2021). Since 2000, the number of city inhabitants lacking safe drinking water raised by more than 50% (UN-Water, 2021). The effects of climate change are most felt through hydrological regime changes (UN, 2020).

Water is essential for the achievement of the 2030 sustainable development agenda. The sustainable development goal 6 reflects strong interlinkages with most sustainable development goals such as poverty reduction (1), agriculture (2), health (3), education (4), gender (5), energy (7), economy (8), infrastructure (12), the environment (14, 15), climate change and resilience (13) ((UN-Water, 2016). Furthermore, to deal with the complex nature of the water sector the sustainable development target 6.5 aims to implement integrated water resources management since this approach is considered fundamental for its sustainability.

1.2 The Integrated Water Resources Management Paradigm

In 1992, the Dublin international conference on Water and Environment defined four core water resource management principles: First, water is a finite and vulnerable resource that sustains life, the environment, and economic development. Second, water management should include the participation of all sectors, users, planners, and policymakers at all levels. Third, women must be considered essential in the water management role. And fourth, water holds an economic value and should be considered an economic good based on all the competing uses of this natural resource (Nicol and Odinga, 2016).

Most of these principles were later incorporated into the international development agenda through the concept of Integrated Water Resource Management (IWRM) at the Rio Earth Summit in 1992. The Global Water Partnership defines the concept as: “The equitable and efficient management and sustainable use of water and recognizes that water is an integral part of the ecosystem, a natural resource, and a social and economic good, whose quantity and quality determine the nature of its utilization” (Global Water Partnership, 2000). The IWRM approach was disseminated to the rest of the globe when, at the 2002 World Summit on Sustainable Development placed in Johannesburg, the United Nations General Assembly agreed on member states to develop IWRM and Water Efficiency Plans by 2005.

IWRM shifted from conventional forms of local water management to river basin scale planning. This form of planning requires the understanding of the interrelation and interconnections across spatial and temporal scales, among the social and biophysical dimensions of these systems. At the same time, river basin management aims to reconcile the spatial misfit problems (Moss, 2012) usually present in natural resources management.

Considering that hydrological systems do not just connect surface waters, the IWRM approach attempts to connect the stakeholders across the river basin, to understand the interrelations between the social and political systems, between the economy and environment.

IWRM is a planning and management approach that considers land and water resources relations. At the same time, IWRM acknowledges two fundamental features: First, the river basin is the appropriate management boundary due to the ecological, social, hydrological, and institutional relations embraced within these systems (Mollinga and Gondhalekar, 2014). Second, IWRM appeals to the multi-stakeholder participation in decision-making and public policy developments, which shapes new forms of water governance.

Although IWRM is widely accepted as the best water management approach worldwide, the implementation is still a challenge in diverse contexts (Nicol and Odinga, 2016; Clement et al., 2017; Alba and Bolding, 2016).

1.3 IWRM planning and the DPSIR framework

Attempting the development of planning tools to articulate the IWRM implementation at the European Union level, in 2003 the Water Framework Directive incorporated the Drivers-Pressures-State-Impact-Responses (DPSIR) framework (EC-EEA, 2003). This framework was developed to understand pressure impact relations and to monitor river basin management plans through sound scientific environmental indicators.

DPSIR was advertised as a causal framework that facilitates the understanding of relations between society and the environment (Smaling and Dixon, 2006). Two main features allowed its widespread use. First, the framework facilitates the organization of environmental indicators based on the political objectives targeting environmental challenges. Second, the framework focuses its attention on the assumed causal relationships. This is helpful for decision-makers designing policies to tackle the environmental issues they encounter (Smeets and Weterings, 1999).

On the other hand, DPSIR tends to grant more attention to the environment than to social considerations (Svarstad et al., 2008). DPSIR applications tend to ignore the fact that environmental changes usually have a larger impact on low-income and vulnerable social groups (Duraiappah, 1998). This can challenge the achievement of environmental justice, which focuses on redressing the environmental burden placed on low-income and minority communities, who are the most vulnerable groups usually impacted by human-driven environmental changes (Bullard, 2018). At the same time, DPSIR does not always consider that social groups are organized on a different scale. The lack of understanding of river basins as multi-scale social systems may represent a challenge at the time to employ this framework as a planning and management tool.

The second chapter of this Ph.D. thesis is a contribution to usually limited understanding of the social and ecological relations linked to the environmental modifications in river basin DPSIR applications. Moreover, we argue that spatial cause-effect considerations, and understanding the hydrological system as a multiscale system may enhance DPSIR water resources management applications.

1.4 Collaborative water governance and transdisciplinary learning communities

Conventional water resources policy developments mainly followed top-down structures in which the government and public officials hold authority and control of the water decision-making (Ansell and Gash, 2008). On the other hand, the IWRM approach incorporated participatory and collaborative forms of water governance.

Collaborative governance has been widely recommended to replace top-down and technocratic approaches. This means that all relevant stakeholders are involved in the development of water policies to reconcile environmental, economic, and societal goals (Ansell and Gash, 2008). Governance results from an interaction process between different actors confronted with a shared problem, in the search for synergetic solutions through the joint appreciation of different but complementary viewpoints (Gray, 1989; Gray and Purdy, 2018).

However, implementing this collaborative governance approach in river basin management may be challenging (Watson, 2004). The process might be quite demanding for the participants, as they have to be able to reflect on their—often implicit—assumptions concerning their views about how (water) problems have to be managed and analyze how different views affect each other and can be linked constructively to foster a shared vision. This implies that the knowledge generated by the water specialists has to be linked with the knowledge of their colleagues from other (human, social, economic, environmental…) disciplines and with the information, insights, and values of governmental, private, and civil stakeholders.

To stimulate social learning between researchers, public authorities, and other stakeholders involved in water management practices, with special attention for the vulnerable local communities, Chapter 3 suggests the transdisciplinary learning community approach. Transdisciplinarity refers to integrating different forms of knowledge from different academic disciplines and different social actors (policymakers, local communities, non-governmental organizations, companies…) in a joint knowledge production process (Craps, 2018a). The concept of learning communities is inspired by the situated learning theory of Lave and Wenger

(Wenger, 1999). In their conceptualization, communities do not refer to homogenous social or ethnic groups, but rather to emergent and informal groups of people—crossing the boundaries in and between existing organizations—that engage in shared efforts for collective learning (Craps, 2019). In this way, transdisciplinary learning communities aim at addressing the complex nature of water management and governance problems with which the most vulnerable social groups are confronted.

1.5 Framing water policy developments.

IWRM implies a form of water governance in which public participation is usually articulated through river basin committees. These committees are usually composed of stakeholders' representatives gathering in round tables of decision-making. However, one of the major challenges relies on the diversity of frames carried by stakeholders involved in these platforms.

Frames consist of individual mental understandings, interpretations, and simplifications of reality. The various disciplines, forms of expertise, and backgrounds involved in these multi-actor settings usually limit individuals to focus their attention on particular aspects of the situation, portraying separate understandings of the issues involved and how these should be addressed (Dewulf et al., 2011).

Effective decision-making in collaborative water governance relies upon connecting these diverse individual frames, the process usually referred to as framing or interactional frame (Dewulf et al., 2009). The connection of frames is a constructive form of dialog in which the participants provide meaningful contributions, which can be questioned by others, and through which the situation dealt with is explored, formulated, and reformulated in a productive way (Dewulf et al., 2011). Framing is a process required to reduce the ambiguity present in multi-actor settings (Dewulf et al., 2009). The connection of frames is the construction of a joint meaningful story in which the common ground is explored and negotiated. Framing is a process of knowledge co-production which may generate motivation and commitment to articulate collective action.

On the other hand, without proper management of the framing process, the participants may limit their attention to specific aspects of the situation, framing the water issues in divergent ways and telling contrasting stories about what is going on and what should be done. This results in different understandings, voices, and opinions around what the problem is about, and the specific situation these platforms are dealing with. Such fragmentation generates a specific kind of uncertainty on the issues to deal with, usually referred to as ambiguity (Craps and Brugnach, 2015). Ambiguity and uncertainty may turn the water decision-making into a potential minefield, from which the policy outcomes are full of big words lacking concrete choices (Dewulf, 2019).

Chapter 4 of this Ph.D. thesis aims to be a contribution to better understanding the drivers behind the fragmentation or connection of frames in a river basin management participatory process. Comprehending the drivers behind the framing process may be highly beneficial to improve the decision-making and policy developments in water resources management.

1.6 Case Study, the Katari River Basin

Located in Bolivia, South America, the Katari River Basin first called the attention of Bolivian national authorities in 2002 when rural indigenous communities located in the river basin downstream area began large protests due to severe contamination present in their region (CGEPB, 2014). Later in 2004, the Bolivian national law 2798 was promulgated. This declares the Katari River Basin "an environmental disaster zone and hydrological emergency" due to the extensive contamination resulting from the anthropogenic activities that had developed within its main tributaries. The relevance of this river basin has to be sought in the connection with Lake Titicaca, which is the highest navigable lake in the world, the largest freshwater lake in South America, and the most relevant water resource body in the Andes Region, into which the Katari river discharges (Revollo, 2001).

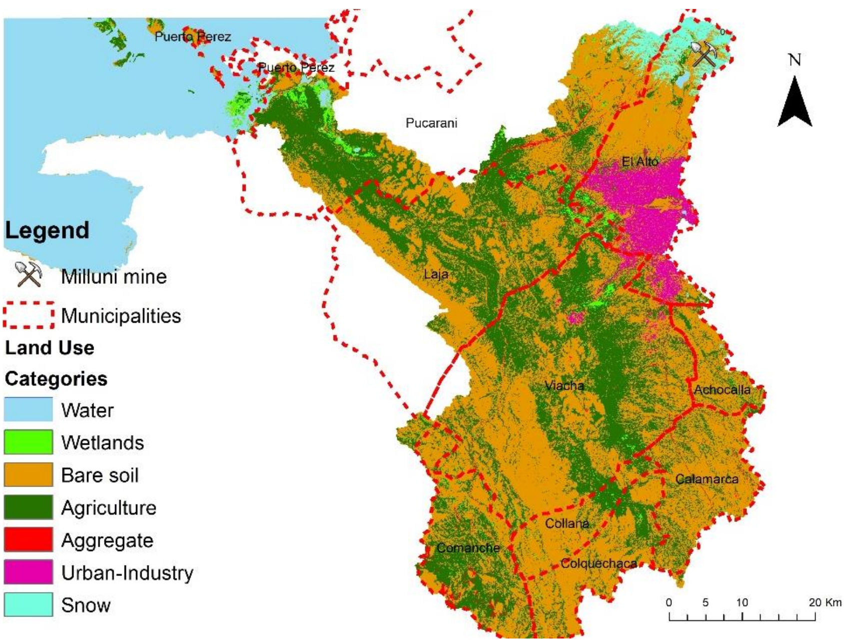

Figure 1: Katari River Basin

1.6.1 Katari River Basin hydroclimatic characteristics

The Katari river basin incorporates an area of 3006 km^2 with elevations ranging from 3800 meters to 5200 meters above sea level (m.a.s.l.) (Jhonatan et al., 2018). The climatic conditions are characteristic of the Andean highlands. The daily temperature fluctuates between -5 °C and 15 °C, which is explained by the high solar radiation present during the day at this high elevation. The average annual precipitation ranges between 470 to 742 mm, with the highest precipitation in the northeastern areas of the basin (Jhonatan et al., 2018).

Four main tributary rivers flow through this river basin: the Seco, Seke, Pallina, and Katari (Archundia et al., 2016). The source of the Seco and Seke rivers is the Cordillera Real. Downstream, the same rivers cross the city of El Alto and then discharge into Pallina river which flows through the city of Viacha. Later, the Pallina river flows into the Katari river, passing through rural agricultural areas. The Katari river enters the Cohana Bay and then discharges into Lake Titicaca. The Katari River Basin has an average river basin outflow at the discharge point of 7.7 m^3/s and is characterized by high seasonal fluctuations since it experiences rises by a factor of ~7 from dry to wet season (MMAyA, 2010).

1.6.2 Socioeconomic characteristics

This river basin represents the most populated river basin in Bolivia, home to approximately 1.3 million inhabitants, the region is characterized by one of the highest population growth rates in the world (Arbona and Kohl, 2004). During the 1970s and 1990s, the river basin received substantial migration from rural indigenous communities from the north-eastern Bolivian Andes. The increasing population has led to the establishment of factories, mining activities, tanneries, slaughterhouses, and agriculture, which all put a large amount of pressure on water resources. These activities have damaged the water quality of the basin.

The Katari River Basin can be structured in three main regions of anthropogenic influence: (1) Milluni valley, (2) El Alto, and Viacha, and (3) the Katari rural lowlands, (see Figure 4, Chapter2).

The Milluni valley is situated at the highest location of the Katari River Basin. This region, which is located at 4450 meters above sea level, was affected by the exploitation of tin, lead, and zinc, which was initiated in 1920 through a private enterprise named "Fabulosa Mine Consolidated", which was owned by British shareholders (Archundia et al., 2017). Later, from 1975 to 1986, the Bolivian company COMSUR continued its operations. Currently, the mine is not under an official concession contract (Salvarredy-Aranguren et al., 2008).

Over 90 years of mining operations in the Milluni sub-basin have left a legacy of water contamination. Local geology holds a high concentration of sulfide minerals. When the minerals are exposed to the atmosphere (oxygen and water), which happens in conventional mining processes, they are a constant source of acid mine drainage. The low pH of the acid mine drainage enhances conditions for the incorporation of dissolved metals in the water.

Downstream of the Milluni valley, the second region is characterized by the presence of urban and industrial developments within the cities of EL Alto and Viacha. The accelerated migration rate generated limited city planning, which resulted in deficient sanitation services, a limited solid waste system, and insufficient control over industrial activities. Consequently, these activities translate to untreated urban wastewater, solid waste, and industrial waste discharges over the rivers crossing these cities. After crossing El Alto, the Seco and Seke rivers qualify as eutrophic waters due to the high concentration of nutrients and low dissolved oxygen concentration (Archundia et al., 2017). The anthropogenic influence of the city of El Alto also incorporates high fecal contamination to concentrations that are harmful to public health.

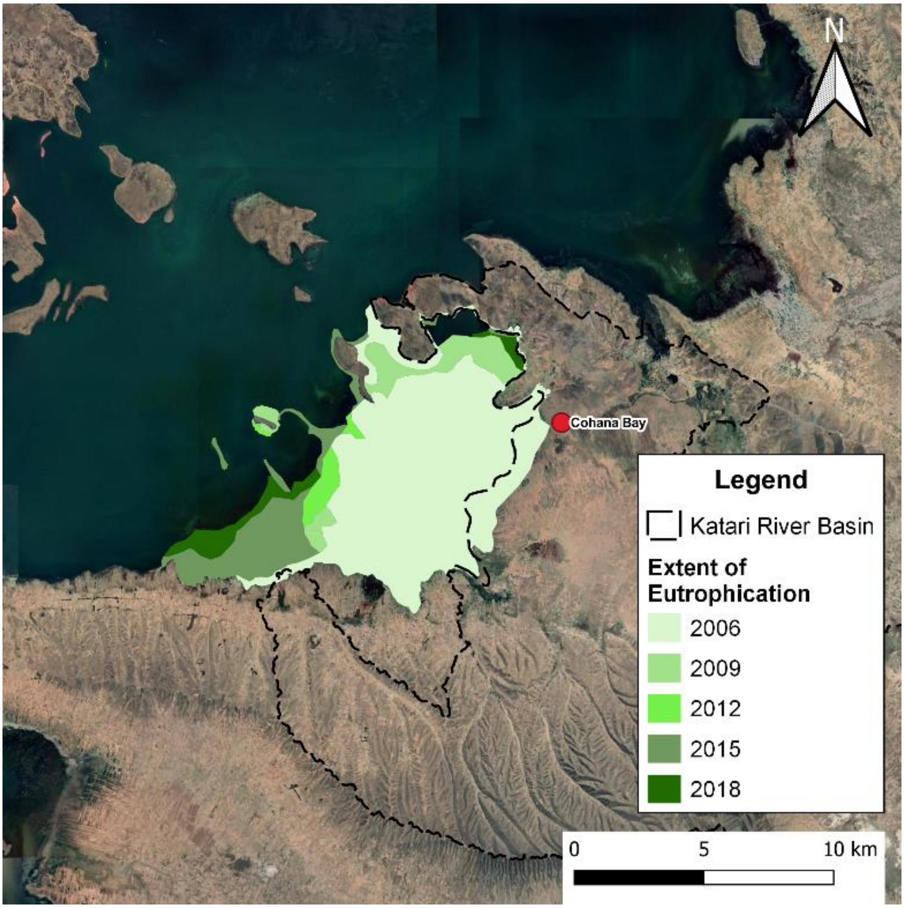

Figure 2: Extent of eutrophication in the KRB discharge area, from Baltodano et al., (2021).

The third sub-region of study consists of rural Andean indigenous communities whose livelihood depends on agriculture in the area. Their main activity is livestock farming and small-scale diary production in the region.

The anthropogenic developments within these regions resulted in severe socio-ecological impacts over rural indigenous communities and the ecosystem in the river basin downstream area. The most evident impact is the large presence of eutrophicated waters at the river basin discharge area, in lake Titicaca, which reflects an extension of 82 km^2 in 2018 (Baltodano et al., 2021), see Figure 2.

1.7 Research Aims

The main objective of this Ph.D. project is to contribute to a better understanding of the social and environmental relations within the planning and decision-making process in the IWRM paradigm. In this study, the first chapter discusses the potential benefits of including social and spatial characteristics in the DPSIR framework applications. Then, the second chapter explores the transdisciplinary learning communities in collaborative water governance as an approach to include vulnerable social groups in the decision-making processes to deal with the wicked nature of socio-ecological systems. The third chapter discusses the framing process in collaborative water governance to reduce the uncertainty and ambiguity behind the decision-making process and water policy developments. Finally, the fourth chapter presents the general conclusions.

The research questions of this study are the following:

1. How can the socioecological driver-impact relations be better understood, and be part of a shared vision within a multistakeholder setting in river basin management?
2. How can we integrate the diverse forms of knowledge, disciplines and backgrounds in a society, policy, and science interface? How can they improve decision-making and policy developments?

At the same time, the following are the research questions structured in each chapter:

Chapter 2:

How can the DPSIR spatial analysis enhance river basin policy management? How does the inclusion of a scale analysis within DPSIR applications influence the understanding of a river basin process? How may an environmental justice approach of the DPSIR framework enhance policy targets to reduce the burdens over the most vulnerable social groups?

Chapter 3:

What are the linkages between collaborative water governance and the transdisciplinary approach? How does the transdisciplinary learning community approach consider the complexity of the water problems caused by social, hydrological, and ecological system imbalances? How may the transdisciplinary learning community approach enhance the understanding and wicked nature of river basins?

Chapter 4:

What are the causes behind the fragmentation and connection of frames in collaborative water governance settings? How do the context and decision-making design influence the fragmentation/connection of frames? How may the fragmentation/connection of frames shape the decision-making process outcome and results?

Chapter 2

Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins. Case study of the Katari River Basin, Bolivia

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The drivers–pressures–state–impact–responses (DPSIR) framework has been used widely to support environmental policy developments. However, we argue that DPSIR tends to oversimplify the complexity behind socio-ecological systems. Based on the Katari River Basin in Bolivia, we explore how the incorporation of spatial and social considerations may enhance DPSIR applications. The results reveal a spatial mismatch between driving forces/pressures and policy responses, and severe impacts on the vulnerable communities. Moreover, we also show that local levels tend to be neglected. The study concludes that integrating spatial and social characteristics in the DPSIR may result in valuable implications for river basin management practitioners.

2.1 Introduction

River basins represent highly complex socio-ecological systems with diverse interrelations between their physical, chemical, biological and socio-economic processes. The anthropogenic developments within these systems tend to exert environmental pressure resulting in diverse environmental effects (Elliott, 2002), which in turn can jeopardize longer term socio-economic development. Rivers connect human communities and places and play an important role in reproducing social values, cultural beliefs and forms of life (Anderson et al., 2019). Hence, the study and management of river basin systems requires information related to human and environmental links. It should also combine natural and social sciences in formulating solutions linked to the problems of socio-environmental nature (Gregory et al., 2013). A socio-ecological systems approach contributes to enhancing the understanding between water and society (Everard, 2019).

To connect the social and environmental systems, conceptual frameworks have been developed to examine, understand and visualize how both systems interact and how decision-making will influence these links and the outcomes. In early 1990s, the drivers– pressures–state–impact–responses (DPSIR) framework was developed to organize essential information in a set of indicators to support decision-making processes and policy developments in a meaningful sense (OECD, 2003). Since 1995, the European Environmental Agency (EEA) and Eurostat have largely applied this framework to organize environmental indicators and statistics (Smeets and Weterings, 1999). In 2003, DPSIR was also incorporated in the Water Framework Directive as part of the Common Implementation Strategy promoted by the European Commission (EC-EEA, 2003) in order to evaluate and design river basin management plans following the integrated water resource management approach. The introduction of DPSIR and its explicit connection between society and ecosystems in water management mirrored a broader and ongoing paradigm shift in water management: away from water as a production factor in a system to be developed and towards water as a fundamental component of ecosystems and their services to society and economy.

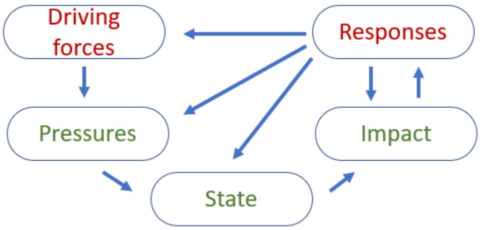


Figure 3: Drivers Pressures State Impact Response framework

As shown in Figure 3, the EEA presents the DPSIR framework as a causal model in which the driving forces, which may be of social and/or economic nature, exert pressures on the environmental system. These pressures translate into changes in the natural state leading to environmental impacts which may cause societal responses (Smeets and Weterings, 1999).

The DPSIR was advertised as a causal framework that facilitates the understanding of relations between society and the environment (Smaling and Dixon, 2006). Two main features allowed its widespread use. First, the framework facilitates the organization of environmental indicators based on the political objectives targeting environmental challenges. Second, the framework focuses its attention on the assumed causal relationships. This is helpful for decision-makers designing policies to tackle the environmental issues they encounter (Smeets and Weterings, 1999).

The DPSIR framework has been applied to diverse environmental research studies such as environmental degradation (Agyemang et al., 2007), reef fisheries (Mangi et al., 2007) and management of marine environments (Atkins et al., 2011; Sundblad et al., 2014). However, despite its wide application by practitioners and acceptance of international development agencies worldwide, the framework tends to oversimplify the complex reality of socio-ecological systems (Gobin et al., 2004; Niemeijer and de Groot, 2008).

The DPSIR grants more attention to environmental than to social considerations (Svarstad et al., 2008). Its applications tend to ignore the fact that environmental changes usually have a larger impact over low-income and vulnerable social groups (Duraiappah, 1998). This can challenge the achievement of environmental justice, which focuses on redressing the environmental burden placed on low-income and minority communities, who are the most vulnerable groups usually impacted by human-driven environmental changes (Bullard, 2018). Furthermore, by usually placing attention to the highest levels of decision-making and ignoring the local levels, the DPSIR framework implicitly creates a hierarchy of actors, which can reproduce inequalities between stakeholders and actors within the system (Carr et al., 2007). The analysis of scales may be beneficial in order to consider an individual assessment of socio-environmental processes at the scale at which they operate and to associate them with different levels of administration and social organization (Leemans and De Groot, 2003). Neglecting these crucial aspects heavily compromises the sustainable development of socio-ecological systems. On the contrary, the maintenance of essential ecological processes and life support systems contributes to sustainable development because it allows the present and future generations to meet their needs (Brundtland et al., 1987).

The complexity of the socio-environmental systems relies on several layers of social, political and economic institutions, and the environmental consequences behind their interactions (Teodosiu et al., 2009). Rather than simplify this complex reality, the sustainability of a socio-environmental system depends on the dissection of its complexity, and on the detailed understanding of the relations between its subsystems and their variables (Ostrom, 2009). Embracing the complexity of the connection between the social and the environmental system is crucial for sustainable development (Carr et al., 2007). Human systems are a fundamental component of socio-environmental systems, holding the capacity to shape environmental changes (Cote and Nightingale, 2012). Thus, they may not be conceived as isolated from each other with conflicting interests. One of the mechanisms to manage the relationship between human and socio-environmental systems in a mutually beneficial manner is through appropriate environmental policies (Jordan, 2001). However, they can at times lack a long-term vision which might then negatively influence the desired sustainable development outcome (Pezzey, 2004).

In this article we thus propose the incorporation of spatial and social considerations in the DPSIR framework for the policy development of river basin management. We aim to illustrate how the incorporation of these elements can contribute to a more effective and sustainable river basin management policy, with more attention devoted to the interests of the most vulnerable local actors. To that end, we analyse how social and environmental aspects are intimately intertwined in the Katari River Basin in Bolivia. This watershed is heavily contaminated due to mining, industrial, urban and agricultural developments, which have had a significant environmental and social impact.

In the methodology section we present a semi-quantitative method to identify the relation between driving forces/pressures and policy responses. Moreover, we also introduce how social characteristics were incorporated. This is based on the scalar analysis and assessment of impacts over vulnerable communities linked to the environmental changes. The results section is organized based on the three key regions within the Katari River Basin case study in order to provide a detailed analysis of the process reproducing environmental impacts. In the discussion section we analyse how the inclusion of spatial and social characteristics influences river basin policy developments and their potential implications. Furthermore, we attempt to answer the following questions: How can the DPSIR spatial analysis enhance river basin policy management? How does the inclusion of a scale analysis within the DPSIR applications influence the understanding of a river basin process? How may an environmental justice approach of the DPSIR framework enhance policy targets to reduce the burdens over the most vulnerable social groups? In the final section, we present our conclusions regarding these questions.

2.2 Methodology

2.2.1 Case Study: Katari River Basin

The Katari River Basin was identified for several reasons as an adequate case study to understand how social and spatial characteristics may influence the DPSIR framework. First, the case represents the most populated river basin in Bolivia, home to approximately 1.3 million inhabitants, and the region is characterized by one of the highest population growth rates in the world (Arbona and Kohl, 2004). During the 1970s and 1990s, the river basin received substantial migration from rural indigenous communities from the north-eastern Bolivian Andes. Currently, more than 93% of the population is located in urban areas upstream, leading to an important asymmetry between rural and urban communities. Second, the rapid population growth has generated three main anthropogenic pressures on the river basin system: housing, industry and agriculture. Indeed, the rivers incorporated in the system collect the major part of the contamination produced by these human developments upstream, which affects the socioenvironmental conditions of the system downstream. Third, the river basin discharges its outflow in Titicaca Lake, which is the most important water resource in the Andes Region. Fourth, for over 15 years, local, regional, national and international agencies invested in river basin management policies to improve the situation of this river basin. However, recent studies show that contamination remains a significant problem (Agramont et al., 2019; Archundia et al., 2017).

The Katari River Basin can be divided into three regions based on the main anthropogenic developments within the system (Archundia et al., 2017). The first region is characterized by the presence of mine waste accumulated from over a century of mining activities. The second region incorporates urban and industrial settlements allocated in the cities of El Alto and Viacha. The third region is mainly characterized by the presence of rural communities that currently practice agriculture and cattle-raising as their main form of livelihood.

The Katari River Basin first called the attention of national authorities in 2002 when rural indigenous communities located in the third region began large protests due to severe contamination (CGEPB, 2014). Since 2004, various environmental policies have been developed, and partially implemented, with the aim to restore the system. Despite these efforts, the ecological degradation of the past decades has not been reversed.

Methods: a modified DPSIR analysis

In order to apply the DPSIR analysis to the Katari River Basin case study, data related to the driving forces (D), pressures (P), impacts (I) and policy responses (R) were collected through a secondary data review of public policies, official government reports and scientific publications (see Table 1). Furthermore, to collect data associated to the changes in the environmental state, a water quality monitoring campaign was implemented in alliance with the Bolivian Ministry of Water and Environment in May 2019. Additional data related to the water quality environmental state changes were collected through a secondary data review of scientific research in this field. The analysis of changes in the environmental state were presented based on surface water quality indicators referenced under the Bolivian environmental regulations.

Table 1: Reports and publications employed for the analysis

DPSIR element	Sources
Driving forces and Pressures	Archundia, D., Duwig, C., Spadini, L., Uzu, G., Guédron, S., Morel, M., . . . Martins, J. (2017). How uncontrolled urban expansion increases the contamination of the titicaca lake basin (El Alto, La Paz, Bolivia). Water, Air, & Soil Pollution, 228(1), 44. CGEPB. (2014). Informe de Auditoría Sobre el Desempeño Ambiental Respecto de la Contaminación Hídrica en la Cuenca del Río Katari y la Bahía de Cohana MMAYA. (2010). Plan Director de la Cuenca Katari PDCKYLM. (2018). Plan Director de la Cuenca Katari y el Lago Menor
State	Vice Ministry of Water Resources (2019), Katari River Basin Water Quality Spreeadsheet May 2019. Archundia, D., Duwig, C., Spadini, L., Uzu, G., Guédron, S., Morel, M., . . . Martins, J. (2017). How uncontrolled urban expansion increases the contamination of the titicaca lake basin (El Alto, La Paz, Bolivia). Water, Air, & Soil Pollution, 228(1), 44.
Impacts	CGEPB. (2014). Informe de Auditoría Sobre el Desempeño Ambiental Respecto de la Contaminación Hídrica en la Cuenca del Río Katari y la Bahía de Cohana Rodrigo, G., Escobar, M., Ortuño, T., Isela, R., Becerra, C., Choque, R., & Ibañez, C. (2018). Contaminación por metales pesados y su efecto sobre organismos vivos en un gradiente de la cuenca Katari [Book].
Responses	CGEPB. (2014). Informe de Auditoría Sobre el Desempeño Ambiental Respecto de la Contaminación Hídrica en la Cuenca del Río Katari y la Bahía de Cohana MAYA. (2018). Informe de Actividades, Resultados, Ejecución Presupuestaria Gestión 2018 y Planificación de la Gestión 2019 de la Unidad de Gestión de la Cuenca Katari

	MAYA. (2019). Detalle de Actividades, Acciones y Proyectos Implementados, en Ejecución Además de Gestionados por la Plataforma Interinstitucional del PDCK y LMT. Katari River Basin General Assembly December 13th, 2019. Katari River Basin Management Unit Plan progress presentation

In order to understand how spatial and social characteristics may influence the sustainability of the river basin's policies, this research incorporated two complementary features in the Katari River Basin's DPSIR framework application. First, the spatial analysis was included to understand the relations between policy responses and the driving forces/pressures. Second, social considerations were incorporated into the DPSIR framework categories.

To provide a spatial dimension to the driving forces and pressures within the Katari River Basin, a land-use map of the watershed was performed. To develop the land use pattern of the Katari River Basin, an unsupervised image classification employing ArcMap 10.2 iso clustering and maximum likelihood tool was applied to a 2 m resolution Sentinel 2-A satellite image. At the same time, driving forces (land-use patterns) and the local administrative jurisdictions were overlapped to identify the links between sources of environmental degradation and the local managerial jurisdiction. To spatially assess the responses, a secondary data review of policies implemented in the Katari River Basin for the period 2004–19 was applied. This policy analysis identified the spatial allocations where these responses/measures were implemented. Moreover, the policy analysis also identified the stakeholders that implemented the responses. The DPSIR spatial analysis incorporated the assessment of the relationship between policy responses and driving forces, to facilitate assessment of the sustainability of river basin management efforts. Responses spatially directed to manage environmental driving forces, which are the sources of the problems, were considered as more sustainable and effective in the long term in comparison with measures to handle other elements of the framework such as impacted regions, which deal more with short-term symptoms.

To incorporate social characteristics, two additional aspects were included in the adapted DPSIR framework: the social impacts related to environmental services and the scalar configuration. First, environmental services refer to environmental functions and their capacity to provide natural resources upon which the livelihood of communities depends, the influence on public health, and the local socio-economic links (Reid et al., 2005). To identify changes in environmental services influenced by the modification of the Katari River Basin environmental state, we applied a secondary data review of official reports and scientific publications recalling shifts in the local livelihood and local public health issues. Furthermore, to articulate the environmental justice approach, this analysis focused on vulnerable communities subject to such modifications, which are located in the third region of the Katari River Basin. Consequently, the literature review paid special attention to stakeholders living in the rural communities located downstream from the main environmental driving forces and pressures that heavily increase their local vulnerability. These communities are a minority group in relation to the population of the entire socio-ecological system.

Second, the scalar configuration refers to the different public management layers according to which the social system is organized and structured. In order to incorporate the scales, this research distinguished different public management layers related to the Katari River Basin and identified the driving forces/pressures level at which the processes took place. Moreover, through a secondary data review, this research also assessed the scale at which the policy responses for the period 2004–19 were developed and implemented. The analysis is based on the relation of the level at which driving forces take place and the managerial level at which policy responses are developed and implemented.

In order to better understand the socio-ecological system, the driving forces/pressures and policy responses were initially analysed separately for each of the three regions: the mining region, the urban–industrial region and the agricultural region. This separate analysis allowed one to comprehend the nature of the anthropogenic development, its spatial allocation, the management jurisdiction and the responses implemented to manage these developments. However, to understand the upstream–downstream relationships and the linkages within the socio-ecological system, the environmental state modification and socio-ecological impacts assessed the nexus among the three regions under study.

2.3 Results

2.3.1 Katari River Basin´s spatial and social DPSIR analysis

Figure 4 presents the results of the land-use assessment in the river basin. It shows the spatial location of the environmental driving forces: mining at the north-east region below the glacial zone, housing and industry in the cities of El Alto and Viacha, and agricultural practices that incorporate cattle-breading and crops in the municipalities of Pucarani, Laja and Viacha, which are mainly composed of rural indigenous communities. Although 10 municipalities share spatial jurisdiction within the Katari River Basin, the main process taking place incorporates just five of these municipalities: El Alto, Viacha, Laja, Pucarani and Puerto Perez.

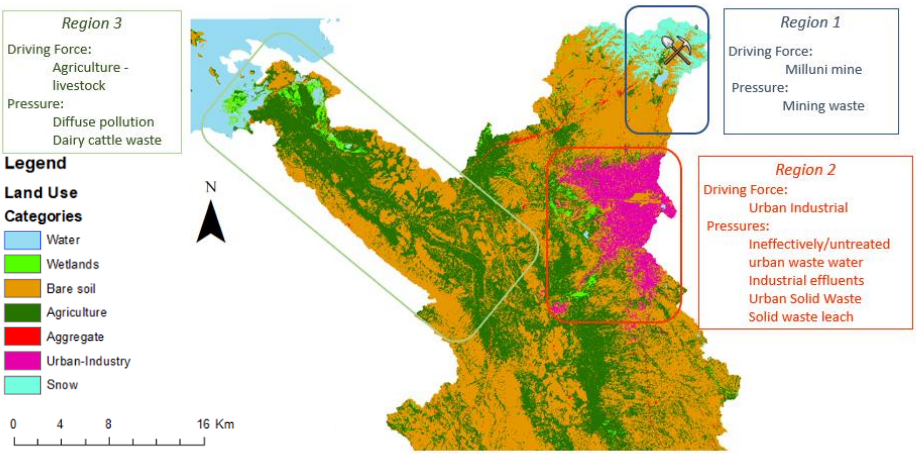


Figure 4 : Katari River Basin and regions of anthropogenic influence

The scalar configuration for the Katari River Basin is composed of five layers of formal management. At the highest level, the governments of Bolivia and Peru created the Lake Titicaca Binational Autonomous Authority (LTBAA) international agency[1]. The second layer is comprised of the Ministry of Water and Environment (MWE). In 2016, the MWE developed a specific decentralized arm named the Katari River Basin Management Unit to implement the river basin plan which was developed in 2010 and officially launched in 2016. The third layer is the State Autonomous Government of La Paz. The state government incorporates the State Secretariat for the Rights of Mother Earth, which is the unit responsible for regulating the environmental issues in all provinces within the state of La Paz. The fourth layer is composed of the municipal

[1] This agency was created to promote and conduct action programs and projects; and to develop and monitor the ordering, control and protection regulations for the Titicaca lake management.

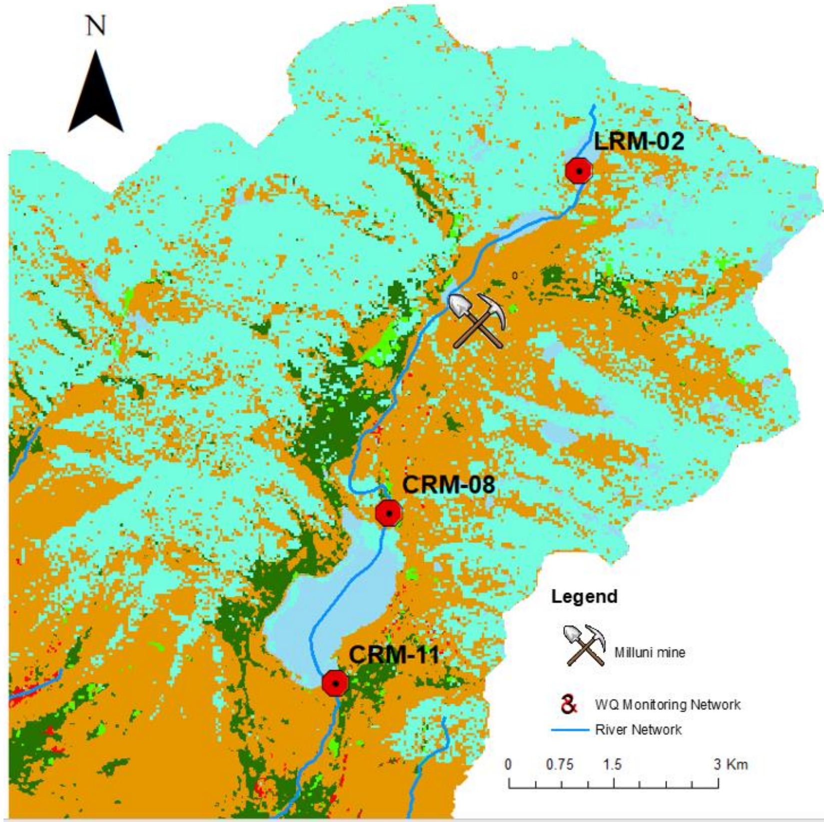
governments of El Alto, Viacha, Laja, Pucarani and Puerto Perez. Based on the current legal framework, all these municipal governments are granted environmental and water services management responsibility under their specific jurisdiction.

The DPSIR analysis was developed separately for the three regions in the Katari River Basin. We will first present the spatial distribution of environmental driving forces and the pressures. This will be followed by a discussion of the changes in the environmental state in terms of water quality indicators as well as their social and environmental impact. Finally, policy responses developed for the period 2004–19 will be analysed to assess the spatial match with driving forces/pressures within each region.

Region 1: The Milluni Valley

The first region, at the highest river basin section, corresponds to the Milluni Valley at 4450 masl. In this region, mining operations started in the 18th century. In the 1920s, La Fabulosa Mine Consolidated, a private enterprise owned by British shareholders, accessed the first concession contract to exploit tin, lead and zinc (Salvarredy-Aranguren et al., 2008). Later, from 1975 to 1986, a public company, COMSUR, operated the mine. At present, most of the mineral's reservoirs have been exploited, and the Milluni mine is not under an official concession contract anymore. However, more than a century of operations left a legacy of environmental problems in the river basin.

Figure 5 shows the land-use patterns and the water quality monitoring network in the Milluni Valley, as well as water quality indicators in three monitoring stations. At LRM- 02, close to the Huayna Potosi glacial, water quality is the highest of the whole hydrological system. This is reflected by the majority of water quality parameters being under permissible levels according to Bolivian water environmental legislation. However, below this point there is a major environmental pressure consisting of 2 million m^3 of mining waste composed of sulphide minerals generated by the Milluni mine (CGEPB, 2014). When exposed to the atmosphere, this mining waste produces constant acid mine drainage. Due to the composition of the acid mine drainage, the environmental state of the water resources in the region and downstream has been heavily modified.



Monitoring Station	EC µS/cm	pH -	As mg/L	Al mg/L
	Class A 0 to 140 Class B >140 to 300 Class C >300 to 500 Class D >500 to 1600 Critical > 1600	Class A 6.0 to 8.5 Class B >8.5 to 9.0 Class C >8.5 to 9.0 Class D >8.5 to 9.0 Critical < 6 y > 9	Class A 0 to 0.05 Class D 0.05 to 1.0 Critical > 1.0	Class A 0 to 0.2 Class B 0.2 to 0.5 Class C 0.5 to 1.0 Critical >1.0
LRM-02	75.5	8	0.01	0.04
CRM-08	1392	2.84	0.79	1.75
CRM-11	1161	2.78	0.05	1.27

Monitoring Station	Cd mg/L	Fe mg/L	Zn mg/L	Mn mg/L
	Class A 0 to 0.005 Critical > 0.005	Class A 0 to 0.3 Class C 0.3 to 1.0 Critical > 1.0	Class A 0 to 0.2 Class C 0.2 to 5.0 Critical > 5.0	Class A 0 to 0.5 Class B 0.5 to 1.0 Critical >1.0
LRM-02	0.002	0.53	0.03	0.33
CRM-08	0.111	128.14	31.65	7.27
CRM-11	0.054	45.22	17.02	3.5

Figure 5: Milluni Valley

The effects are more significant at the Milluni dam, which is the second most important reservoir in the region, with the capacity to store 10.3 million $\boldsymbol{m^3}$. This water reservoir is employed to supply drinking water to the cities of El Alto and La Paz through the Alto Lima and Chuquiaguillo treatment plants, respectively. The water quality at the Milluni dam, measured at CRM-11, holds high levels of acidity and high electrical conductivity. Under the local regulations, these waters cannot be used for any purposes and represent a high risk to public health. Furthermore, high levels of aluminium, arsenic, cadmium, manganese and zinc were also detected there.

Furthermore, a large heavy metal concentration coming from upstream can be observed in sediments downstream. The sediments evaluated in regions 2 and 3 exceeded heavy metal permissible levels established by the Environmental Protection Agency 2002 and were composed by arsenic, copper, mercury, chrome, lead and zinc (CGEPB, 2014). Furthermore, heavy metals contamination was also found in local fauna and flora present in region 3 in a form of xenobiotic content, and thus potentially in the local food chain (Gloria Rodrigo, 2018).

Concerning the responses linked to the Milluni mine, the analysis for the period 2004–18 reveals only two responses that were actually implemented. First, the local water operator channelled the clean water upstream from the Milluni mine to bypass the mine waste area and to avoid the contamination of the surface water (Pérez, 2017). During the wet season, the channelized water is employed to supply the water operator’s drinking water plant. However, the bypass channel flow is insufficient to supply the demand in the dry season. As a result, the drinking water operator mixes waters from the bypass channel and the contaminated Milluni dam outflow to meet the demand. To neutralize high acidity present in the dam outflow, the drinking water operator incorporated a pre-treatment process, which constitutes the second response. This additional process clearly increases the operational costs for the production of drinking water. The pre-treatment plant later delivers neutralized water to two drinking water treatment plants where metals are sedimented. Ironically, while these two drinking water treatment plants remove the heavy metal contamination from the raw water to provide safe drinking water to the cities of La Paz and El Alto, the facilities discharge the removed toxicological content to the surface water bodies neighbouring the drinking water plants (Pérez, 2017), increasing the social and environmental impacts downstream.

These two responses (bypass and pre-treatment) can be classified as impact responses since they deal with issues of the already contaminated surface water rather than the source of the environmental problem itself. Managing the mining waste could be a beneficial policy response for the whole river basin since it would result in a better drinking water quality for the cities of El Alto and La Paz, and in the control of the socioenvironmental impacts for the indigenous rural communities downstream and around Titicaca Lake.

Based on the 2014 National Comptroller environmental audit, the responsibility for the lack of measures to improve and restore the environmental impacts produced by the Milluni passive mine waste can be assigned to the Ministry of Mining and Metallurgy, the Ministry of Water and Environment, and the State Government of La Paz and the Municipal Government of El Alto. The results of this environmental audit state that:

> *"… the Ministry of Water and Environment, the Ministry of Mining and Metallurgy, and the State Government of La Paz did not develop actions tending to improve and restore the environment affected by the Milluni passive waste. On the other hand, the Municipal Government of El Alto has worked on the interinstitutional coordination, partially developing actions related to the issue"*

The National Comptroller requested the Ministry of Water and Environment, the Ministry of Mining and Metallurgy, the State Government of La Paz and the Municipal Government of El Alto to report their actions to manage, reduce or mitigate the environmental problems caused by the Milluni mine. Their reports not only reveal a lack of effectiveness of the environmental policies they developed and implemented, but also limited coordination between these governmental agencies (CGEPB, 2014). This shows a significant problem of governance at the river basin scale.

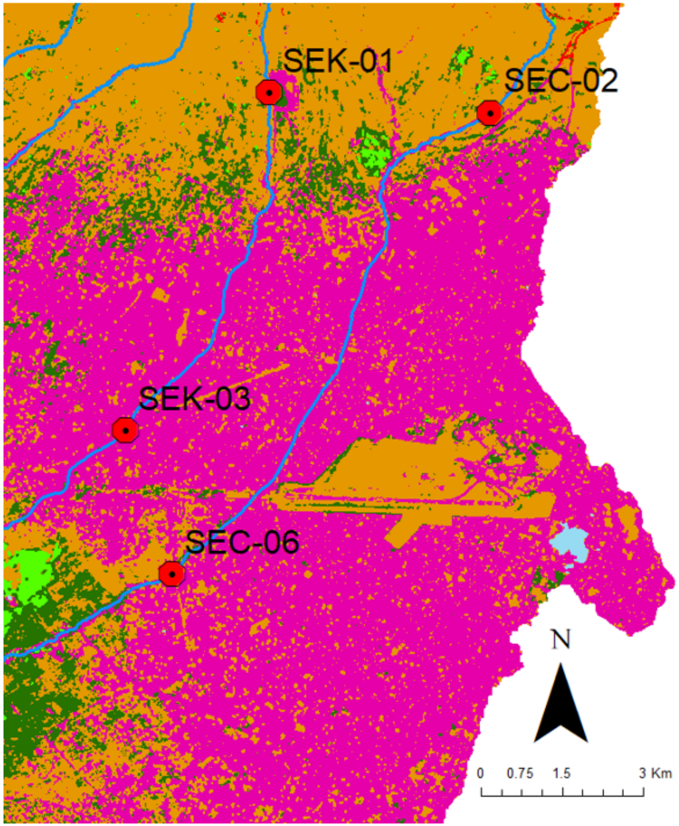
Region 2: Urban industrial area El Alto - Viacha

The second region is characterized by the presence of major urban settlements mixed with industry randomly distributed within the cities of El Alto and Viacha. El Alto and Viacha hold the largest population size representing 93.4% of the residents within the Katari River Basin (PDCKYLM, 2018). The city of El Alto was initially planned to be an industrial park for the neighbouring capital La Paz. However, since then, it has experienced substantial immigration rates (Arbona and Kohl, 2004), which have not been accompanied by appropriate infrastructure and management developments. Consequently, the Katari River Basin suffered considerable environmental degradation due to a lack of wastewater services, industrial environmental control and monitoring, and proper urban solid waste management (Chudnoff, 2009).

The environmental pressures produced by the urban and industrial forces incorporate four types of burdens: household wastewater, industrial liquid discharges, urban solid waste and land field leach disposed of in the rivers crossing the cities of El Alto and Viacha. First, the cities of El Alto and Viacha jointly discharge 20 million $m^3/year$ of untreated or ineffectively treated urban wastewater to the Seke and Seco rivers (CGEPB, 2014) increasing by seven times the rivers' natural flow irrespective of the season (Duwig et al., 2014). As a result, the Seke river receives 20 Tn/year of organic pollutants in terms of Chemical oxygen demand and Biological oxygen demand increasing 8 and 12 times the concentrations of these two indicators, respectively. Moreover, the Seke River discharges more than 160 Tn/year of total dissolved solids, which include the presence of dissolved heavy metals. Furthermore, this river releases close to 1 Tn/year of nutrients, nitrogen and phosphorus, raising the total nitrogen concentration 24 times (CGEPB, 2014). The Seco River further receives 8,000 Tn/year of organic pollutants, chemical oxygen demand and biological oxygen demand, increasing 58 and 22 times the concentrations of these two indicators, respectively. The Seco River releases more than 30,000 Tn/year of total dissolved solids and over 400 Tn/year of nutrients in the form of nitrogen and phosphorous (CGEPB, 2014). For instance, Seco river increases 55 times the total nitrogen concentration after crossing this region. Furthermore, both rivers, Seco and Seke, experience an exponential increase in fecal coliform contamination and electrical conductivity, and a significant reduction of dissolved oxygen. These results are qualified as critical according to the Bolivian surface water quality regulations meaning that these waters cannot be employed for any purpose. Figure 5 shows in detail the environmental state changes before and after crossing the urban-industrial region based on surface water quality indicators.

The Puchukollo wastewater treatment plant (WWTP) is the only system processing urban wastewater produced by the city of El Alto. Nevertheless, this WWTP holds a capacity to treat less than 50% of the urban liquid wastewater generated by El Alto (Archundia et al., 2017). Therefore, considering a population close to 1 million inhabitants, there is an alarming volume of untreated urban wastewater discharged in this Second Region. To increase the complexity, the unique WWTP in El Alto also receives effluents generated by diverse industries settled within this city. Some factories are connected to the household sewer system under an agreement contract between the local water operator and the industries without significant control or monitoring (CGEPB, 2014). Consequently, the Puchukollo WWTP not only has insufficient capacity to treat El Alto urban wastewater, but also is further overwhelmed by industrial wastewaters delivered to this facility without previous announcement or coordination (PNUMA, 2011).

The solid waste management represents another crucial environmental pressure in this region. The urban solid waste recollection service in El Alto has a service coverage of only 63.5% of the city. As a result, the city annually releases 800 Tn of solid waste over the rivers (PDCKYLM, 2018). Due to the marked seasonality in the river basin, the accumulated solid waste is carried downstream during the rainy season, traveling through the rural communities to be finally delivered to the Titicaca Lake. Additionally, the land fields collecting the urban and industrial solid waste of El Alto and Viacha, Villa Ingenio and Santa Barbara, respectively, discharge a significant volume of the land field leach over the rivers crossing these cities, incorporating high organic content and heavy metals among other contaminants (CGEPB, 2014), see Figure 6.



	Monitoring Station	EC µS/cm	OD %	pH -	Fecal Coliforms MPN/100mL
		Class A 0 to 140 Class B 140 to 300 Class C 300 to 500 Class D 500 to 1600 Critical > 1600	Class A >80 Class B 70 to 80 Class C 60 to 70 Class D 50 to 60 Critical < 50	Class A 6.0 to 8.5 Class B 8.5 to 9.0 Critical < 6 y > 9	Class A 0 to 5 Class B 5 to 200 Class C 200 to 1000 Class D 1000 to 5000 Critical > 5000
Seke River	SEK-01	324	99.9	5.16	23
	SEK-03	1188	60.6	8.63	>1100
Seco River	SEC-02	72.6	103.4	7.21	43
	SEC-06	806	60.4	8	>1100

	Monitoring Station	N_T mg/L	NH_3 mg/L	BOD_5 mg O_2/L	COD mg O_2/L
		Class A 0 to 5 Class B 5 to 12 Critical > 12	Class A 0 to 0.05 Class B 0.05 to 1.0 Class C 1.0 to 2.0 Class D 2.0 to 4.0 Critical > 4.0	Class A 0 to 2 Class B 2 to 5 Class C 5 to 20 Class D 20 to 30 Critical > 30	Class A 0 to 5 Class B 5 to 10 Class C 10 to 40 Class 40 to 60 Critical > 60
Seke River	SEK-01	3.2	2.23	62	102
	SEK-03	76	59.94	779	782
Seco River	SEC-02	0.15	0.08	15	9
	SEC-06	55	39.03	335.6	520

Figure 6: Urban-Industrial region

The social and environmental impacts caused by the industrial-urban region is worsened by the mining impact upstream in region 1 and becomes manifest in the region downstream. Consequently, this driving force can be considered an indirect driving force for the rural indigenous communities in region 3. The socio-environmental impacts, product of the aggregated driving forces from regions 1 and 2, will be further discussed in the following section.

An analysis of the policy responses in the period of 2004 -18 shows a limited focus on only one of the four environmental pressures within this region, namely urban wastewater. Furthermore, only three measures were implemented in that period. First, in 2008, the Vice-Ministry of Drinking Water and Sanitation carried out a project to increase the Puchukollo WWTP's capacity. However, this project has not been entirely implemented and has resulted in an increase of only 5% of Puchukollo's processing capacity (CGEPB, 2014). Second, although the MWE accessed funding to develop a second urban waste water treatment plant in the city of El Alto in 2014, rural communities neighbouring the water works rejected the project (ERBOL, 26/05/2015). Unfortunately, due to the continuous attempts on behalf of the local communities to prevent its construction, this infrastructure has not yet been developed (Página7, 30/01/2018). Third, in 2016 the Central Government provided the funding for and implemented the construction of the first water treatment plant in the city of Viacha. It is expected that this infrastructure will initiate its operation in the second semester of 2020.

The policy responses implemented during the period 2004-19 spatially located in the urban-industrial region reflect a significant focus on wastewater infrastructure developments in the cities of El Alto and Viacha. The municipality of Viacha is on a good path to resolve the environmental problem related to urban wastewater. However, it is important to remark that the volumes of wastewater are proportional to the size of the populations. As El Alto´s population is 10 times larger than Viacha's, the environmental pressure linked to the urban wastewater of El Alto remains the largest urban wastewater problem in the entire Katari hydrological system.

On the other hand, the public policies implemented during the period 2004–19 did not deal with the surface water bodies waste nor with industrial discharges to the urban sewage. Furthermore, the urban solid waste and the land field leach released to the surface water bodies crossing the cities of El Alto and Viacha were also not dealt with. Consequently, the policies were not able to handle the large contamination originated by these types of environmental pressure from region 2.

Region 3: downstream agricultural area

The third region of the Katari River Basin system is a rural region characterized by agriculture, livestock and dairy production practiced by Aymara indigenous communities. This region is composed of the municipalities of Laja, Pucarani, Puerto Pérez, and a rural section of Viacha. Together these 3 municipalities represent only 6.6% of the total Katari River Basin´s population.

The main environmental driving forces identified in the indigenous rural region are linked to agriculture, livestock and dairy production. The environmental pressure consists of diffuse pollution generated by agriculture and livestock waste. However, a comparison of the environmental contamination between the urban-industrial region and the rural-indigenous region shows that the former is certainly the greatest source of pollution. For instance, region 2 shows an increase of 716.85 and 320.25 mg/l of biological oxygen demand at the Seke and Seco Rivers, respectively. In comparison, an increase of 6.4 mg/l of biological oxygen demand at the Katari River can be observed in Region 3. Similarly, region 2 increases 680 and 511.5 mg/l of chemical oxygen demand at the Seke and Seco rivers, respectively. In comparison, region 3 only increases 12 mg/l of BOD5 at the Katari River. Concerning the nutrients, region 2 shows an increase of 60.8 and 54.85 mg/l of total nitrogen at the Seke and Seco rivers, respectively. In comparison, region 3 increases 4.57 mg/l of total nitrogen at the Katari River. At the same time, the urban-industrial region increases 57.21 and 38.95 mg/l of ammonia at the Seke and Seco Rivers. In comparison, agricultural/grazing land use increases 2.02 mg/l of ammonia at the Katari River. Consequently, beyond being an environmental driving force, the indigenous rural region can be qualified as the most socio-environmentally impacted region considering that all the aggregated pollution developed by the mining waste and the urban industrial contamination is delivered to Region 3.

The socio-environmental impacts present in this region are not produced locally. Instead, they are caused by exogenous environmental driving forces upstream, as the aggregated pollution comes from the Milluni valley and urban-industrial regions. There are two specific locations that are highly impacted: the rural communities of Chonchokoro, Kiluyo, and Cabaña, and the Cohana bay.

In the medium section of the Katari River Basin, below the cities of El Alto and Viacha, the rural communities of Chonchokoro, Kiluyo, and Cabaña are the first impacted social systems. These local communities used the surface water bodies to fish, for agricultural purposes and to process potatoes with an ancestral Andean technique ("chuño"[2]). However, the high levels of contamination forced these communities to shift the local livelihood to cattle raising and dairy

[2] Dehydrated potato under an ancestral Andean technique aimed to preserve and storage the potato for long period of time

production (Gloria Rodrigo, 2018). These rural indigenous communities claim that they do not employ river surface waters for any purposes but grazing areas.

The Molecular Biology and Biotechnology Research Institute found elevated concentrations of heavy metals in the local vegetation. Local flora registered elevated concentrations of arsenic, copper, and mercury (Gloria Rodrigo, 2018) showing evidence of the incorporation of the xenobiotic content in the local food web. Community members recognize that their dairy products are contaminated, and local markets tend to reject their produce. Consequently, they usually hide or change its origin to commercialize them at the local markets. The presence of this type of contamination in the local food web can be also extrapolated to the local drinking water sources. Community members expressed their concern for a potential contamination infiltration towards their local drinking water wells. Due to the composition of contaminants, there is a high risk for the health of the local community.

"…you can see the waste waters and totally contaminated. Before, since this river was clear, we used to dehydrate a little of our product (potato), we used to make chuño, we carried (our potatos) to the river and we had good tuntas[3], for our consumption or to sell. Now, in this river there is no fish, there is no suchi[4], there is nothing in this river, is totally contaminated. And now, we poor, drink what infiltrates."

Chonchokoro community member, 73 years old

From, (Gloria Rodrigo, 2018)

The second group of indigenous rural communities (Cohana Grande, Pampa Cohana, Tacachi and San Pedro) impacted by the Katari River Basin´s changes in the environmental state is located at the discharge area known as the Cohana Bay. Since these communities are settled in a river delta, historically the local livelihood depended on the diverse and extensive fish populations. However, the large increase of pollution strongly impacted 30 Km2 of the Titicaca Lake at this discharge zone (CGEPB, 2014), which produced eutrophic waters (Duwig et al., 2014) heavily limiting the ecosystem's capacity to sustain aquatic life. Consequently, these communities were forced to shift the local livelihood from fisheries to dairy livestock production.

[3] Dehydrated potato under an ancestral Andean technique aimed to preserve and storage the potato for long period of time
[4] Endemic Andean fish

> *"They even used to come from other islands to fish (Taripe y Surique), they fished with nets. At four in the afternoon, they used to launch their nets and at four in the morning they used to get the fish, around 138 to 173 Kg."*
>
> *San Pedro community member, 36 years old*
>
> *From, (Gloria Rodrigo, 2018)*

Community members observed that the problems of contamination began approximately 15 years ago, and that the contamination has progressively increased, also impacting their new form of livelihood. For instance, the problems of the solid waste carried by the surface water bodies and disposed in this region heavily impact the dairy livestock.

> *"..the animals get sick when eating that, and there is no way to treat that part. For instance, when an animal eats a lot of plastic bags, they remain in the animal stomach and become a braid which stocks the other things that the animal eats and the animal dies"*
>
> *Pampa Cohana community member, 52 years old*
>
> *From, (Gloria Rodrigo, 2018)*

There is also evidence of heavy metal presence in surface waters, sediments, soil and the local vegetation holding potential toxic and xenobiotic effects (Gloria Rodrigo, 2018). At the same time, elevated concentration of heavy metals such as arsenic, chrome, copper, iron, lead and zinc were observed within Cohana Bay's sediment samples. Even more problematic is the fact that there are alarming concentrations of arsenic, cadmium, lead and mercury within the local vegetation employed by the communities to feed their dairy cattle (CGEPB, 2014). Consequently, these toxicological agents are now present in the local food web, increasing the health risks of the indigenous population consuming these dairy products.

Furthermore, a 2019 study (unpublished) showed evidence of significant microbiological contamination. A total of 95% of the sampled drinking water sources showed evidence of the presence of *Escherichia coli* and total coliforms in the communities settled in this region. The presence of *E. coli* can be linked to gastrointestinal diseases and persistent diarrhoea (Nataro and Kaper, 1998) which is the second cause of mortality in children under five years old and the leading cause of malnutrition in the same group (WHO, 2017).

Concerning the policy responses, Region 3 is where most responses were developed during the period 2004 -19. A total of 33 policy measures were implemented within this rural indigenous region (see Table A1 in the Appendix). From 2006 to 2013, the Titicaca Lake Binational Authority implemented 9 policy interventions focused in the Cohana Bay. From 2007 to 2013, the State

Government of La Paz implemented the Cohana Bay Cleaning Program, which included the development of drinking water infrastructure, deworming of dairy cattle, cattle waste management, and the development of sanitation services within the rural communities. In 2010 the Ministry of Water and Environment, in alliance with the Catalan Agency for Development, released the Katari River Basin Management Plan (MMAYA, 2010). However, this plan was not implemented until 2016. From 2018 to 2019, the Katari River Basin Management Unit implemented 11 policy measures located within Region 3 and in neighbouring areas. The new river basin management plan developed in 2018 increased the spatial scope to an additional 19 municipalities (See Figure 7).

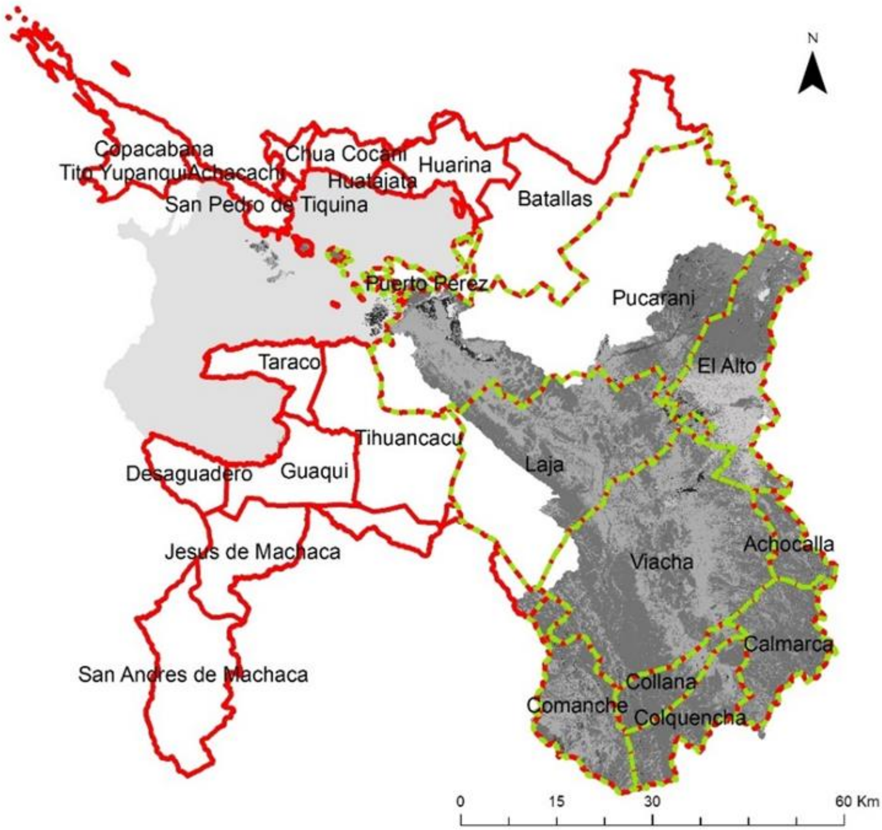


Figure 7: In red the regions addressed by the 2018 Katari River Basin management plan, in green the municipalities sharing spatial jurisdiction within the Katari River Basin.

2.4 Discussion

Incorporating a spatial assessment within the DPSIR framework allows to (1) understand the sources reproducing socioecological distress within the Katari River Basin and (2) unveil that policy responses are implemented without taking such an understanding of source-impact relation into account. The analysis of the Katari River Basin in this way shows that the majority of environmental driving forces and pressures are spatially located in regions 1 and 2 upstream. On the other hand, the majority of policy responses implemented in the past 14 years have been located in region 3 downstream. Consequently, policy response efforts deal with symptoms of the problems only. Regardless of the amount of efforts policy makers invest downstream, if the sources of socioecological distress are not managed upstream, the social and environmental impacts will remain present. Our analysis of pressure-impact relation in Katari River Basin confirm previous findings showing how environmental pressures manifest themselves over different social systems. This is even more evident in large river basins as actions performed upstream have an indirect influence over communities allocated downstream (Anderson et al., 2019). To incorporate a spatial dimension within the DPSIR and the river basin management policy design could thus result in a more effective outcome in terms of the sustainability of these efforts.

The lack of effectiveness in the implementation of river basin policies to manage the environmental pressures visible in the Katari River Basin may also be due to the protagonist role of centralized government policy action at the highest levels. The limited local participation in the policy design and implementation can also be linked to a lack of understanding of the Katari River Basin as a multiscale system. Incorporating a scale assessment in the Katari River Basin DPSIR application shows that the majority of policy responses were designed and implemented by the highest layers of government, within the Lake Titicaca Binational Autonomous Authority, the Ministry of Water and Environment and State Autonomous Government of La Paz. On the other hand, the Municipal Governments of El Alto and Viacha merely participated in these processes, even though the majority of environmental pressures originated in their jurisdiction.

By neglecting the local scale, fundamental knowledge, values, and capacities are excluded. However, they represent a significant resource to design and implement river basin management policies. The multiscale assessment can thus provide greater detail on causal relations. This approach can favor a match between policy responses and the appropriate administrative level, with which local stakeholders, communities, and groups of organizations can relate and act upon. Incorporating the multiscale approach in the DPSIR framework can be an important improvement in terms of river basin management policy since it may enhance both effectiveness and subsidiarity in terms of policy developments and implementation. In the Katari River Basin the participation of the Municipal Governments of El Alto and Viacha can be considered crucial to solving the social and environmental impacts produced downstream in the hydrological system. Incorporating the scales assessment with DPSIR allows to identify key local actors for policy development and implementation which enrich policy responses aiming at sustainable management of the whole socio-environmental system.

The majority of research and studies employing DPSIR tend to assume a causal unidirectional relation of driving forces/pressures and impacts (Svarstad et al., 2008). However, the Katari River Basin shows evidence of more complex relations and the need for a further detailed analysis of this system. A more precise analysis should consider both the direct and indirect, as well as endogenous and exogenous nature of the driving forces category (Leemans and De Groot, 2003). A direct driving force is a factor that unquestionably influences the ecosystem process and that can be clearly identified and measured. On the other hand, an indirect driver can shape the level or degree of change produced by the direct driver. The distinction between endogenous and exogenous nature depends on the decision-making level, as some drivers can be considered endogenous at certain levels of decision making but exogenous at others.

On the one hand, the Milluni mine's waste can be considered a direct driver based on the abrupt impact over the Milluni dam's water quality, which increases the public health risks and drinking water operation costs for the populations of La Paz and El Alto. On the other hand, the mine waste can be considered an indirect driving force causing a significant social impact towards the local public health and livelihood in rural communities and the ecosystem located in region 3. At the same time, the mining waste problem can also be considered an exogenous driving force in the eyes of local rural communities in region 3 since the management and control of this contamination is out of their local control. However, the same environmental pressure can be classified as an endogenous factor at the national government scale since the Ministry of Water and Environment and the Ministry of Mining and Metallurgy hold legal jurisdiction over these activities.

Furthermore, the impacts over region 3 must be conceived as a causal network (Niemeijer and de Groot, 2008) since they are produced by the aggregated driving forces/pressures located in regions 1 and 2 upstream, in the form of acid mine drainage coming from the mining waste, urban waste water contamination, solid waste discharges, and industrial contamination. Consequently, solving socioecological problems of rural communities in region 3 demands a detailed analysis of these driving forces networks and the scale at which they operate.

The conventional use of DPSIR applications mostly refers to biophysical environmental aspects of the system which do not always have a direct meaning to the social systems. Literature shows that just a small sample of DPSIR studies considers the socio-economic aspects associated with changes in the environmental functions (Maxim and Spangenberg, 2006). DPSIR applications recognizing the burdens on the social systems may reveal strong links between the social and environmental systems and the fundamental influence of environmental changes over social systems. The incorporation of social aspects within the Katari River Basin DPSIR application shows evidence not only of effects over the biophysical system, but also of fundamental social impacts on the most vulnerable parts of the social system. This impact is manifested in the local public health based on the ecotoxicological burden within the food web and the impacts on the livelihood of the indigenous communities. Furthermore, river basin policies conceived from the perspective of environmental justice may allow to incorporate targets to decrease the social burdens related to changes in the environmental state. This can be an advantage for river basin DPSIR applications to motivate local action and gain legitimacy at local levels.

2.5 Conclusions

The DPSIR framework has been widely accepted by academics and practitioners around the world to develop, design and implement environmental policies and indicators. This research aimed to investigate how the incorporation of social and spatial characteristics within the DPSIR framework may influence river basin policy developments. One limitation of this study relies in the indirect analysis of social and spatial characteristics, by assessing their current absence within the Katari River Basin case. Nevertheless, this research offers some important contributions in relation to its inclusion within the DPSIR framework with several practical implications for river basin policy and management purposes.

This research demonstrated that spatial characteristics in the DPSIR analysis provide a better understanding of river basin socio-ecological systems. A spatial analysis allowed to unveil the mismatch between environmental driving forces/pressures and 14 years of river basin policy responses in the Katari River Basin case study, heavily influencing its effectiveness. Therefore, the inclusion of spatial characteristics to the DPSIR framework might enhance the understanding of links between driving forcers/pressures and policy responses and be useful for river basin policy purposes.

The social characteristics incorporated in the DPSIR framework suggest two main conclusions. First, the implemented scalar analysis showed that the river basin policy was mostly limited to the highest layer of government within the Katari River Basin. The inclusion of this analysis within the DPSIR framework is useful to better understand the levels at which driving forces/pressures are taking place and to match these to the appropriate stakeholders/policy actors' levels within this typology of socio-ecological systems. Furthermore, this scalar analysis may stimulate local participation to take advantage of valuable local knowledge, capacities and values in the design and implementation of river basin policies.

Second, the assessment of social impacts revealed its limited effectiveness from an environmental justice perspective. The local communities located downstream from the main driving forces and pressures have experienced severe negative impacts on their local livelihood and public health. However, 14 years of policy developments in the Katari River Basin were not sufficiently effective to tackle the sources of pollution influencing these social systems. DPSIR applications that acknowledge the burdens on the social systems may reveal the links between the social and environmental systems and the fundamental influence of environmental changes on human systems. Finally, river basin policies conceived from the perspective of environmental justice may stimulate the incorporation of targets to decrease the social burdens related to changes in the environmental state.

Chapter 3

Transdisciplinary Learning Communities to Involve Vulnerable Social Groups in Solving Complex Water-Related Problems in Bolivia

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Bolivia has influenced the international water arenas as a pioneer of the Human Water Rights Declaration before the United Nations General Council. However, despite a positive but rather ideological evolution, the country is still facing several water challenges in practice. Water governance is extremely complex due to intricate social structures, important spatial and temporal differences in the availability of water resources, ecological fragility, and weak institutions. A Transdisciplinary Learning Community approach has been adopted by the Universidad Católica Boliviana to take into account the complexity of the water problems caused by social, hydrological, and ecological system imbalances. In this approach, researchers and non-academic actors work closely together to integrate different ways of conceiving, using, valuing, and deciding on water issues. The approach aims at co-creating resilient solutions by recovering and restoring not only the ecological system, but also the social system in which all actors are aware of their role and responsibility. We explain the challenges and concerns raised by this approach in a case study of the Katari River Basin (KRB), which is impacted by a high degree of contamination that is mainly caused while crossing El Alto city, leading to dramatic consequences for the Lake Titicaca ecosystem and its surrounding communities.

3.1 Introduction

Water is becoming a scarce resource with difficult access in many places. For more than 844 million people in the world, basic drinking water is still a dream, and for another 2.3 billion people who lack basic sanitation services, the Millennium Development Goals on water and sanitation have not been fulfilled (WHO-UNICEF, 2017). According to the World Health Organization (WHO), diseases associated with the lack of drinking water, adequate sanitation, and hygiene are still one of the main causes of mortality for millions of inhabitants of developing countries (WHO, 2018). Almost half of the inhabitants of developing countries suffer from diseases that are caused directly or indirectly by the consumption of polluted water or food, or by organisms that cause diseases that develop in water.

Besides, half of the water in drinking water supply systems in developing countries is lost through leaks, a lack of maintenance, poor dimensioning, illicit connections, and/or vandalism. As the population grows and income increases, more water is needed. In the year 2025, demand for water will have increased by at least 50% compared to 1995 (Rosegrant and Cai, 2002). As a consequence, water has become a crucial element for socio-economic development. Water is such a necessary resource that its infrastructure (dams, irrigation channels, purification and desalination technologies, sewage systems, and wastewater treatment) could become the object of political fights, social conflicts, and international wars.

The Sustainable Development Goals (SDGs), which were adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development, place even greater demands on societies than the MDGs, which they replace (Nilsson et al., 2016; Stein et al., 2018). Addressing water provision for all (SDG 6), while taking into account interactions and trade-offs with other global challenges such as climate change, renewable energy, food and health, requires strong institutions (SDG 16) as well as partnerships between public, private, and civil organizations (SDG 17) (UN, 2015). Scientists of different disciplines will have to design metrics, establish monitoring mechanisms, and propose adequate criteria in close cooperation with all involved actors (Lu et al., 2015). Within SDG 6, SDG 6.5 aims at the implementation of Integrated Water Resource Management (IWRM) as part of the response to “ensure [the] availability and sustainable management of water and sanitation for all” (UN, 2015).

IWRM is internationally recognized as the course to make an efficient, equitable, and sustainable use of water resources (UN-Water, 2008). This approach tends to reform institutional arrangements and systems of water governance (Jager et al., 2016; Watson, 2004) under the premise that the participation of actors and sectors at all levels is essential to achieve sustainability (UN-Water, 2008). By definition, the IWRM requires a high level of institutional coordination and collaboration among stakeholders. A collaborative system of governance among governmental and non-governmental actors, organizations, and sectors facilitates a more efficient, effective, and equitable management of the water resources (Watson, 2004). This demands the interaction between individuals belonging to diverse disciplines, backgrounds, and cultural realities.

In this article, we want to focus precisely on the interactions between scientists of different disciplines and representatives of different stakeholder groups in water management. To deal adequately with the wicked character of the socio-hydro-ecological system, new transdisciplinary research practices have to be developed that are able to meaningfully link different insights, interests, and values. In the Global South, socio-economic inequalities cultural differences, and the social exclusion of native communities and other vulnerable social groups often aggravate the challenges for transdisciplinary research. However, at the same time, we find there a fertile soil for inspiring alternative research practices to bridge the gap between sciences and society.

In what follows we analyze the ongoing experience with Transdisciplinary Learning Communities (TLC) initiated by the Universidad Católica Boliviana (UCB) in Bolivia to address the complex problems of water quantity and quality that affect the Katari River Basin, flowing into the Lake Titicaca. In this case, the main question is how a transdisciplinary approach can contribute to taking the interlinkages between the different ways of making sense and dealing with water-related problems into account.

After this introduction, we situate our research question in the broader framework of IWRM and the need for collaborative water governance. Then, we describe the TLC approach as an action research methodology in our case study of the Katari River Basin. In the results section, we first describe how water management has evolved in recent years in Bolivia; then, we analyze the current situation in the KRB with the TLC approach. In the discussion section, we look more in depth at the challenges with which the TLC is confronted. In the final conclusions, we look forward to how our current experiences can inspire future actions, not only in the KRB but in many other river basins with similar characteristics in the Andes and elsewhere in the Global South.

3.2 Integrated Water Resources Management and the Need for Collaborative Governance

Water resource management has played a historical role in nation-building worldwide (Mollinga and Gondhalekar, 2014). The International Conference of Water and Environment in Dublin in 1992 defined four principles as the core of water resources management. First, water is a finite and vulnerable resource that sustains life, the environment, and economic development. Second, water management should incorporate participation of all sectors, users, planners, and policy makers, at all levels. Third, women should be considered as having an essential role in water management. Fourth, water holds an economic value and should be considered an economic good based on all the competing uses of this natural resource (Nicol and Odinga, 2016).

In 2000, the discussions continued at the Second World Water Forum in The Hague, in which the statement "a water crisis is often a governance crisis" reflected the need of integrated institutional and managerial arrangements as prerequisites to finding sustainable solutions to problems related to the water sector (Solanes and Jouravlev, 2006). This international conference incorporated the concept of Integrated Water Resources Management (IWRM) in the international development agenda in order to favor a holistic view of the water sector, and promote it as the approach to find sustainable solutions for problems related to the water sector.

The definition provided by the Global Water Partnership (GWP) in 2000 stated, "Integrated water resources management is based on the equitable and efficient management and sustainable use of water and recognizes that water is an integral part of the ecosystem, a natural resource, and a social and economic good, whose quantity and quality determine the nature of its utilization". This approach gained attention and spread worldwide based on three principles that the definition incorporated. First, water management should consider this resource as essential for economic development. Water is used in a diversity of productive sectors, such as industry, mining and agriculture, relying on its availability and quality. Second, water is vital for social systems. A just and fair distribution between uses of water allows societies to avoid problems of social conflicts and public health that are related to water availability and quality deterioration (Boelens et al., 2014). Third, ecosystems rely on water resources (quality and quantity) to survive and keep a good ecological status.

At the same time, IWRM delineates the river basin as the best biophysical management boundary due to the ecological, social, hydrological, and institutional relations embraced within this system (Mollinga and Gondhalekar, 2014), as upstream water activities, practices, and values have a direct influence on downstream environmental, ecological, and social systems. Furthermore, this element aims to connect actors and sectors across the river basin, promoting the participation of stakeholders in decision making as one of its main pillars (Mollinga and Gondhalekar, 2014; UN-Water, 2008), in order to find a balance between the sector and actors' water interests.

However, the three principles incorporated in the IWRM approach tend to be contested, since water uses compete for the allocation of water resources based on sectorial interests. Moreover, productive sectors such as agriculture and mining, which have positive impacts on local economies, heavily impact the quality of water resources and their ecological status. To reach sustainable development, which according to the now classical definition of the 1987 Brundtland report, is "development that meets the needs of the present without compromising the abilities of future generations to meet their own needs", IWRM must take into account economic feasibility, social equity, and environmental issues. Moreover, since the time of origin of that definition, more emphasis has been put on ecological boundaries and social inclusiveness (UN, 2012), which is linked to new forms of water governance (Jager et al., 2016). For that purpose, the IWRM approach facilitates sustainable management by considering the river basin as an appropriate natural boundary that connects the actors, sectors, and up/downstream relations. At the same time, IWRM considers the participation of all stakeholders in decision making as one of its main pillars (Mollinga and Gondhalekar, 2014; UN-Water, 2008). As water governance refers to the interplay between political, social, economic, and administrative systems to manage and develop water resources and to deliver water-related services (GWP, 2003), the IWRM approach is nowadays commonly considered as the most influential water governance model worldwide (Clement et al., 2017).

Moss called attention to the necessity of appropriate sectorial interplay to enhance sustainability in water resources management, since water-related issues are often also related to other policy sectors that influence or rely on the water sector [18]. Additionally, the vertical interplay presented by Moss reflects the need for a co-action across administrative levels to face problems of scale linked to river basin resource management [19] in order to organize institutional arrangements, from national administrative levels to local levels.

However, although IWRM is widely accepted as the best water management approach worldwide, the implementation is still a challenge in diverse contexts (Alba and Bolding, 2016; Allouche, 2016; Basco-Carrera et al., 2017; Biswas, 2004; Brugnach and Ingram, 2012; Clement et al., 2017; Giordano et al., 2013; Harsha, 2012; Isendahl et al., 2009b; Mitchell, 1990; Nicol and Odinga, 2016; Rahaman and Varis, 2005; UN-Water, 2008). Moss highlighted that the 'successful' examples of IWRM worldwide reflect diverse water problems and the objectives behind their solutions (Moss and Newig, 2010). The implementation of solutions in the United States is linked to navigation, energy production, and flood control (Lilienthal, 1944; Straffin and Heaney, 1981). In Spain, the implementation of IWRM principles is connected to an agricultural reform (Swyngedouw, 1999). In England, the employment of IWRM shifted from flood control to ensuring water services for the urban population (Newson, 1996). For instance, the Tennessee Valley Authority in the United States is a recalled positive example of IWRM application (UN-Water, 2008), since the results experienced by the adoption of the Tennessee River Basin Management improved energy production, navigation, flood control, and agriculture (Swyngedouw, 1999) through a participatory process of decision making (Lilienthal, 1944). Consequently, the success of an IWRM policy implementation heavily depends on the sensitivity toward the local context, the understanding of existing governance arrangements, and the specific objectives linked to the local identified water problems (Pahl-Wostl et al., 2008).

Failure to consider the (social) embeddedness of natural resources management has been a key factor in limiting the success of previous governance reforms. For that reason, various scholars already argued more than a decade ago for collaborative water governance and social learning to broaden the IWRM scope of administrative coordination (Brugnach and Ingram, 2011; Mostert et al., 2008; Pahl-Wostl et al., 2007; Watson, 2004). Indeed, water-related problems are typical examples of “wicked problems”, which cannot be objectively described nor definitively solved (Rittel and Webber, 1973), as multiple stakeholders with different perspectives and possibly conflicting interests are all involved in it. They are intertwined with other wicked problems such as climate change, decreasing biodiversity, extreme poverty, and migration flows. They are characterized by a plurality of decision makers, pervasive uncertainties and ambiguities, spatial and intertemporal externalities, an interplay of human and natural components, and an evolving understanding of policy objectives. They are not neutral objects of inquiry, but already from the problem definition they are value-laden and guided by a perspective toward a more desirable state of affairs (Magnuszewski et al., 2018).

When wicked problems are at stake, collaborative governance has been widely recommended to replace top–down and technocratic approaches. This means that all relevant stakeholders are actively involved in the development of water policies to reconcile environmental, economic, and societal goals (Ansell and Gash, 2008). Governance results then from an interaction process between different actors confronted with a shared problem, in the search for synergetic solutions through the joint appreciation of different but complementary viewpoints (Gray, 1989, 2007; Gray and Purdy, 2018). Through an emergent and possibly conflictive process, actors increase their insights in the intertwined nature of complex problems while they negotiate mutually beneficial agreements.

Barbara Gray (1989; 2007) described this joint problem-solving and decision-making process in four phases: problem-setting, direction setting, implementation, and institutionalization. Critical tasks in the first problem-setting phase include identifying the relevant partners and getting them to commit to a collaborative partnership. Then, direction setting implies the exploration of shared issues and reaching agreements about how to address them. The implementation of a collaborative initiative has to engage the involved actors in the execution and follow up of the agreements. Finally, the institutionalization of collaborative governance has to structure and regularize the ongoing interactions among the actors, and it has to enhance social learning for continuous adaptations and improvements, and for the replication of similar partnership processes in other contexts (Gray, 1989, 2007; Gray and Purdy, 2018).

However, it is difficult for this collaborative governance approach to be put into the practice of river basin management (Watson, 2004). The process might be quite demanding for the participants, as they have to be able to reflect on their—often implicit—assumptions concerning their views about how (water) problems have to be managed, and analyze how different views affect each other and can be linked constructively to foster a shared vision. This implies that the knowledge generated by the water specialists has to be linked with the knowledge of their colleagues from other (human, social, economic, environmental…) disciplines and with the information, insights, and values of governmental, private, and civil stakeholders. Reflexivity allows questioning values, background assumptions, and normative orientations with four purposes in the search for sustainability: (1) to develop a shared understanding of a problem, (2) to reflect on the social relevance of the problem framing, (3) to set up joint social experiments and collective learning processes between the involved actors, and (4) to create a critical research agenda that is able to help transform the current governance system into a more sustainable system (Popa et al., 2015).

Due to the importance of the quality of the relations between the actors that participate in collaborative water governance, the attention is then drawn to activities that enable the development of joint knowledge, such as: getting the attention of all stakeholders and raising awareness of their mutual dependency, getting their commitment to engage in a joint learning endeavor, legitimating participants and leadership, connecting stakes and interests, dialoguing to explore diverse views and action possibilities, negotiating roles and contributions, guaranteeing the commitment of constituencies, and aligning efforts and agreements (Bouwen and Taillieu, 2004; Craps Marc, 1998). Although these activities may not be considered independent from the more conceptual, technical, and legal governance issues, they need specific attention and require specific competencies and skills that can be acquired through social learning (Mostert et al., 2008; Pahl-Wostl et al., 2007).

In the next section, we explain how the transdisciplinary learning approach that was applied in our case study aims at stimulating social learning between researchers, public authorities, and other stakeholders, with special attention for the vulnerable local communities, which is necessary for collaborative water governance.

3.3 Transdisciplinary Learning Communities as Action Research Methodology

The water research project to which this article relates is part of a broader Transdisciplinary research program between the Universidad Católica Boliviana San Pablo (UCB) in Bolivia and the Flemish Interuniversity Council (VLIR-UOS). With this program, the UCB wants to enhance its social impact by giving priority in research and outreach to the most vulnerable social groups in the Bolivian society. The lack of capacities of the UCB to counter the challenges presented by the intertwined problems of water quality and quantity, food sovereignty, social discrimination, legal rights, and a lack of economic opportunities that affect the poorest communities is common in the higher education landscape in Bolivia and in the Global South more in general. Universities invest most of their efforts in teaching, with a subsequent lack of engagement with society´s development. To reverse this situation, universities not only need to strengthen their relations with national and international research networks to increase the academic quality of their research. They also need mechanisms to co-create, together with local actors, knowhow that is adapted to the local socio-ecological and cultural circumstances of the most vulnerable groups. For this purpose, the university does not only need resources and technical knowledge for doing sound scientific research, it also needs to become more acquainted with the reality as it is experienced by the vulnerable groups that the university intends to support. The university also needs acceptance as a legitimate partner by the communities and other developmental actors. However, the UCB has a limited tradition and experience with this kind of research. Spaces and opportunities for dialogue between academic scholars and developmental actors are scarce. Cultural differences, disciplinary and institutional boundaries, and social inequalities complicate an open, bilateral exchange of information. Women, adolescents, and children are often not involved in the development of solutions for their own problems.

To reach its strategic objective to contribute substantially to the improvement of the living conditions of the most vulnerable groups in Bolivia, the UCB started a long term inter-institutional cooperation program with the Flemish Interuniversity Council (VLIR-UOS), which has a long tradition in academic development cooperation (www.vliruos.be/en). Its motto, “Sharing minds, changing lives”, expresses its mission of supporting partnerships between universities in Flanders and the Global South, to transform them as drivers of local and global sustainable development. Although the VLIR-UOS cooperation receives positive evaluations in general, there is need to better assess the consequences of the predominantly disciplinary and expert-driven way of doing research on the sustainability and social impact of the results. This resulted in a group of Flemish and Bolivian academics who were motivated to put a collaborative and transdisciplinary learning community approach at the core of the program with the UCB. The vision of the program is that of a community of academic scholars, belonging to different disciplinary projects, who work closely together with each other, with public and non-governmental development actors and with local communities in so-called “Transdisciplinary Learning Communities” (TLC). Together, the participants in the TLCs aim at co-creating “actionable knowledge” (Dewulf et al., 2005), which is adequate, contextualized, and “ready to use” by the local actors, because by participating in the research, they develop the knowledge, competencies, and willingness to put the results in policies and practices.

Transdisciplinarity refers to integrating different forms of knowledge from different academic disciplines and from different social actors (policy makers, local communities, non-governmental organizations, companies…) in a joint knowledge production process (Craps, 2018a). The concept of learning communities is inspired by the situated learning theory of Lave and Wenger (Wenger, 1999). In their conceptualization, communities do not refer to homogenous social or ethnic groups, but rather to emergent and informal groups of people—crossing the boundaries in and between existing organizations—that engage in shared efforts for collective learning (Craps, 2018b). In this way, TLCs aim at addressing the complex nature of the problems with which the most vulnerable social groups are confronted, intertwining water management and governance with issues of food sovereignty and nutrition, production development, human and indigenous rights, and social conflicts.

According to a transdisciplinary view, different disciplines are not dealing with different parts of reality; instead, they offer different frames to make sense of the real world built upon experiences. Consequently, a river basin is not only a physical–hydrological phenomenon, it is also a socio-geographical system, with legal–administrative implications within which an economic dimension is also incorporated with a variety of productive activities depending on or impacting the water quantity and quality. At the same time, it is a place of living with a sense of belonging for families and communities. Considering a river basin as a complex socio-economic and ecological system also draws the attention to the interrelations between a variety of social groups, living in rural, peri-urban, and urban environments with different cultures, interests, and expectations.

Through the TLCs, the university is building networks beyond its own walls to engage in and benefit from system-wide collaborative learning. The collaborative approach of the TLCs offers space for exchange and dialogue between the university, local communities, governmental agencies, non-governmental organizations (NGOs), and other participants. However, as there is a limited tradition of doing this kind of research in Bolivia, and since the legitimacy of the UCB is still under development, the necessary involvement of the other actors in the TLCs is far from evident. National public agencies demonstrated only a limited interest to be part of it during the preparation of the program. Apparently, they also often lack knowledge about problems from the perspective of the most vulnerable social groups. Nevertheless, their participation is important, and is sought for through formal agreements. Local public (municipal and departmental) agencies showed a stronger interest and greater disposition than the national agencies for getting involved in the TLCs, which can enable access to the local communities. NGOs and indigenous organizations also showed a high interest in the program, even without having clear ideas on how their members were going to benefit from it. For that purpose, a permanent dialogue with them about how the TLCs can favor the interests of their members is a key condition for the success of the TLCs.

A collaborative research strategy is considered most adequate to generate the “actionable knowledge” that takes into account the specific needs, values, and interests of the most vulnerable social groups in the river basin. This means that researchers from different disciplines work closely together with the stakeholders in their study throughout the whole research process. There is a long tradition of Participatory Action Research (PAR) in Latin America, which can be built upon. However, these PAR methodologies have been predominantly developed outside the universities by non-governmental organizations and social movements. As a consequence, the emphasis is often more on social action, and they are poorly integrated in the academic world, and are predominantly in the social sciences, if their presence is felt at all. The current tendency of Latin American universities to focus more on academic research risks to marginalize these PAR methodologies even more as a form of “social outreach” that is separate from the real scientific research. That is the reason why we focus here on the collaborative research methodology as a means for generating knowledge that is relevant beyond the specific case in which the research was done. Although this kind of research is realized in such a way that the contextual factors are fully accounted for, it does not lower the academic quality requirements, nor does it mean that the results are only relevant for the case under study. It informs theory that is applicable in other cases as well (Eden and Huxham, 1996). The “thick description” (Geertz, 2008) of the KRB case allows an “inferential generalization” of the conclusions by considering carefully the contextual similarities and differences between this case and other cases in Bolivia or elsewhere, and then adapting the conclusions accordingly. The learning conclusions of this specific case are also compared with the insights of existing theories regarding the implementation of IWRM. By confirming or disconfirming the existing theories through the evidence in this case, the study also allows so-called “theoretical generalization”.

The KRB, see Figure 8 was identified as a convenient case to study collaborative water governance. It presents an extremely high degree of ecological and social vulnerability, with tensions and conflicts between upstream and downstream, and between urban and rural areas. In the following paragraphs, we describe only briefly the geographical and hydrological basic facts and figures of the KRB. In the next section, we analyze more in depth how the recent socio-economic history and water policies in Bolivia have affected the water quality and quantity, and how this has impacted the living conditions of its inhabitants.

The KRB is located in the Andes region near La Paz, which is the capital of Bolivia in South America. This river basin covers 2955 km2, and its altitude ranges from 3800 to 5720 meters above sea level, with slopes from 4% to 90% (Ureña et al., 2018). The mean temperatures in the last 15 years have oscillated between −5°C and 15°C, and the average precipitation ranges from 470 to 742 mm (SENAMHI, 2015). The average river basin outflow at the Cohana Bay, the discharge point, is 7.7 m3/s (MMAYA, 2010).

The KRB is composed by the following rivers: at the highest altitude, the river basin is composed by the Seco and Seke rivers. These two rivers flow in the Pallina river, which later joins the Katari river, and finally discharges at the Cohana Bay into Lake Titicaca.

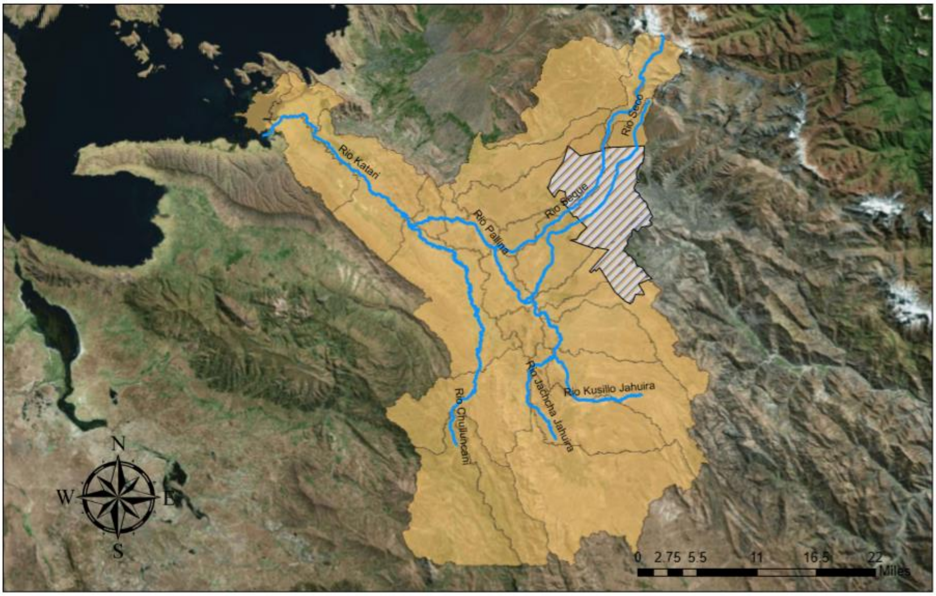

Figure 8: Katari River Basin

The KRB with over one million inhabitants is the most populated river basin in Bolivia (IDB, 2016). The region of the Katari Basin has one of the highest rates of population growth in the world, which is due to massive rual migration to the city of El Alto and its surroundings (Arbona and Kohl, 2004). The river basin crosses the city of El Alto, which is known as one of the fastest-growing regions in the world (Arbona and Kohl, 2004). El Alto experienced an increase of 95,000 to 1.2 million inhabitants between 1976–2011 (Chudnoff, 2009). This massive population increase has contributed to environmental problems related to water resources in the region.

3.4 Results

We start this section with an analysis of how water policies have evolved in Bolivia and how this has impacted the socio-ecological conditions in the river basins in recent history; then, we analyze more in depth the challenges for collaborative water governance in the Katari River Basin.

3.4.1 Integrated Water Management and the Challenge of Collaborative Governance in Bolivia

In Bolivia, water governance has struggled intensively with the wicked interplay of social, ecological, and economic factors that go beyond the conventional scope of technically informed management. To address this wickedness, the Bolivian National Government followed the global tendency of incorporating the IWRM approach in its national policy agenda as the mechanism to face water problems at the national level in 2006 (Ruíz and Gentes, 2008). The policy was buttressed by the creation of a Vice-Ministry of Water Resources and Irrigation, and was materialized by the creation of the National River Basin Plan, with the aim of the “good” governance of water resources in Bolivia (GTZ, 2010).

Despite the incorporation of international policy mechanisms at the national level, water governance challenges are still increasing in Bolivia due to political, administrative, economic, and social factors. Inefficient water services, asymmetries in resource allocation, ambiguity of the regulatory framework, lack of control, and unclear water rights continue to be part of reality. In some cases, these conditions result in significant social conflicts, which are experienced for instance during the so-called “Cochabamba water war” between the local inhabitants and its government, which was willing to privatize the drinking water service in early 2000.

The Bolivian water governance reflects a lack of coordination between subnational and national authorities, which is mostly due to political differences between both levels. As a result, there is an evident inefficient vertical interplay (Moss, 2014; Moss and Newig, 2010) that heavily influences the design and implementation of water policies. Moreover, the design and implementation of the water policy depends on the highest level of the administrative system, the National Government, since its technical executive department is considered to hold the expertise in the water field. As a result, national policies neglect local knowledge as crucial for sustainable solutions for water resource management.

In Bolivia, there is a tendency to have boundaries between policy sectors (Young, 2002b), which results in obstacles for the necessary sectorial interplay (Moss, 2014; Young, 2002a). As a matter of fact, other sectors such as agriculture, energy, and mining heavily influence water resources management. In the last decade, Bolivia has experienced a growing trend in its GDP (MEFP, 2017), which is linked to the increase of production in various sectors, and consequently, there is also a growing water demand. For instance, from 2006 to 2015, there has been an increase of 120% in agricultural production, which requires a significant volume of water resources to irrigate the 3.68 million hectares occupied by this sector (La-Razon, 2017). At the same time, the mining production increased 205% for the period 2006–2015 (MMAYA, 2016), which has extraction and refinery processes that also demand water resources. The growing economy also has a link with water contamination, as increasing amounts of the solid waste of industrial and urban pollutants are discharged in the water courses.

The coordination, participation, and collaboration among local administrative actors regarding decision making and the planning of water resources present serious challenges in Bolivia. The country holds a complex social structure with a growing power asymmetry between the urban and rural areas. This power asymmetry results in asymmetries in water allocation and water contamination, which often has the biggest negative impact on the most vulnerable communities.

Furthermore, water services heavily rely on national authorities, which do not always understand local realities, and as a result, potential water conflicts tend to be reproduced.

Conflicts can find their origin in claims of limits between communities, municipalities, or departments (because water sources or water courses are disputed by those who claim property), the wastewater treatment plant allocation, and water services’ fees. To all these potential reasons for conflicts, the increasing demand of water for the generation of electrical energy must be added. It is indeed the goal of the national government to guarantee 100% coverage of electricity, clean water, and sanitation by 2025 for all Bolivian citizens, which will rely on the availability and quality of water resources.

At the same time, the Bolivian water regulatory framework does not support sustainable water resources management. The Bolivian water law was adopted in the early 2000s. This law requires an update to align it with the legal system, which regulates the water resources and services. The Bolivian water law of 2000 recognizes the participation of the private sector in water services management. However, the 2009 new Constitution of the Plurinational State of Bolivia neglects the participation of the private sector in water management issues.

There is an ambiguous definition of the water management roles, and/or the formal roles are usually not followed. Administrative responsibilities between different public entities at national and local levels tend to overlap, while key issues such as water withdraw and discharge permits are not covered by any authority. Due to the lack of water abstraction and discharge registration, there is no clear information for the planning and application of a regulation that puts into perspective the availability of water and the future responsible uses of it, taking into account the sustainability of water as a delicate natural resource. On the other hand, under the national constitution, there is a clear definition of the responsibility for the water services at the urban level. Here, the municipal government holds the main responsibility. However, in the main cities, as in La Paz, the National Government attributes to itself the responsibility for the management of the water company. In the city of Santa Cruz, the urban water provision relies on a water cooperative whose shares are owned by the water users connected to the system.

There are no public records of water allocation, which is supposed to be acquired through concessions or legal provisions. Such a water abstraction and discharge registration could then assign rights to the use of certain volumes of water in such a way that it does not put ecological and hydrological balances at risk, by taking into account the projection of the demand in the future and the return of part of the water (treated and in good conditions) to the same source from where it was taken in a sustainable way.

Currently, the appropriation of water resources occurs in two main ways: by territorial appropriation (the purchase of land, including its natural water resources and biodiversity), and by the “official concession” of water. In Bolivia, a large portion of water resources is allocated to indigenous communities. They consequently grant the legal right over these water resources under a territorial jurisdiction framework. However, local communities are not included in the decision process to promote a dialogue about water governance and the implications for local development.

3.4.2 Challenges for Collaborative Water Governance in the Katari River Basin

The hydrological system of Katari gained attention in 2004 when the president at the time promulgated the law 2798, declaring this river basin "an environmental disaster zone and hydrological emergency" due to the contamination resulting from the anthropogenic activities that had developed within its main tributaries. The reason for this law has to be sought in the connection with Lake Titicaca, which is the largest freshwater lake in South America and the most relevant water resource body in the Andes Region, into which the Katari river discharges (Revollo, 2001). Lake Titicaca is under the binational water management of Bolivia and Peru.

The environmental evaluation performed by the Bolivian Vice-Ministry of Water Resources and River Basins identified two main problems related to the water resources in the Katari Sub-Basin. First, the increasing population has led to the establishment of factories, mining activities, tanneries, slaughterhouses, and agriculture, which all put a large amount of pressure on water resources demand. Second, the mentioned activities have also damaged the water quality of the sub-basin, since environmental legislation is not enforced (Chudnoff, 2009). Only 55% of the residential sewage is processed at a wastewater treatment plant, and the effluents of these water treatment plants do not comply with current water quality regulations. Additionally, there are problems with solid waste management in the municipalities within the KRB (Fontúrbel Rada, 2005), which further negatively affects water quality.

As framed by Archundia (2017), illustrated in Figure 9, there are four regions of anthropogenic influence on the water resources in the Katari River Basin: (1) Milluni valley, (2) El Alto, and Viacha, (3) the Katari rural lowlands, and (4) Lake Titicaca (see Figure 9). The Milluni sub-basin is situated at the highest location of the Katari River Basin. This sub-region, which is located at 4450 meters above sea level, is affected by the exploitation of tin, lead, and zinc, which was initiated in 1920 through a private enterprise named "Fabulosa Mine Consolidated", which was owned by British shareholders (Archundia et al., 2017). Later, from 1975 to 1986, the Bolivian company COMSUR continued the operations. Currently, the mine is not under an official concession contract, but two local communities dispute the exploitation of the minerals when tin prices increase (Salvarredy-Aranguren et al., 2008).

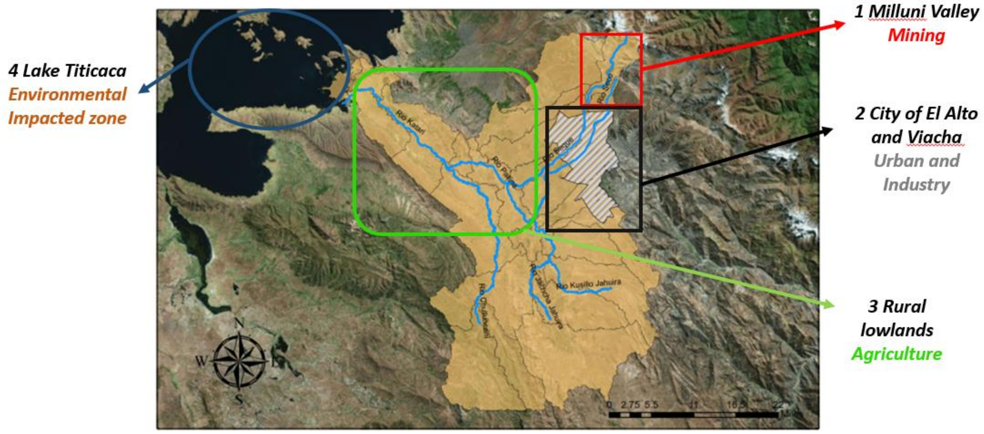

Figure 9: Katari River Basin/sub-regions of study

Over 90 years of mining operations in the Milluni sub-basin have left a legacy of water contamination. Local geology holds a high concentration of sulfide minerals. When the minerals are exposed to the atmosphere (oxygen and water), which happens in conventional mining processes, they are a constant source of acid mine drainage. The low pH of the acid mine drainage enhances conditions for the incorporation of dissolved metals in the water. Downstream of the mining area, the second largest water reservoir is located, which is known as the Milluni Dam. This dam holds a capacity of 10 million cubic meters, and partially supplies water to the cities of El Alto and La Paz. The local drinking water supply company currently incorporates additional steps to treat the contaminated water in order to comply with local standards for drinking water.

Downstream of the Milluni valley, in the cities of El Alto and Viacha (Figure 9, Urban and Industrial zone), pH recovers to a neutral state due to a natural oxidation process during transportation. At these locations, the water of the Seco and Seke rivers, which are part of the Katari River Basin, is considered to be of good quality, according to Bolivian local standards. However, when these rivers cross the city of El Alto, their water quality heavily deteriorates. The accelerated massive urban migration of El Alto did not allow a proper city planning of the infrastructure for water services. The city of El Alto has only one wastewater treatment plant, which has an installed capacity of less than 55% of the total effluents generated by the local population. Moreover, this wastewater treatment plant, which is known as the "Puchukollo", discharges an effluent of low water quality that cannot be employed for irrigation or any other purposes (Archundia et al., 2017).

After crossing El Alto, the Seco and Seke rivers qualify as eutrophic waters due to the high concentration of nutrients and low dissolved oxygen concentration, which limits the presence of the endemic species that are characteristic of these types of ecosystems. The anthropogenic influence of the city of El Alto also incorporates fecal contamination to concentrations that are harmful to public health.

The third sub-region of study consists of rural communities whose livelihood depends on agriculture in the area. Their main activity is linked to livestock and small-scale diary production in the region. However, the problems of contamination caused by the cities upstream of El Alto and Viacha, which were mentioned before, do not appear to be the main problem identified by these communities. They claim to be historically neglected communities lacking water infrastructure to develop and increase agriculture in the region.

The last sub-region of the study incorporates the communities around the Cohana bay at Lake Titicaca. These communities are heavily impacted by the contamination developed upstream. However, since the promulgation of the law declaring the Katari River an ecological disaster, nothing has changed, and the river basin contamination is still impacting the environment and the local livelihood as before.

The approval of the law 2798 in 2004 by the Bolivian National Congress, declaring the Katari Sub-Basin an environmental disaster zone and an area of hydrologic emergency, meant that the national government recognized the seriousness of the environmental problems in the KRB, and that it declared environmental remediation to be a national priority. At the same time, the law granted the involved municipalities the possibility to restructure their annual operational budgets in order to implement plans, programs, and projects to improve the environmental scenario. Furthermore, the law gave origin to the “River Basin Environmental Conservation Management Committee” for the Katari River Basin. The governance model was structured under a board of directors that was composed by representatives of the national government, the association of municipalities, universities, the federation of farmer unions, neighborhood associations, and the water services company “Aguas del Illimani”.

The enacted law of 2004 mentioned important principles for an integrated, transdisciplinary, and collaborative approach regarding the river basin. First, the law recognized the importance of a participatory and multi-sectorial approach to articulate actions for the improvement of the environmental scenario. Second, the law recognized the importance of establishing the hydrological boundaries of the river basin as the basis to delineate an administrative system.

However, although the enacted law seems to contain important principles for an integrated river basin governance, the “River Basin Environmental Conservation Management Committee” did not issue any plans, programs, or projects afterwards. One of the reasons of this lack of initiatives might be the ambiguity of the institutional framework resulting from this law. The law vertically designated a number of heterogeneous organizations to be part of the Management Committee, but without a process through which these actors could come to a joint understanding of the different problems and an agreement regarding the possible solutions and the contribution of each to these solutions. Moreover, the committee also lacked information and expertise to establish the adequate tools and mechanisms for the required operations.

Later, in 2010, the Bolivian National Government incorporated the IWRM approach in the national development and environmental agenda through the establishment of a new government agency called the “River Basin National Plan”. This government agency developed various river basin plans with the objective of articulating the IWRM in the river basins prioritized by the national government; among these was the “KRB Director Plan”, which was published by the National River Basin Plan in 2010.

The “KRB Director Plan” identified three dimensions that are in continuous contestation with each other: the environmental, the socio-economic dimension, and the institutional/administrative dimension. The plan presents a problem definition that incorporates problems related to water quality and water quantity regarding the contamination of the Katari River and Cohana Bay, and the insufficient water resources to attend to all of the local demands. The plan also points to the diversity of the stakeholders and social sectors that are involved and the legal plurality in the area as special challenges for an integrated management of the Katari River Basin (IMKRB).

As shown in Figure 10, the “KRB Director Plan” structured a governance model consisting of four parts. First, the River Basin Board is composed of local authorities, as well as members of the state government, municipalities, the national irrigation service, and the vice ministry of water resources and irrigation. Second, an Executive Unit is responsible for the implementation and daily management of the plan. Third, a Technical Council is composed of “institutions and enterprises” with technical water management expertise. And last, a Participatory Forum “coordinates and communicates with the productive and social forces” present in the river basin.

However, the river basin management plan had not been implemented until 2016, after the algae bloom experienced in 2015 at the Cohana Bay which resulted in two tons of dead fish collected at the Titicaca shores. Furthermore, the 2010 Katari Basin Director Plan did not incorporate concrete measures to face the environmental problems.

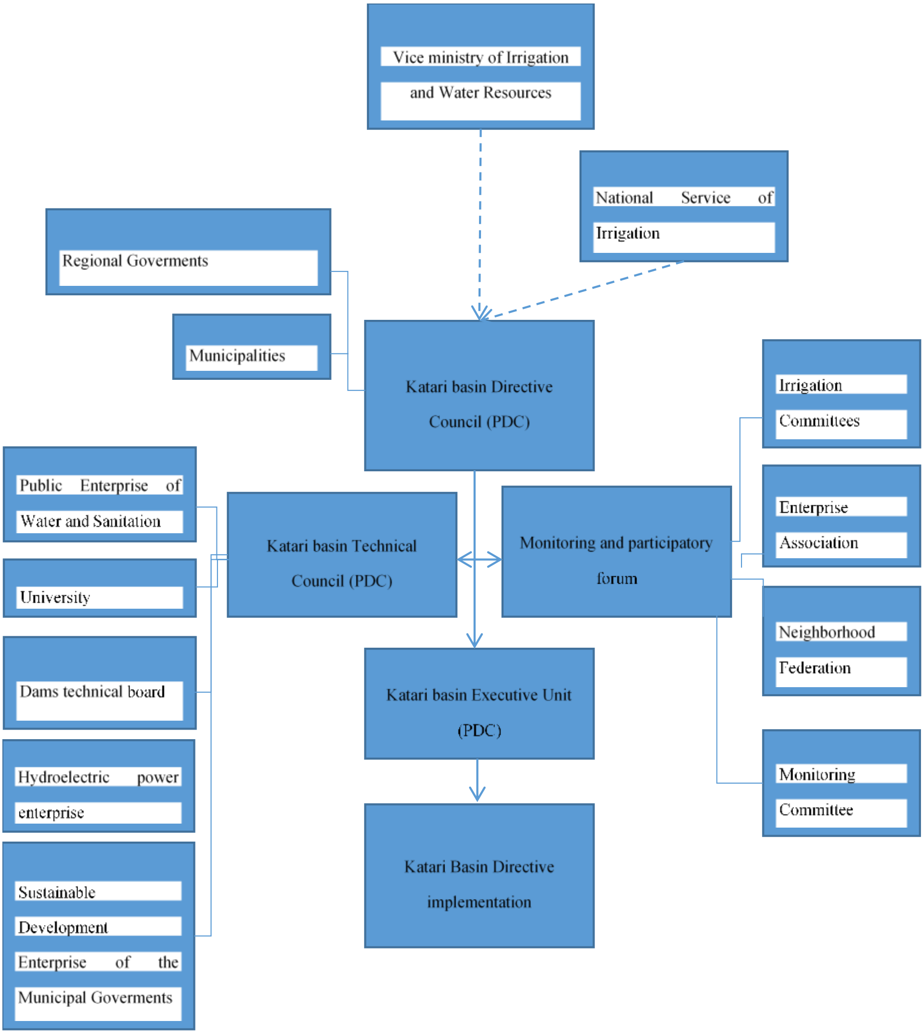

Figure 10: KRB Institutional Structure from 2010 Katari Basin Director Plan.

As the KRB management plan currently under implementation was developed and implemented exclusively by the National Agency of the Ministry, there is a lack of participation by the municipal and community actors in the design and implementation of the KRB management plan. Consequently, the existing ambiguity concerning the causes, responsibilities, and possible solutions of the problems cannot be addressed adequately. This decreases the legitimacy at the local level of the proposed solutions for the problems of the Katari River Basin.

3.5 Discussion

To counter this situation, the TLC initiated by the UCB helps provide a holistic view of the problems, as it offers a space in which academic experts with different disciplinary backgrounds as well as policy makers and local communities link their knowledge, experience, and expectations. To mitigate the influence of water pollution and water quality deterioration on the urban and rural vulnerable population (indigenous communities, slums, farmers' associations, and secondary cities settled along the Katari sub-basin), the development of a water quality monitoring strategy is considered to be a priority. This implies identifying the indicators of water quality and the sources of water contamination together with the local stakeholders. By understanding the source–impact relation, an IWRM policy framework can be better directed to the most polluted areas in the most critical periods. As these practices are developed together with the local stakeholders, they are aligned with the local and national context. The articulation of this commitment stimulates important stakeholders (such as the International Development Bank, the Ministry of Water and Environment and other governmental departments, local NGOs, and others) to become actively involved in the project with the UCB.

What can be done to overcome the barriers for the improvement of IWRM policies to respond to the needs of the different stakeholders, and especially of the most vulnerable social groups in the Katari River Basin? Certainly, more "technical" information is still needed about water quantity and quality. The UCB water specialists can help identify the main sources and pollutants causing the deterioration of water quality in the main rivers of the Katari sub-basin. They can also help clarify the relationship between these sources and their impact on water quality, and establish the required frequency of monitoring for the proper assessment of water quality.

However, this information will not suffice to deal with the intricate problems in the Katari River Basin. That implies a better understanding of the different water management policies that were developed by the national, regional, and local authorities to face the multiple problems of the Katari sub-basin: how were they developed and implemented, and how were different actors involved or excluded from this process? Currently, a thorough review and analysis of the existing documents related to the IWRM policies of the KRB (river basin plans, government reports, environmental publications, formal regulations, and scientific publications) is complemented by field work featuring in-depth interviews with all stakeholders related to the Katari basin, including representatives of national, regional, and local authorities, managers of industrial companies, local water utilities and water cooperatives, farmer's associations, community leaders, and local water activists. This information helps outline the diverse activities that take place along the river basin and understand how they influence or are impacted by the water quality deterioration of the river.

Talking with all these stakeholders not only enhances the understanding of how the integrated water resource policy was developed and implemented, it directly generates new ideas about the role of the local actors in this process. Interviewees are stimulated to reflect on their interests, roles, and responsibilities. By feeding their ideas back to the other stakeholders, the research is stimulating a joint reflection and co-creation process for the IMKRB, in which the concerns of a vulnerable environment and of the most vulnerable social groups are included.

3.6 Conclusions

Integrated Water Resources Management was once conceived as a panacea to address water problems by coordination between different governmental, agencies, policy domains, and administrative levels. Later, it became clear that the wicked nature of water-related problems requires the active incorporation of a variety of stakeholders from the private and civil sector in collaborative water governance. Vulnerable social groups in local communities deserve special attention in this governance process. They often have important contextual information that should be taken into account and they are confronted most directly with the consequences of inadequate river basin management, as the KRB clearly illustrated.

In this publication, we draw attention to the implications of the shift toward collaborative governance as a way of doing research. All of the relevant stakeholders should be involved throughout the whole research process, rather than only in the last phase, when conclusions are translated into new policies. TLCs have to come up with research questions that include and reflect the worries of the most vulnerable social groups. TLCs are also mechanisms for joint information gathering and analysis. They offer spaces in which formerly excluded social groups can express how they make sense of the situations and problems with which they are confronted. Together with them, we have to reflect on how they can be empowered to be actively involved in the IWRM and in this way play a proactive role in the improvement of their own reality.

In our research practice, we are confronted with the challenge of connecting scientific and local ways of knowing, because science aims at producing generalizable knowledge with objectifying, distant methods, whereas local community knowledge aims at practical and context-specific solutions that are rooted in the subjective and rich experience of intimate and engaged contact with the environment. Overcoming these epistemological differences and incongruences is complicated because of the unequal prestige and power between academic and local knowledge holders. The TLC approach of the UCB and VLIR-UOS cooperation program offers an opportunity for academic researchers and external stakeholders, including the most vulnerable groups, to learn by doing and experimenting with joint practices that contribute to the co-creation of scientifically sound, locally adequate, and socially relevant water policies.

In this way, our research contributes to the development of a transdisciplinary approach for the design and implementation of IWRM policies, taking into account the particularities of the local geographical context, the governance structure, the institutional framework, and the complex nature of the water sector. Follow-up research will determine the long-term impact of this innovative approach on water quality and quantity, from the perspective of the different stakeholders.

Chapter 4

Framing water policies, a transdisciplinary study of collaborative governance. The Katari River Basin Case (Bolivia).

Collaborative water governance deals with diverse actors under participatory systems of decision making. This form of water governance involves stakeholders with fundamentally different values and premises about water resources, as well as a different understanding of the problem they deal with and how to approach it. Thus, one of the major challenges of collaborative water governance relies on the diversity of frames carried by stakeholders involved. Divergent frames of the actors can represent an obstacle, impede mutual understanding, and negatively influence decision-making and policy outcomes. In this study, we explored the drivers behind the framing process in the Multi-Actor Platform of the Katari River Basin, located in Bolivia. The results evidence a participatory process design favoring the fragmentation of frames. The case study evidences a design in which public authority, scientific-technical and local community´s knowledge tend to be insulated. At the same time, this research reveals the influence of the political context as one of the drivers behind the fragmentation of frames.

4.1 Introduction

The disparity of water and sanitation access, agricultural expansion, climate change, and impacts related to draughts and floods brought the attention to the sustainability of the water sector as essential to deal with today´s global challenges (UN-Water, 2016), 2016). However, rather than merely depending on biophysical conditions, the water challenges depend on diverse sector interdependencies, political agendas, economic interests, and cultural aspects, which call for integrative approaches to manage water resources (Edelenbos and Van Meerkerk, 2015). Such collaborative forms of water governance acquire interest to deal with the complex nature of these socio-ecological systems since they bring together multiple and diverse stakeholders involved in the decision-making process. Yet, the diversity of backgrounds, disciplines, cultures, and knowledge may engage differing frames, which can represent an obstacle to the collaboration (Gray, 2007).

The framing process in a multi-actor water governance can be decisive to cope with the challenge that diversity represents (Dewulf et al., 2011). Without proper management of the framing process, the participants may limit their attention to specific aspects of the situation, hence they frame the water issues in divergent ways and telling contrasting stories about what is going on and what should be done. Effective decision-making relies upon connecting the way individuals make sense of a problem, process usually referred as framing, connection of frames or interactional frame (Dewulf et al., 2009). Aligning the frames of the actors involved can help to reduce the ambiguity usually present in participatory water policy making processes. Framing in water management research reached ample attention in the past (Korbéogo, 2020; Hulshof and Vos, 2016; Isendahl et al., 2009a), however not much attention was given to understand the drivers allowing a successful framing process.

This chapter aims to understand the determinants of the fragmentation and connection of frames in multi-actor water governance settings. Through the sensemaking approach (Weick, 2005), this research focused in understanding the water meanings that participants of the Katari River Basin Multi-Actor Platform employ to frame the situation. It aims to answer the following research questions: What are the drivers which influence the fragmentation and connection of frames? How the framing process is related with the water governance outcomes and results? How collective sensemaking about water issues can contribute to water governance?

The results confirm a strong relationship between the participatory process design (Newig, 2007) and the framing process. We also argue that the water policy framework can influence the participatory process design, and consequently the framing process. Moreover, this research considers that a collective sensemaking about water issues can improve effectiveness of water governance platforms. At the same time, this research unveils the political context as one of the drivers behind the fragmentation of frames.

This chapter is organized as follows. First, we present the conceptual framework. In the methodology section, we present the qualitative methods to identify the drivers behind the fragmentation and connection of frames in a participatory water governance platform. The results section first presents KRB public participation findings; then, these data are linked with the framing and sensemaking process; finally, we explore how this finding is linked to the collaborative water governance outcomes. In the discussion section, we argue about the participatory process design and the political context as drivers for the fragmentation and connection of frames.

4.2 Conceptual framework

4.2.1 Collaborative water governance and the transdisciplinary approach

Integrated water resource management (IWRM) brought a new paradigm in which the river basin is considered the appropriate boundary system to deal with today´s water challenges, and in which the participation and collaboration of stakeholders is imperative to deal with the complex water related problems. This approach mobilizes multiple stakeholders in forums of decision-making to develop and/or implement water policies related to common water resources. This collaborative form of water governance represents a shift from a conventional government control driven model to a stakeholder shared management network (Ogada et al., 2017).

> *Collaborative governance refers to a governing arrangement where one or more public agencies engage non-state stakeholders in a collective decision-making process that is formal, consensus-oriented, and deliberative and that aims to make or implement public policy or manage public programs or assets (Ansell and Gash, 2008).*

This form of water governance is expected to be more adequate than traditional institutions in shaping regulatory outcomes, ensuring compliance, facilitating implementation, and enhancing the effectiveness of water policies. This is due to more knowledge acquisition and acceptance of the decisions (Berkes, 2002; Coenen et al., 1998).

Collaborative water governance usually involves stakeholders representing public and private sectors such as agriculture, industry, energy, and forestry. At the same time, it frequently crosses public management jurisdictions at different spatial and jurisdictional scales, encountering contested interests, diverse forms of knowledge and different understanding of the water problems. Consequently, a transdisciplinary approach can be considered necessary in the water decision-making processes.

Aligned with collaborative water governance, the transdisciplinary approach crosses many disciplines and integrates diverse forms of scientific and non-scientific knowledge, facilitating a systemic way of addressing a complex problem (Craps, 2019; Mauser et al., 2013). It also includes non-academic actors in the process, involving community-based stakeholders who are usually closely related to and/or affected by the decisions made. Transdisciplinarity can be defined as "a different manner of seeing the world, more systemic and more holistic" (Max-Neef, 2005, p. 15), from which collaboration is essential to articulate knowledge co-production. It can thus be considered a collective learning and innovation process, which is particularly employed in ecological and sustainable development issues (Craps, 2018b; Polk and Knutsson, 2008). Concerns multi-stakeholders' collaboration and working with diversity. Consequently, the transdisciplinary approach seems relevant to investigating the collaborative water governance process.

Decision-making can be considered at the core of collaborative water governance (Peters and Pierre, 2016). Decisions are usually driven by how decision-makers make sense of the situation they are dealing with. The web of interdependencies among actors, the lack or uncertain information, and the ambiguity, because people may disagree on what exactly the problem is, turn the decision making into a difficult task (Dewulf, 2019). To deal with this, framing is a process employed to connect the diverse ways participants understand the water problems.

4.2.2 Framing and making sense of the water problems

Collaborative water governance involves actors with fundamentally different values and premises about water resources, as well as a different understanding of the problem they deal with and how to approach it. Thus, one of the major challenges of collaborative water governance relies on the diversity of frames carried by stakeholders involved in these platforms. Frames consist of individual mental understandings, interpretations, and simplifications of reality (Dewulf et al., 2011). The various disciplines, forms of expertise, and backgrounds involved in these multi-actor settings usually limit individuals to focus the attention on particular aspects of the situation, portraying separate understandings of the issues involved and how these should be addressed.

However, in complex water related issues, where there is high uncertainty and ambiguity, collective sensemaking may help to enact meaningful decisions (Dewulf, 2019). Sensemaking refers to how people make sense - attributing and constructing meanings - about particular situations (mainly new, ambiguous, or that just represent change), and act as a result. This process is strongly based on interactions, and the way people express, talk, and share their sensemaking (Louis et al., 2005; Baly et al., 2016). Sensemaking must be considered as a process strongly related with the particular context where it takes place (Weber and Glynn, 2006; Scott, 2013).

Framing and sense making are highly related processes. As argued by Fiss and Hirsch (2005), frames constitute "schemata of interpretation" (Fiss and Hirsch, 2005), and as a result they "are both guide and outcome of sensemaking process" (Gray, 2007, pg.32). This relation is based on the understanding that sensemaking allows to think, talk and act on the question of "what is going on here?" (Dewulf, 2019). The answer to this question, built through interaction, will eventually contribute to a scheme of interpretation (a frame), while this frame will influence the attribution of meanings that will be done through a sensemaking process. Sensemaking can be of high importance to understand the framing process because it offers a stronger link with the role of social structure in the meaning-creation process.

Effective decision-making in collaborative water governance relies upon connecting the way individuals make sense of a problem, process usually referred as framing, connection of frames or interactional frame (Dewulf et al., 2009). The connection of frames is a constructive form of dialogue in which the participants provide meaningful contributions, which can be questioned by others, and through which the situation dealt with is explored, formulated, and reformulated in a productive way (Dewulf et al., 2011). Framing is a process required to reduce the ambiguity present in multi-actor settings (Dewulf et al., 2009). The connection of frames is the construction of a joint meaningful story in which the common ground is explored and negotiated. Framing is a process of knowledge co-production which may generate motivation and commitment to articulate collective action.

On the other hand, without proper management of the framing process, the participants may limit their attention to specific aspects of the situation, hence framing the water issues in divergent ways and telling contrasting stories about what is going on and what should be done. This results in different understandings, voices, and opinions around what the problem is about, and the specific situation these multi-actor platforms are dealing with. Such fragmentation generates a specific kind of uncertainty on the issues to deal with, usually referred to as ambiguity (Craps and Brugnach, 2015). Ambiguity and uncertainty may turn the water decision-making into a potential minefield, from which the resultant policies are full of "big words lacking concrete choices" (Dewulf, 2019).

4.2.3 Framing and effective public participation

To understand the fragmentation and connection of frames causes, this research relies upon the analytical framework proposed by Newig (2007). This analytical framework was developed to understand the public participation effectiveness in environmental governance. However, it is also applicable to the study of framing based on the dimensions incorporated and the detailed characteristics proposed within the framework, see Figure 11.

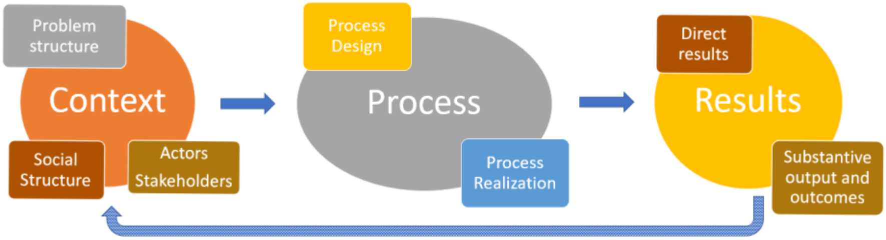

Figure 11: Public participation effectiveness framework from Newig (2007)

This model is based on the assumption that the results and outcomes are dependent on how the public participation process is carried out, at the same time, the societal context influences the participatory process. Furthermore, the results and outcomes feedback into the societal system. Each dimension of this model incorporates specific characteristics allowing for a better understanding of the variables influencing public participation in environmental governance, see Table 2, which are also useful to understand the causes and potential influence of the fragmentation and connection of frames in collaborative water governance platforms and its policy outcomes.

*Table 2 From Newig (2007). *CA refer to competent authority (NSA stands for non-state actors).*

Context	Process	Results
Problem structure - problem complexity (expertise and time required for understanding) - spatial scale - possible solutions (technical and other, costs) ***Actors*** - interest, concern - power/resources - informedness / understanding of the problem	***Process design*** - opportunities for NSA to participate (process type as given by CA) - fairness (representativeness, etc.) ***Process realization*** - information flow from CA to NSA (measure of relevant information that is provided) - information flow from NSA to CA	***Direct results of the participation process*** - information gain for the CA - consensual conflict resolution - NSA's acceptance of and identification with the decision - strengthening of trust relationship among NSA and between NSA and CA ***Substantive output and outcome*** - result of decision (suitability of measures; incentives, sanctions, implementability) - implementation and compliance by the addressees

- willingness to participate ***Social structure*** - public attention towards the issue - collective social capital (generalized trust) - social norms	- actual participation and intervention on the part of NSA	- environmental outcomes (measurable effects according to the stated goal)

4.3 Methodology

4.3.1 The Katari River Basin Case Study

The Katari River Basin is located in South America, in the Andes region of La Paz-Bolivia. This case first called attention of national authorities in 2002, when rural indigenous communities initiated several protests due to the high levels of contamination present at the discharge area of this watershed. The rural migration and mineral reservoirs within this river basin had triggered the development of mining activities, urban expansion, industrial growth, and the increase in agricultural practices (see Figure 4 - Chapter 2). These developments are responsible for the environmental disaster present in the river basin since they all contribute to diverse forms of contamination.

Over 16 years, although public policies developed by the national, regional, and municipal governments attempted to deal with the problem of contamination, the trend of environmental degradation continued, reflecting a lack of policy effectiveness (Agramont et al., 2021). In 2016, the Bolivian Ministry of Water and Environment initiated the implementation of a River Basin Master Plan in which the KRB Interinstitutional Platform was initially established. This platform was created to bring together diverse stakeholders and involve them in a collective decision-making process to deal with the severe contamination problem. The Katari River Basin incorporates 5 main municipalities: El Alto, Viacha, Laja, Pucarani and Puerto Perez. The KRB interinstitutional platform includes various levels of public authority´s jurisdictions in which the vertical interplay incorporates the national and regional governments, municipalities and rural indigenous communities.

Consequently, this inter-institutional platform includes representatives from diverse government levels such as national, regional, and municipal governments. At the same time, it incorporates representatives from universities, research institutions, and international cooperation agencies. Furthermore, the interinstitutional platform also includes civil society representation in terms of community-based organizations such as rural indigenous representatives and farmer unions, among others. This platform is presented in Figure 12.

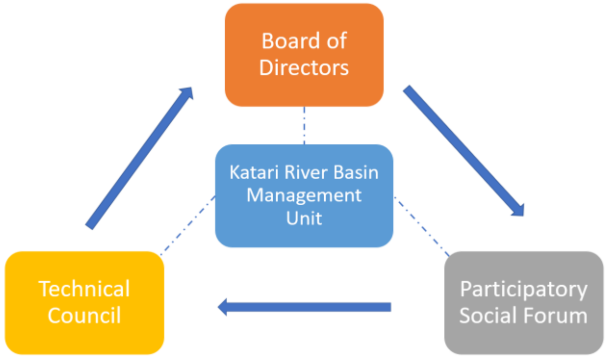

Figure 12: Katari River Basin Platform's organizational structure, MAyA (2018)

The rich diversity of the involved actors, and the problem complexity behind this river basin make this case study a suitable scenario to explore the drivers behind the fragmentation and connection of frames. Furthermore, it represents a good opportunity to understand the relationship between collaborative water governance and the fragmentation/connection of frames, based on sensemaking, within transdisciplinary decision-making systems.

4.3.2 Methods

This study has been conducted following an interdisciplinary approach. The researchers come from different fields, such as engineering, communication studies, law, and psychology. These diverse backgrounds have contributed to this research. As water management problems tend to be highly complex, they require different forms of knowledge, expertise, perspectives, and ways to make sense of it. The research team has worked in a collective and dialogical process for the data collection, the data analysis, and the writing of this article. This enriched the discussion about framing in collaborative water governance.

Data collection

The semi-structured interviews were held during April 2021 with members of the KRB interinstitutional platform, such as community-based organizations, national government agencies, regional environmental agencies, municipal governments, and international cooperation agencies. Initially, 30 different members of the KRBIP which had attended its last General Assembly were considered for this study. From this initial pool, we selected 11 interviewees through randomized purposive sampling. At least one member of the four groups of actors was selected randomly (see Table 3). Moreover, we aimed to maintain a gender balance.

Table 3 Stakeholders interviewed

Group of actors	Gender (Female/Male)	Code
Community Representative 1	M	CR-M-01
Community Representative 2	M	CR-M-02
Ministry of Environment and Water Representative 1	F	MEW-F-01
Ministry of Environment and Water Representative 2	F	MEW-F-02
Ministry of Environment and Water Representative 3	F	MEW-F-03
Other Ministries Representative	M-M	OM-MM-01
Regional government representative	F	ARGL-F-01
Municipal Government Representative 1	F	M-F-01
Municipal Government Representative 2	F	M-F-02
International Cooperation Representative 1	M	I-M-01
International Cooperation Representative 2	M	I-M-02
University Representative	F	U-F-01

We used semi-structured interviews according to an open interview guide (Kvale & Brinkmann, 2009). Participants were asked about their perceptions of the water problems in the area, the possible solutions, the main challenges, the river basin committee work, its outcomes, their participation, the results from that process, and their suggestions to improve the work and the water situation. These questions allowed us to understand how each actor builds his/her frames regarding the object of study. Against this backdrop, it was possible to reveal in which way frames are disconnected or connected.

Furthermore, we observed the KRB interinstitutional platform functioning during the annual technical and general assembly of December 2020. The purpose of this observation was to understand the interactional framing, namely, how the actors contribute, question, and explore the river basin water issues, and how the assembly shapes and formulates the river basin scenario. We observed how the participatory process occurs, who intervenes more often, why, and how. Furthermore, in February 2021, we observed the Board of Director's assembly and in July 2021 the Participatory Social Forum and Technical Council meetings. Additionally, during the Participatory Social Forum, we held informal interviews with three community-based representatives. These observations aimed to better understand the actors involved, their actual roles in the platform, the KRB interinstitutional platform meetings' structure and organization in practice, and their actual decision-making capabilities.

Describing the fragmentation/connection of frames implies understanding the KRB context, policy framework, current real-life events, and people perceptions through several pieces of evidence. This research describes the KRB's circumstances and environmental situation based on formerly published studies such as Agramont et al., (2019, 2021), Rodrigo et al., (2018), Archundia et al., (2017), Chudnoff, S. M. (2009), Duwig, C. (2014). The analysis of these secondary data focused attention on the understanding of the river basin context and the environmental characteristics. The policy framework analysis evaluated the problem framing, the policy objectives, and the scale considered with the policies developed in the Katari River Basin. This secondary data review incorporates Law 2798 (2005), the Katari River Basin Plan (2010), the Bolivian Government Comptroller Environmental Audit (2014), and the Katari River Basin Plan (2018), which is the current river basin policy under implementation. This research also explored local media articles published in the period from 2004 to 2019, to consider the social context and important (political) events that took place during the period in which the decision-making and policies regarding the Katari River basin studied here took place.

Data analysis

The study is based on an abductive strategy, based on Blaikie (2009). The former, which seeks to test the theory in particular cases, was applied to develop the semi-structured interviews guide. This research is based on public participation conceptualization by Newig (2007), the conceptualization of decision-making by Dewulf (2019), the fragmentation and connection of frames contributions from Dewulf et al., (2005); Dewulf et al., (2011), and a contribution from the sensemaking approach, based on Weick (1995, 2005). The abductive strategy consisted in the development of new categories, based on the interviews, participants interactions during their meetings, and supported by the notes made by the researchers during the observation process.

In the data analysis: First, we organized the data based on the theoretical framework. We applied the model proposed by Newig (2007) – see Figure 11. Then we build new categories based on the language expressed by the actors. The data analysis was implemented through the coding and categorization method (Coffey and Atkinson, 1991). We used the NVivo software to analyze the 11 interviews, the transcript of the General Assembly meeting (December 2020), of the Board of Directors Assembly (May 2021), of the Participatory Social Forum (June 2021), of the Technical Council (June 2021), and of an informal discussion with three community-based representatives, held after the Participatory Social Forum.

In the open coding stage, we labelled the most important information using the three key categories from Newig (2007) - context, process, and results - and the "fragmentation and connection of frames" category. For this process, we considered the notes from the observation and the information based on the documents review. Then, we started to build new categories, from the axial coding. There we established political context as a category influencing the fragmentation and connection of frames. This new category is presented in the discussion section.

4.4 Results

4.4.1 A complex context, a fragmented system.

Newig (2007) suggests that the societal context influences the public participation process. At the same time, three dimensions are considered with the societal context: The problem complexity, societal structure, and the spatial scale. In the following sections we discuss these three in relation to the KRB.

Problem complexity

The KRB represents a high level of complexity since there are four main environmental drivers generating the contamination: Mining passive environmental waste allocated in the Milluni Mine, urban wastewater, industrial effluents, and solid waste produced in the cities of El Alto and Viacha (Agramont et al., 2019; MMAYA, 2010; CGEPB, 2014; Archundia et al., 2017; Archundia et al., 2018; Molina et al., 2017). These drivers occur in divergent local spatial and jurisdictional scales and involve many authority jurisdictions and stakeholders. Moreover, the impacts associated with these environmental drivers are materializing in a different spatial scale in which vulnerable indigenous groups are affected by the environmental impacts (Agramont et al., 2021). To find a sustainable solution to the problem of environmental degradation, the potential solutions must be linked with the origin of this problem in which these environmental drivers are the primary sources of contamination.

Spatial scale

As shown in Figure 4 – Chapter 2, the spatial scale, which is linked to the problem of contamination, points to a hydrological system incorporating five main municipalities: El Alto, Viacha, Laja, Pucarani y Puerto Perez (Agramont et al., 2019; Chudnoff, 2009; Duwig, 2014; Duwig et al., 2014; Molina et al., 2017). Moreover, river basin policies developed from 2004 to 2010 align with this spatial scale in which the hydrological system is linked to the previously mentioned municipal jurisdictions involved. On the other hand, the KRB´s Plan 2018 incorporated the "Lago Menor", now involving 24 municipalities in total. This policy is currently under implementation (see Figure 13). This change on the policy spatial scale may have important implications for how the KRB scenario is framed, since hydrological spatial scale shows a link based on the river basin interrelations, i.e., stakeholders are connected through the surface water crossing their jurisdictions. In contrast, the municipalities in the 2018 policy increase the number of problem frames involved. At the same time these lack an interconnection. This increases the complexity and challenges in the framing process during the river basin committee meetings.

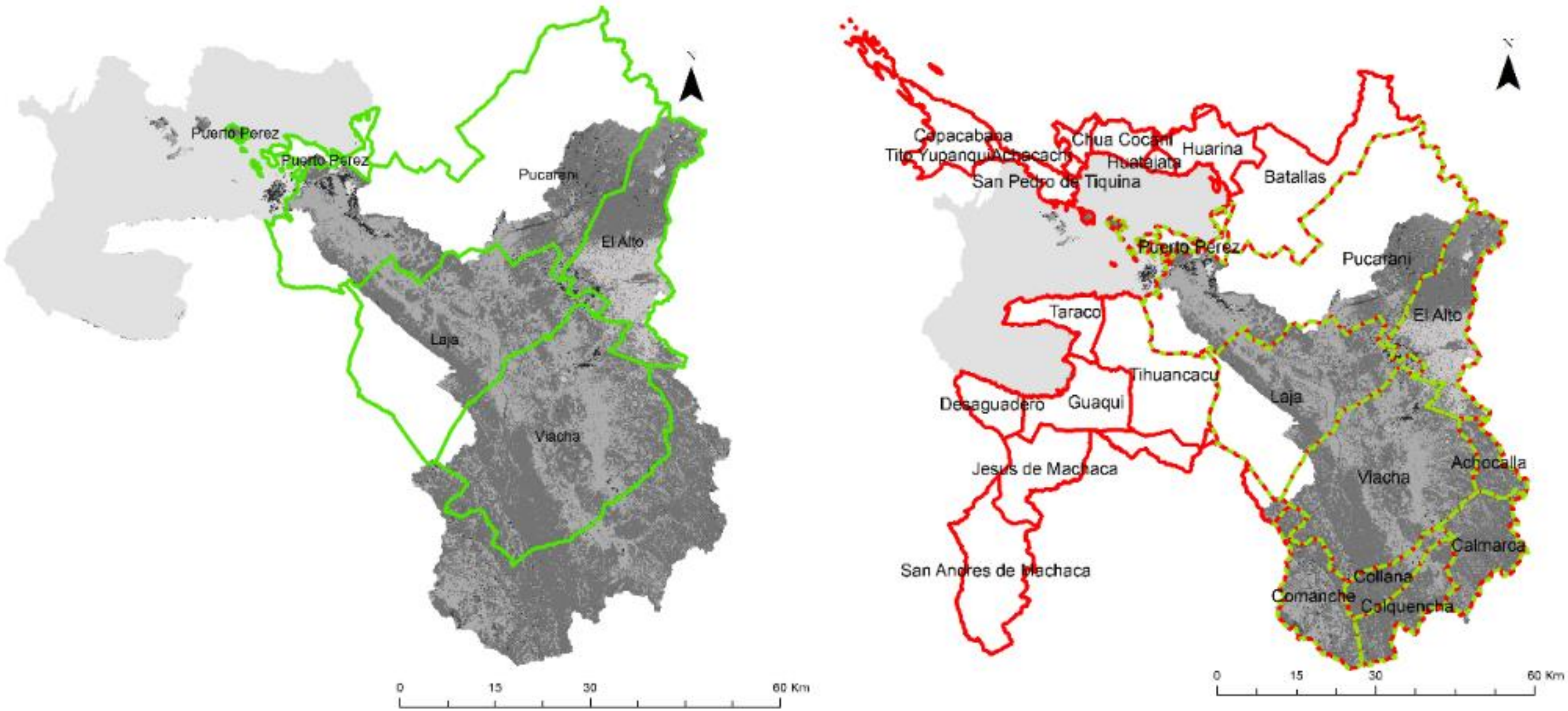

Figure 13: Spatial Scale. Left shows the intersection between KRB and the main municipalities' jurisdictions involved. The right shows the 2018 KRB intersected with the 2018 Katari River Basin Plan jurisdictions involved.

Actors/stakeholders

Actors are considered a fundamental dimension of the context. They certainly determine how a collaborative decision-making process takes place. At the same time, the actors are the ones bringing the diverse frames to the discussion tables, which will shape the decision making and water policy outcomes. The Katari interinstitutional platform involves a large diversity of stakeholders in the participatory process. However, although the problem of contamination in the KRB impacts local rural communities, these are currently not considered as relevant stakeholders in the participatory process:

> *Almost no, we are not invited to participate. Perhaps further down, other communities, other municipalities are invited. Of course, it would be important to participate, to have knowledge and [to know] what improvements are being made by the central government, it would be interesting. (Community representative 1)*

Moreover, since most environmental drivers are allocated in EL Alto municipality, this can be considered a fundamental actor to solve the problem of contamination. However, several stakeholders considered that the participation of this stakeholder has been significantly limited:

> *This has also been another big problem, that the municipality of El Alto itself has not always been a participant despite the fact that it is the main source of contamination (Ministry of Water and Environment Representative 2)*

This could be explained through the following argument of a municipality representative:

> *In two of their assemblies, I complained because the rest of the twenty-odd municipalities were given the same weight as El Alto… El Alto did not have a main role, nor the importance it deserves, investing to solve the problems according to the other municipalities. It has lost its prominence and really the problems are in El Alto, because it is the largest concentration of people living here compared to the municipalities that surround the Lake and that really do suffer the consequences. I've seen that deficiency (Municipal Government Representative 1)*

The results of the data analysis reflect 39 references in 11 interviews mentioning that the lack of participation of El Alto is linked to the political context:

> *The main factor is the political divergences that it has had, in the last 5 years another (municipal) government has been, not related to the MAS (national) government, then the national government has not given much importance to the municipal government. And it has also been reciprocal, the municipal government (of El Alto) participates but at*

the level of its technicians, who do not have a lot of decision (Ministry of Environment and Water Representative 1).

At the same time, the KRB participants reflect some important divergencies in framing the problem at different scales. On the one hand, most of the participants frame the situation of the Katari river basin as situation of surface water contamination. On the other hand, at the municipal local levels it seems that there are also other priorities involved:

They all demand solutions to the environment, to have projects and other things, but when it must be seen where the resources are going to be allocated, they prefer (to invest) more in other types of projects, such as classrooms, football fields, paved streets, it is what is prioritized the most, more infrastructure. (Municipal Government Representative 2).

Also the community-based representation reflect additional water challenges present at the local levels:

What we want and several of our communities also, here in the region of the Ingavi province and all the provinces that we have attended this forum, we do not have drinking water… They said: ´we need wells to be drilled, we need water, you know well that water is life´ (Informal Interview – Social Participatory Forum)

It seems that the higher levels of authority, Ministry of Water and Environment, are considering environmental priorities over other local needs. Consequently, the ministry authorities developed and tried to implement environmental infrastructure in municipal and rural communities, albeit without much success:

We have already had bad experiences with the case of Copacabana, Tiquina, Achacachi, they have been given infrastructures and for Z or X reasons they do not operate to date, they have had these infrastructures for more than 6 years. So, it is complex ... (Ministry of Water and Environment 2).

At the same time, there is evidence of a lack of trust among stakeholders involved in the KRB interinstitutional platform. This mistrust is expressed by the community-based organizations toward the ministry government agencies.

But our own technicians don't know about the environment, they don't know the laws, the rules or their functions. When we go and say brothers we want this project (…) they do not know where to direct, they only tell us there is no budget, nothing more. But they don't guide us (Informal Group Interview-July 2021).

Sometimes they carry out activities and they do not call us (community-based authorities), they do not take us into account (…) they only tell us: such a day will come from such a ministry, there is this activity prepare, organize, come. So, we are there on

> *that day, we are attending, everything, but we do not know what is behind it, what institution is behind it, whether or not this project can be continued. (Informal Group Interview-July 2021).*

Furthermore, there was expressions of mistrust to the people chosen by the Ministry, because they are "outsiders":

> *The one who is now from the Ministry of the Katari basin, who is there? a cochalo[5], that cochalo, does he know our reality? No, the government is making a mistake. (Informal Group Interview-July 2021).*

One of the representatives from the international cooperation argued that the mistrust can be a result of the lack of constant information. This could also be a trigger of discontent, as one representative of the communities complained:

> *Now another thing is that mayors sometimes, from my point of view, sometimes seek prominence and that's why they just do everything, they meet with whoever, they do everything. But in the end, all these projects, all these agreements do not reach us, we do not know anything and that was also our annoyance (Social Forum Interview).*

4.4.2 Decision-making process.

In collaborative forms of governance, the type of decision-making process and its design will determine who participates and the flows of communication and interactions among actors. This can be considered essential for the coproduction of knowledge and the connection of frames. Within the decision-making process, there are two categories explored: participatory process design and process realization.

Participatory process design

The process design takes an important role in warranty fairness in terms of equal opportunities for participants to share their concerns and express their ideas. It can be considered relevant for the framing process and find collective solutions to deal with the socio-ecological complexities.

The Katari river basin shows that the decision-making process design did not directly involve the local communities impacted by the contamination. The invitation enacted by the Ministry of Water and Environment was delivered to a regional community-based organization[6] , which is

[5] A person from Cochabamba department, located in the east of La Paz department (where it is the Katari River Basin). However, the Ministry of Water Management is actually from Pando (north of Bolivia).
[6] Bartolina Sisa and Tupac Katari indigenous organizations.

above the KRB geographical scale. The local community representation was informed about the KRB Social Forum event through other canals, and the participant reflected discontent about this situation:

> *Although we received the invitation, the executive authorities, it has been from the federation[7], the coordination it is not directly with us (Community Representative - Informal Interview – Participatory Social Forum).*

> *I suggest including especially the people who live in the place, from the communities on the shore of Lake Titicaca. If we could integrate the people who know the reality, the people who also speak Aymara sister, I am not against us only speaking Spanish or Aymara[8], but rather, the person who speaks Aymara directly in their language will explain to us, and in that way, I believe that we can take concrete actions with the participation of the communities (Community Representative 2).*

Second, the process design includes representation of local public authorities in terms of Municipal Governments. However, since 2018, the river basin policy has incorporated 24 municipalities (see Figure 13). Consequently, this process design included municipal governments out of the KRB hydro-geographical scale. In river basin collaborative governance, the influence of an inconsistent match between the hydrological geographical scale and the participatory design may have a crucial influence over the connection of frames. Some participants observed this issue and considered that this might negatively influence the process:

> *So, if it's not my problem, what am I going to contribute? I'm sitting there looking at everything they talk, don't you see? So maybe the board of directors or the one that does, let's say, the organization, (should) identify all different problems at the beginning and identify which institutions relates with that problem. So, by affinity, if it's my problem, I'm going to complain, I'm going to say something, I'm going to complain (Regional Government Representative).*

As mentioned previously, the KRB interinstitutional platform has a design in which it clusters stakeholders based on their institutional background. The structure of this river basin governance system was designed under 4 clusters (see Figure 12). First, The River Basin Board of Directors incorporates the Ministry of Water and Environment, the State Government of La Paz, and the autonomous municipal governments. Second, The Technical Council includes university representatives, research institutes, and international cooperation agencies.

[7] Regional rural organization, this one is larger than the hydrological geographical scale.
[8] Local indigenous language spoken in the Andes region.

Moreover, the Participatory Social Forum gathers community-based representation, which incorporates farmer unions, fisherman associations, neighbourhood boards, dairy producers' cooperatives, and irrigation federations, among others. Finally, the River Basin Management Unit is the decentralized Water and Environment Ministry´s arm responsible for the coordination and operationalization of the river basin plan; in other words, it is the public authority responsible for the KRB plan implementation. Clustering the interaction among these forms of knowledge may be considered a driver behind the connection and fragmentation of frames within the participatory process.

Process realization

The KRB participatory process realization includes a system in which the Social Participatory Forum takes place first, then the Technical Council is launched, and one week after the board of Directors meeting is held. Finally, a General Assembly, which includes all representatives of these three groups, takes place. The structure of all the above-mentioned meetings included three segments: an introduction ranging from two to two and a half hours, a round table discussion from one to one and a half hours, and the resolution presentation from thirty to fourthly five minutes. In the introduction, the Ministry of Water and Environment presented the KRB management plan and the implementation progress. It was a one-way information flow that highly limited the interaction and discussion among participants and restricted any form of connecting frames.

> *The information provided to the beneficiaries of the Katari Basin is highly biased (Ministry of Water and Environment Representative 3).*

> *Mostly, what they have done is inform us what projects are being done, in what percentage of progress they are and how they are facing it. That is what they reported in the assemblies, but I have not seen scenarios where they tell us 'what ideas do you have? ', or 'what projects do you have? present them' so we can manage them through the platform (Ministry of Water and Environment Representative 2).*

> *It is a presentation of the UGCK*[9] *showing their annual report and that explains that everything has been done very well, that it has spent its budget, that is everything ... in fact when we leave that (the assembly) we have the impression that world is perfect (between laughs), I hope that is the case, but I sincerely doubt that it is really the case knowing the basin (International Cooperation Representative 2).*

[9] Ministry´s Katari Basin River Management Unit.

During the second part of the meetings, the ministry staff organized discussion tables and assigned participants to each roundtable. By design, the process realization was fragmented since each meeting incorporated six discussion tables which were clustered by the following five themes: 1) Institutionality with plural participation and social control, 2) population and water security for production, 3) hydraulic-environmental quality management (two tables), 4) life systems sustainability, and 5) knowledge management and hydro-environmental information. Each table was assigned to a specific topic, and the discussion was hence framed around a specific theme. The majority of organizations were represented by one individual. Consequently, they were limited to participate in just one roundtable and did not have the opportunity to have a dialogue about other themes that might be of their interest:

> *Not all municipalities participated in these working groups (tables), because all municipalities have their problems that are not always similar. In other tables, for example, the theme worked was wastewater, well I have not participated (of that one) but we also have wastewater problems, and we have ideas to solve it. (Municipal Government Representative 2).*

It is worth noting that these six roundtables were organized based on the KRB 2018 policy strategy, which suggests approaching these 6 topics in order to implement the plan. In this second segment of the meeting, the observations showed a higher level of interaction and dialogue among participants. However, after the first few hours of introduction, many participants showed participation fatigue, and some others left the meetings before the last segment.

Finally, the third part of the process realization was to present the meeting resolution. During this part, in the Board of Directors and General Assembly, the ministry staff presented the resolution. In the Technical Council and the Participatory Social Forum, each roundtable assigned one representative to present their resolution.

The lack of interaction and dialogue about the actual participation observed in the meetings was also commented on in the interviews. Participants considered that the KRB interinstitutional platform is a space in which the Ministry informs about the KRB plan implementation progress:

> *I would not really evaluate it very positively because as I tell you I see it a lot as a meeting of components that can interact but do not really interact, we meet but we do not interact and the worst thing is that since we do not interact, we do not discuss, we did not conclude and therefore we did not act. So, as you see, it is a sequel, there are steps that must be distinguished and we have stayed in the first step, in the idea that we have to improve, that there is a problem (University Representative).*

In sum, the observations during the KRB interinstitutional platform meetings show that although there seems to be a willingness to participate, the degree of intervention in the meetings is rather low. The behaviour ranged from some participants interacting with their cell phones or leaving the meeting room to attend phone calls, to some participants falling asleep during the meetings. In fact, almost 50% of the participants left the room before the meeting resolution was presented. This can be linked with the unidirectional flow of information in the meetings. Namely, ministry representatives presented their activities and their results, without involving the participants in their presentations. The only time participants had the opportunity to talk is during the working tables, which started after two or three hours of participants only listening. However, even then, the discussion was fragmented by the topics chosen by the Ministry representatives who had designed the process. Moreover, even though there was a diversity of actors present, not all of them seemed to intervene with the same frequency as others.

4.4.3 Participation results: uninformed actors, unilateral initiatives.

The decision-making results of a collaborative process can be classified into two main categories: the direct results of the decision-making process and the substantive output and outcomes.

Direct results

Within the direct results of the participatory process, the model reflects that there will be an information gain on behalf of the competent authority, a potential conflict resolution and the acceptance and identification with the decision made during the process. The KRB results show a limited information gain on behalf of the competent authority since, as mentioned previously, the information flow was mainly unidirectional. Participants did not have significant interaction with public authority, and consequently, they did not provide considerable insights into the process. At the same time, non-state actors also reflected a limited information gain and understanding of the KRB interinstitutional platform. For instance, many interviewees showed confusion between the river basin plan, the interinstitutional platform, and the KRB management unit. Some participants referred to the interinstitutional platform as the KRB plan and others to the KRB management unit as the interinstitutional platform. This reveals a limited information gain and a clear lack of understanding of the governance structure system and its functioning.

By design, the KRB decision-making process did not allow consensual conflict resolution. As mentioned previously, each cluster of stakeholders was limited to similar forms of knowledge and institutional background, consequently to a certain form of frames. As a result, since transdisciplinarity benefits are hampered through this compartmentalized dialog among stakeholders, potential conflicts become active:

> *We are already thinking, since they ignore us, that we are going to close their (water supply) valve (Community Representative - Informal interview Participatory Social Forum).*

This can also be linked to the acceptance and identification with the decision from the local actors. Thus, the community-based organization tends to criticize the limited actions and results on behalf of public authorities, and on the other hand, ministry representatives tend to accuse local communities of blocking the projects they try to implement within their municipalities.

> *Here the great limitation also, from my perspective, are the communities; when one wants to do a project there are communities that are opposed and because of the issue of not having social consensus, (the project) it is delayed a lot and funding is lost, the issue of solid waste is complicated (Ministry of Water and Environment Representative 2).*

The lack of trust is also an effect of the previously mentioned elements. The KRB shows a lack of trust towards the KRB management unit and the interinstitutional platform:

> *But as I said, the platform at this time is not something essential for us to carry out our projects. (Ministry of Water and Environment 2).*

> *At the end, many decisions are not made with really positive impacts for the management of this basin. (International Cooperation Representative 2).*

Substantive outputs

In relation to the participatory decision-making substantive outputs there are three considerations to take into account: decision outcomes, the implementation of the decision, and the environmental outcomes. The decision outcomes refer to the actual resolution arising out of the process. However, the KRB shows no evidence of consensus-oriented decisions emerging from the process. Instead, ministry agencies, municipal governments, and international cooperation agencies mentioned individual projects implemented based on each organization´s unilateral decision as their contribution to the river basin problem:

> *We have also done an action, as I told you, we have done a cleaning of the entire lake shore, of our sector, of our section, up to there no more, which corresponds to us; we cannot go anywhere else, because it is another section, other communities, they shall also have to mobilize and clean up. in this way I think we can maintain our lake (Community Representative 2).*

At the same time, the decisions made during the participatory process should be included in the river basin policy as measures to be implemented. However, the KRB plan did not result from a consensus-oriented decision-making process developed by the interinstitutional platform, but was developed by the ministry staff and delivered to the stakeholders involved. Furthermore, the 2018 policy plan lacks concrete objectives and reflects a high level of ambiguity:

> *As long as they do not really have a planning instrument … that is not the (Katari River Basin) Master Plan because it is more an assessment, and it is very biased, it is not very specific; for example, all compliance is not being measured based on indicators (Ministry of Water and Environment Representative 1).*

> *For me it is not a plan, it seems more an assessment and perhaps recommendations for strategies. Planning should be long-term (actions) based on the diagnosis and really identify what are the biggest problems (International Cooperation Representative 2).*

Concerning the implementation of the decision, the Ministry and Municipalities pointed to limitations for the KRB plan implementation due to the resistance of community-based organizations:

> *After the community has told us we do not want (the project), we have found another place, it has been with dialogue, with the regional government. It has been very complicated, and we have finally had the land. But the last thing that came to us is that this new place for the treatment plant, the local people do not want it (Ministry Representative - Board of Directors Assembly).*

The environmental results are expected to reflect the improvement on the environmental condition such as water quality, biodiversity, or other environmental indicators linked to the policy objective. However, the timeframe of the KRB policy implementation does not allow to see actual environmental effects linked to the participatory process, since the policy implementation under analysis was initiated in 2018. On the other hand, there have been over 16 years of river basin policy implementation, and the trend of contamination does not show any improvements (Agramont et al., 2021).

At the same time, community-based representatives considered that the measures that are currently implemented lack sustainability. For instance, one of the measures implemented by the ministry is the solid-waste recollection on the Titicaca Lake shores. This action may be considered positive in the short term to deal with the environmental impacts in the river basin, but it does not seem a solution in the long term. On the other hand, without measures tackling the sources of the problem, which are located in the cities of El Alto and Viacha, the solid waste will still be present on the Lake Titicaca shores.

> *I remember that two years ago or maybe a year and a half, they have cleaned the entire shoreline of Lake Titicaca, the Huajta cemetery, the entire shore up to Cohana I think they have arrived; I don't know that place well, but they did clean. But that was momentary, if we return now it is still contaminated (Community Representative 2).*

4.4.4 Framing the Katari River Basin Scenario.

In this section, we distinguish two main ways of framing the KRB problem. On the one hand, we assess how policies and government official reports frame the water challenges in the river basin. On the other hand, we discuss the problem framed by stakeholders participating in the KRB interinstitutional platform.

Policy framing

The public policies developed since 2004 have mainly framed the KRB problem as a scenario of water pollution. In 2004 a national congress decreed the Bolivian Law 2798, declaring the KRB an “environmental disaster zone” and recalling a “fundamental need to decontaminate” the river basin (Law-2798, 2004).

Later, in 2010, the Ministry of Water and Environment introduced the Katari River Basin Plan. This plan framed the problem of the KRB in terms of water contamination, from which it specifies the “increasing deterioration of water quality due to its intensive use, insufficient treatment, the disposal of solid waste in water bodies and the organic contamination from agricultural activities in the rural area downstream” (MMAYA, 2010). At the same time, this policy also identifies that the water resources are insufficient to supply the river basin demand.

The 2014 KRB´s Environmental Audit report frames the KRB as a problem of water pollution. At the same time, this environmental audit evidences three main environmental drivers within the hydrological system: the acid mine drainage linked to the mining region; the urban wastewater, solid waste, land field leachate, and industrial emissions associated with the cities of El Alto and Viacha, which are considered the urban industrial region; and farming organic pollution related to the rural region (CGEPB, 2014). In contrast, the 2018 KRB policy frames the situation of the Katari river basin as: 1) degradation of environmental functions and hydrological micro-river basins; 2) reduction of biodiversity and fish fauna; 3) degradation of the totora[10], decrease of its environmental functions and its uses; 4) unsatisfied demand for water, water shortages and conflicts; and 5) life systems vulnerability (PDCKYLM, 2018). This shows that until 2018, the majority of policies framed the KRB as a problem of contamination and insufficient water resources. On the other hand, the KRB policy 2018 frames the situation in a rather ambiguous manner, whereby the “critical problems” presented do not have a strong link with the previous policy domain.

Actor´s framing

The interviews with the stakeholders reflect a diverse understanding of the problem present in the Katari River basin. The majority of participants framed the issues of the Katari River basin within a water contamination domain. This gives an opportunity to explore the common ground, negotiate and explore common values in relation to the KRB situation. On the other hand, the problem frame reflects divergencies (see Table 4).

Table 4 Actor´s problem frame

Stakeholder	Interview response	Problem frame

[10] Andean plant, a subspecies of the giant bulrush sedge

Community Representative 1	The city of El Alto produces a lot of wastewater which is what is polluting Lake Titicaca	Wastewater Pollution from El Alto
Community Representative 2	for us, who understand the environment, we are worried Because the city of El Alto is polluting the Titicaca Lake	Pollution from El Alto
Municipal government representative 1	The river basins have not been taken into account, or in this case the micro-watersheds, I'm talking about El Alto	El Alto not taken into account
Municipal Government Representative 2	This has also been another big problem, that the municipality of El Alto itself has not always been a participant despite the fact that it is the main source of wastewater, sewage, industrial and solid waste contamination generation. Nobody was interested in that subject; it was like the fifth wheel not so much for our municipality, for the municipality that is next to it, which is El Alto	El Alto´s lack of participation Lack of environmental interest Pollution from El Alto
Regional Government Representative	activities related to solid waste management so far we have not really identified which is the company that emits the most discharges for this pollution	Solid waste contamination coming companies Lack of detection of the company reproducing solid waste

International Cooperation Representative 1	The Katari river basin has most of the population concentrated in the city of El Alto and this population of course produces important effluents not only from domestic wastewater but also from industrial use water. You already know that in Bolivia we still do not have a water law, which is what would allow us to have a much more rigid control over discharges. the Katari river basin, the majority of the population is concentrated in the city of El Alto	Industry and urban wastewater produced in El Alto Lack of water legislation Population growth in the city of El Alto
International Cooperation Representative 2	the impact of the city of El Alto in terms of industrialization there is no sewage collection - There is a phenomenal use of antibiotics in El Alto it could be due to the lack of a water law	Industry contamination from EL Alto Sewage infrastructure Large use of antibiotics in El Alto Lack of water legislation
Ministry of Environment and Water Representative 1	The issue of decontamination is established as the main problem of the basin, with the issue of the bloom, that is the main problem.	Environmental contamination in the River Basin
Ministry of Environment and Water Representative 2	also what is in the matter of solid waste as these rivers are open, we do not have the education where both industries and people dispose of their liquid discharges into rivers	Lack of population´s solid waste education Wastewater from industries and citizens

Ministry of Environment and Water Representative 3	wastewater from the city of El Alto the city of El Alto does not participate in these roundtables for dialogue and discussion	Wastewater from El Alto Lack of participation of El Alto
Other Ministries Representative	save contaminated sites, but that contaminated link it to whether or not it affects human health The main concern is the environmental issue	Environmental remediation linked to human health Environmental problems
University Representative	all the garbage that comes from the city of El Alto in the Katari basin the problem of contamination by heavy metals is serious ... there are also health problems	Solid waste from EL Alto Heavy metals contamination

For international cooperation representatives the water issues are linked with the lack of water regulations. They frame the problem in terms of lack of a water law and the "phenomenal use of antibiotics in El Alto". For the community representative 1 and Municipal representative 2, the water problem understanding is more related with the city of El Alto. However, for community-based representatives the problem is framed as a situation of wastewater contamination produced by El Alto. On the other hand, Municipality representatives frame the problem as El Alto´s lack of participation. At the same time, the regional government representative mainly framed the problem as a problem of solid waste management and industry contamination.

Moreover, the different types of pollution linked to the meaning of water issues are also linked with the frames of the stakeholders interviewed, based on their institutional context and respective backgrounds. For instance, the person responsible for solid waste in the Ministry of Water associates the problem and its solution with solid waste, while the representative of the University associates both with education. A community-based representative framed the problem based on a sense of community that goes beyond the human being.

> *When we speak of caring for the environment as a central point is the person, the human being, which should not be the case. I believe that we should start from the sense of community, considering that the community is not only a human community, the community is also made up of all the elements of nature, be they stars, animals, plants, the*

> *air we breathe, the sun, the coexistence that we have every day, that is the true community (Community Representative, 2).*

Moreover, stakeholders' perception of the potential solutions also reflects an important fragmentation, although there seems to be a common understanding of water-related issues. Moreover, despite the fragmentation of the problem, there is an agreement regarding El Alto's contamination as a pivotal cause of water issues. In relation to the solution perspective, most agree about the necessity to encourage interest, participation and communication among the actors (see Table 5).

This diversity of problem and solution frames seem to have another unexpected result in a collaborative system. Some of the solutions implemented in the framework of the 2018 river basin policy for the Ministry of Water and Environment have attracted complaints from the communities around the Katari River Basin.

> *Yes, we are entering very strongly with the issue of decomposition in the projects, in the socialization, in explaining the characteristics of the project to them removing the taboos that they have that we are not going to generate another dump without any measure of control towards the environment, they think that they will continue to pollute the infrastructure, we have fully explained them what is intended rather with these new infrastructures. This is to ensure that adequate provision is made and safe environmental sanitation and what we tell them a lot is that this follows the law and, as the law says, in keeping with the protection of mother earth (Ministry Representative, 2).*

Table 5 Relation among actors and frames of problem/solutions

Relation among actors and frames of water problems (P) and solutions (S)																		
Actor	Solid Waste		Industry Contamination		Wastewater		Lack of legislation		Environmental Protection		Pollution from El Alto		Information, participation and communication		Mining		Education	
	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
Community Representative 1	X				X				X		X			X				
Community Representative 2		X							x		X			X			x	X
Municipal Government Representative 1	X										X			X				
Municipal Government Representative 2	X		X		X						X	x	x	X			x	X
Regional Government Representative	X		X											X	x			
International Cooperation Representative 1			X		X		X	x			X			X				
International Cooperation Representative 2			X		X		x	X			x			X				
Ministry of Water and Environment 1									x	x		x		X				
Ministry of Water and Environment 2	x	x	X		X									X				X
Ministry of Water and Environment 3					x						x	x	X	X				
Other Ministries Representatives									x	x			X	X				
University Representative	x												X	X	x		x	x

4.5 Discussion

There are two main outcomes from the analysis of the results. First, the decision-making process design has an important influence on the fragmentation of frames. Second, the political context influences over the framing process.

4.5.1 Fragmentation by design.

The Katari River Basin presents a fragmented system scenario by design. The governance structure design clusters the organization´s representation and insolates forms of knowledge, which very likely contributes to the fragmentation of frames. The Platform structure is divided in three different groups. First, at the Directive level there is no participation of social organizations, or community representatives, neither of academics. Second, the Social Forum is only composed of social organizations and community-based representatives. Finally, the Technical Forum is restricted to academics, international cooperation agencies and technicians from the public administration. As we could observe, the meetings of each division were reserved to the members of each group.

Without a proper consideration for the integration of different forms of knowledge in the participatory process design, the interaction and dialogue among participants becomes fragmented. The KRB shows evidence of a design that limits the co-construction of understanding of the situation dealt with in this river basin. As a result, it is suggested that the participatory design consider a process in which the problem framing can be jointly constructed to connect frames, build common values, develop trust, and engage in the process.

At the same time, the KRB 2018 policy developed by the Ministry is the one guiding the participatory process design. This shows a strong link between the decision-making outcome/results and the process design. The 2018 KRB policy, which can be considered the first stage outcome/result, is now being employed as a guiding document for the participatory process design to structure the KRB interinstitutional platform and the roundtable discussion´s themes. This confirms the model developed by Newig (2007). At the same time, many participants interviewed considered that the KRB 2018-2030 plan is just an assessment and lacks clear objectives. Thus, the lack of precise objectives and policy ambiguity permeated the participatory process design influencing the effectiveness of this governance system.

At the same time, this case study revealed that the relation between spatial scale and the participatory process design holds strong links. The Katari river basin evidences an essential mismatch between spatial problem scale and the participatory design, which may be considered one of the meaningful elements behind the fragmentation of frames. The lack of consistency between the problem’s spatial scale and the participatory design increases the frames involved.

These broad spectrums of frames do not show evidence of an interrelation and connection since their water problems' background relies on divergent realities and needs.

The participatory process design must considers the interconnection and relationships incorporated in the these socio-ecological systems at the time to select participants which will participate of the river basin committee. River Basins do not merely connect rivers, but also social, political, and economic structures. Without a clear understanding of these interrelationships and of the connections among participants involved, the participatory process may lack effectiveness. Furthermore, the lack of interrelations among stakeholders may increase ambiguity and consequently, the fragmentation of frames may increase.

4.5.2 Political Context.

The analysis unveiled a frequent association of the political context with the KRB participatory process. There were 39 references in which the participants recalled a limitation based on the political context or the political interests within the interinstitutional platform. For example, the city of El Alto can be considered the most important setting and main actor associated with the water contamination problem and the potential solution at the river basin level. However, El Alto has not been an active stakeholder participating in the river basin interinstitutional platform. This can be linked to the strong influence of the political context over the KRB interinstitutional platform because of political differences between the national government and the municipal government.

> *I think that the decision-makers, because of this political pressure from the voters, are responding to their rural voters. (International Cooperation representative, 1).*

This shows an additional exogenous factor influencing the participatory process. The political context has been a considerable influence on the river basin committee, informally limiting and restricting the participation of the stakeholders, and consequently limiting a collective framing process. At the same time, the municipal government of El Alto does not seem to perceive water contamination as a main problem within their local scale. In contrast, if they acknowledged their role in the contamination problem, they would also be held responsible for resolving this problem. This would imply high expenditures and investments to reach beneficial results, in the first place for downstream communities, and not for its own inhabitants.

Furthermore, political context seems to influence the framing in the KRB interinstitutional platform because of the staff that is constantly being changed, as a consequence of the changes with the political party of the government11. It is thus suggested that future analyses incorporate institutional stability and staff turnover in the public as another element of analysis in participatory and framing process.

4.6 Conclusions

The diversity of backgrounds, disciplines, cultures, and knowledge usually brings a variety of frames and understandings related to the problems and issues in collaborative water governance. However, the fragmentation of frames that are at stake in these governance bodies... the fragmentation of frames under these transdisciplinary networks may impede a common understanding. This can result in controversies which can impede effective decision-making and influence water policy outcomes. This study aimed to understand the causes behind the fragmentation and connection of frames. Such understanding may be highly beneficial in managing the decision-making ambiguity, building shared values structures, and improving collaborative processes of water resources policy developments.

The results reveal a strong link between the participatory process design and the framing process. The Katari River Basin multi-actor platform evidence an insulation of frames restricting collective knowledge construction, enhancing potential conflicts and impeding collective decision-making. Such a design contributes to the fragmentation of frames in collaborative water governance. This study also showed an intricate relation between the spatial problem scale, the decision-making design, and the fragmentation of frames. The case of the Katari River Basin demonstrates an essential mismatch between spatial problem scale and the participatory design, which can be considered one of the meaningful elements behind the fragmentation of frames.

The political context also holds a strong influence over the framing process. This case study evidences the potential political context implications over the participatory and decision-making process, which at the same time, influence the framing process. The political context may permeate and influence river basin committees, fragmenting the decision-making process and informally limiting and restricting the participation of divergent stakeholders. The differing frames expressed by stakeholders are thus strongly related with the different meanings they attribute to the water issues. These meanings are part of how the actors develop their sensemaking about water issues, strongly connected with the social, political, and institutional context.

[11] Between 2019 and 2021, Bolivia had three different governments, one of them (from December 2019 till December 2020) represented the opposition to Movimiento Al Socialismo (2006- 2019/ 2020- Currently).

These findings have some important implications for practice, particularly for decision-makers and water resources managers developing river-basin committees to implement integrated water resource management policies. They may allow practitioners to manage better the fragmentation and connection of frames in collaborative water governance arenas.

Chapter 5

General Conclusions and Recommendations.

5.1 General Conclusions

While IWRM is widely recognized as the best water management approach, its implementation has been challenged for over a decade in several contexts worldwide. One of the main challenges relies on the limited understanding of the social and environmental relations behind river basins.

Employing the KRB case study, this study evidenced the need for a detailed understanding of the social and environmental relations behind the IWRM approach. River basins not just connect water through the surface flows, but also connect political, administrative, environmental, and cultural systems that all have an impact on the way water is used and managed. Sustainable solutions of the water related problems demand the understanding of this complexity, and requires the recognition of the interrelations, and interdependencies among these systems. Trough the KRB case study, this research confirms that the limited understanding behind the interdependencies and interrelations among social and environmental systems within the river basin resulted in over 14 years of ineffective and unsustainable water resources policies.

5.1.1 IWRM planning and the transdisciplinary approach

The Driver-Pressure-State-Impact-Response (DPSIR) is a framework initially developed during the 1990s for the development of environmental indicators, this to follow up on environmental policy developments. DPSIR has been widely employed for planning purposes under the IWRM implementation around the globe. However, the socioecological complexities behind river basins must be taken into consideration when employing the DPSIR framework. The complexity behind river basins resides in not only on the interconnection among local spatial scales shaping the hydrological systems, but also on the layers of social administration within these systems. These layers refer to the public administration systems which are usually organized by the national, regional, municipal, and local levels. Water policies tend to be developed and implemented at the highest levels of government, neglecting local levels. Consequently, water policy developments usually lack an understanding of local realities, the culture, interests, and how local groups make sense of the water problems.

This study confirms that the understanding of river basins as a multiscale system allows a broader consideration of stakeholders, notably those from local levels. These stakeholders represent a valuable resource in terms of local knowledge and resources that can articulate water policy design and implementation. At the same time, the understanding of river basins as multiscale systems brings the possibility to tackle the water problems at the appropriate level and spatial scale, where the environmental drivers and pressures are taking place. This understanding can enhance the design of water policies that better fit the scale and involve stakeholders directly linked to the water problems typology.

At the same time, chapter 2 of this study shows that the spatial characteristics within the DPSIR analysis allowed to unveil a mismatch between environmental driving forces/pressures and river basin policies implemented for over 14 years. Consequently, incorporating a spatial analysis within the DPSIR framework may be highly beneficial to better understand the driver-impact relations in river basin policy developments and the management of water resources.

The understanding of the spatial and scalar interrelations of different sectors, public administration systems, and stakeholders certainly increases the level of complexity behind the management of water resources. However, an understanding of this complexity is required to find sustainable solutions to the water problems. Through this socio-ecological complexity dissection, it is possible to increase the sustainability behind water policy developments to better manage the water resources. Practitioners and policy makers must be aware of scalar and spatial considerations to better understand the socio-ecological complexities behind the river basin.

To deal with the sectorial interests and power asymmetries, IWRM recalled the importance of stakeholders participation as a key factor behind water resources management. This is usually articulated through forums organized by public agencies in which non-state actors are engaged in a collective decision-making process that aims to make or implement public policies to manage water resources. However, the diversity behind the knowledge, disciplines, cultures, and backgrounds of stakeholders involved in these processes is not always taken into consideration. This is another element of socio-ecological complexity under the IWRM paradigm. In many contexts, as in Bolivia, the technical and formal scientific knowledge tends to neglect other ways of knowing about water. This can represent a significant obstacle to achieving collaboration among the stakeholders involved. Also, it can influence the functioning of river basin committees since the voices, interests, and values of local informal groups tend to be silenced.

To integrate the diverse disciplines, cultures, and backgrounds behind the river basin management, chapter 3 of this research proposes the transdisciplinary learning community approach. The transdisciplinary learning communities' approach is a process to integrate the diversity behind the river basin committees. This can help to decrease the imbalance in terms of sectorial interests and to integrate the diverse meanings behind water into policies. At the same time, the transdisciplinary learning communities approach aims to integrate the different forms of knowledge from different academic disciplines and different social actors in a joint knowledge production process.

The transdisciplinary learning community approach aims to reduce the asymmetries behind knowledge recognition, to consider voices, values, and the interests of other stakeholders in the decision-making process. Furthermore, this approach represents an opportunity to grant special attention to the vulnerable social groups, who are directly influenced or impacted by the decision-making and water policies. In addition, chapter 2 of this research also confirms the need to pay special attention to vulnerable social groups and to include water policy targets to reduce the burdens over these groups to enhance environmental justice.

Transdisciplinary learning communities are mechanisms to articulate collaborative water governance and IWRM implementation. These can support joint information gathering and analysis. They offer a space in which formerly excluded social groups can express how they make sense of the situations and problems with which they are confronted. Together with them, we have to reflect on how they can be empowered to be actively involved in the IWRM and in this way play a proactive role in the improvement of their reality.

The spatial and scalar characteristics of river basins may be highly beneficial to understanding the driver-impact relations in river basin management. Also, this allows recognizing key stakeholders at the different layers and spatial scales of the system. At the same time, through the transdisciplinary learning community approach, it may be possible to involve these in a collective process of knowledge co-production to integrate the diverse disciplines, cultures, values, and backgrounds of stakeholders involved.

5.1.2 From Transdisciplinary Learning Communities to the KRB Interinstitutional Platform

The water research project to which this Ph.D. relates is part of a broader transdisciplinary research program between the Universidad Católica Boliviana San Pablo (UCB) in Bolivia and the Flemish Interuniversity Council (VLIR-UOS). The vision of the program is that of a community of academic scholars, belonging to different disciplinary projects, working closely together with each other, with public and non-governmental development actors, and with local communities in so-called “Transdisciplinary Learning Communities” (TLC).

The program´s strategic objective is to contribute substantially to the improvement of the living conditions of the most vulnerable groups in Bolivia. This resulted in a group of Flemish and Bolivian academics motivated to put a collaborative and transdisciplinary learning community approach in the Katari River Basin in practice. Also, to implement a collaborative research strategy, to generate the “actionable knowledge” that considers the specific needs, values, and interests of the most vulnerable social groups within the Katari River Basin.

While writing the third chapter of this Ph.D. thesis in 2018, related to the transdisciplinary learning community approach, the Bolivian Ministry of Water and Environment was also developing the Katari River Basin Policy 2018-2030. This policy incorporated the establishment of a river basin committee, to involve diverse stakeholders in the water resources decision-making process and water policy developments. The composition of the river Basin committee developed by the Ministry of Water and Environment included significant similarities with the transdisciplinary learning community proposed in the third chapter of this research. For instance, this incorporated the participation of ministry agencies, regional governments, and municipalities. It also incorporated community-based representatives, international cooperation agencies, non-profit organizations, and universities in the water resources decision-making. Moreover, the Bolivian local university, Universidad Católica Boliviana San Pablo, was formally invited to participate in the river basin committee.

Consequently, the strategy of this water research project needed to be reformulated. Instead of investing efforts in developing a transdisciplinary learning community organized by the Bolivian-Flemish program, we decided to invest our research efforts in the Ministry´s River Basin Committee. However, not all the researchers involved in the Flemish-Bolivian collaboration program agreed or were interested in this new strategy. Some researchers considered that the focus of the research should remain at the local rural local communities scale. As a result, three out of six disciplinary projects engaged in the new research strategy whereas the other three focused on developing a separate learning community at local scale.

This research belonged to the former group and shifted from developing a transdisciplinary learning community to trying to understand the functioning and the structural characteristics of the Ministry´s transdisciplinary learning community named the KRB Interinstitutional Platform. However, we first focus to understand the water problem framing within this river basin committee.

5.1.3 Framing water policies and planning under the DPSIR framework

The river basin committees usually involve stakeholders coming from diverse disciplines, cultures, and backgrounds. Based on their situatedness, stakeholders tend to direct special attention to specific elements of the water problem the river committees are dealing with. For instance, for a private sector representative, the main water problem may rely on water security to warranty their production. On the other hand, for a Ministry Representative, the problem may be framed as an issue of water contamination since there is large public attention on the pollution levels present in the river basin. One of the factors of river basin socio-ecological complexity relies on how stakeholders frame water problems based on the institutional background, discipline, or culture.

Chapter 4 of this research confirms the need to integrate the diverse ways in which stakeholders make sense of the water problems in river basin committees. The Katari River Basin multi-actor platform shows evidence that the insulation of frames restricts collective knowledge construction, enhancing potential conflicts, and impeding collective decision-making. The KRB participatory design cluster groups of stakeholders in separate meetings; (1) public authority, (2) community-based representatives and, (3) research institutes, universities, and international cooperation agencies hold separate roundtable meetings, which restrict the interaction among these stakeholders. This participatory process design certainly contributes to the fragmentation of frames in participatory water governance.

Consequently, this research reveals a strong link between participatory design and the framing process. This study also shows an intricate relation between the spatial problem scale and the fragmentation of frames. As shown in chapter 2, the spatial assessment within the DPSIR analysis exposed that the KRB policy 2018-2030 established a spatial scale beyond the river basin boundaries. This essential spatial mismatch certainly influenced the participatory process design and resulted in several stakeholders involved in the participatory process coming from outside the river basin boundaries. It is important to consider that stakeholders coming from diverse local spatial scales hold specific frames linked to their local realities. When these do not share the same hydrological system, the lack of interconnection among stakeholders certainly increases the ambiguity of the process. Consequently, this spatial mismatch can be considered a significant driver behind the fragmentation of frames within the KRB.

Chapter 2 of this study confirms that the multiscale and spatial analysis, while applying the DPSIR framework, is crucial to understand the socio-ecological characteristics of the river basin. This DPSIR analysis allows us to comprehend the level and the spatial scale where driving forces are taking place, and to determine which stakeholders are linked. Also, this detailed analysis of the river basin allows establishing the level and scale where the socio-ecological impacts are arising, to establish the stakeholders' influence by these impacts. Consequently, a better understanding of the driver-impact relations and the stakeholders involved can be established for a more effective participatory process design.

Furthermore, this study evidences the potential political context implications over the participatory and decision-making process, which at the same time, influences the framing process. Consequently, the political context also holds a strong influence over the framing process. The political context may permeate and influence river basin committees, fragmenting the participatory process and informally limiting and restricting the participation of divergent stakeholders

Without a process to connect society, public authority, and science frames carried by stakeholders within river basin committees, these forums may turn into a space full of ambiguity and uncertainty concerning the problem they are dealing with. Consequently, the process may result in potential conflicts, lack of engagement, and policy outcomes full of *"big words and no choice"*. On the other hand, the connection between society, public authority, and science frames may allow the construction of a joint meaningful story in which the participants can see a more complete picture of the situation they are dealing with. This is beneficial to integrate the diverse forms of knowledge, disciplines, and backgrounds in a society, policy, and science interface, and to engage stakeholders to act and be involved in the development and implementation of water policies.

5.2 Further research

Beyond the fact that this research evidenced the need for interaction among stakeholders within river basin committees to connect the society, public authority, and science frames, it is important to explore methodologies to assure such interaction. To gather stakeholders in the same roundtable does not ensure that stakeholders will interact, reach a consensus and engage in the process. Consequently, participatory methodologies that foster engagement across frames must be explored to support the functioning of the river basin committees, the decision-making process, and policy outcomes.

One of the drivers behind the fragmentation of frames was related to the political context. This research evidences an important influence of the political context towards the fragmentation of the participatory process. This issue should be further explored in terms of power asymmetries and how the power relations within river basin management is structure and be related to the problem in the participatory design, its implementation, and the outcomes of the process.

This research reflects an unsustainable policy development and implementation for over 14 years. However, the relation between river basin policy effectiveness and the functioning of the river basin committee has not been explored yet. Further research efforts must be driven towards this relation.

This research studied the causes and drivers behind the fragmentation of frames in the KRB committee. However, larger attention must be given to scale and the water problem framing. This may allow us to better understand how scales and their power relations influence the framing process, the decision-making, and the water policy outcomes.

5.3 Policy Makers' Recommendations

Who should sit around the table for the water governance of the KRB?

- The KRB environmental driving forces and pressures are spatially located upstream, in regions 1 and 2, see Figure 4. Consequently, to improve the effectiveness of water policy efforts the responses must be directed to manage: 1) the mine waste allocated at the Milluni valley, 2) the liquid urban discharges from the cities of El Alto and Viacha 3) The urban solid waste from the cities of El Alto and Viacha, and 4) land field leach from the Villa Ingenio and Santa Barbara land fields allocated in El Alto and Viacha, respectively. These are considered the most important and prioritized environmental pressures within the hydrological system. Regardless of the amount of efforts policy makers invest downstream, in region 3, if the sources of socioecological distress are not managed upstream, the social and environmental impacts will remain present in the KRB.

- Future river basin policies must consider the actual hydrological spatial boundary of the KRB, see Figure 13. The mismatch between the hydrological system and the river basin policy 2018-30 reflects an important negative influence in many aspects: 1) the lack of understanding of cause-impact relations 2) the lack of effectiveness in terms of the allocation of projects and investments 3) a negative influence on the selection of stakeholders involved, and 3) the increase of ambiguity related to the problem present in the river basin.
- There are two key stakeholders that must receive special attention in future policy efforts: On one hand, the municipality of El Alto is a key stakeholder in the KRB. Most of the environmental driving forces/pressures are taking place under its jurisdiction. Consequently, its participation and engagement are essential to solve the problem of the KRB. On the other hand, the local communities directly impacted should be specially considered. Recognizing the burdens on the local social systems may reveal strong links between the social and environmental systems and the fundamental influence of the KRB environmental changes over social systems.

- Future policy design and implementation must consider actors at the different levels of the KRB system. So far, majority of decision-making and water policy has been developed and implemented at the national government level. To involve local levels can be highly beneficial to increase the effectiveness of future policies and its implementation.

Science-policy interfaces

- The river basin monitoring system should be developed to monitor policy implementation efforts. To include sound scientific indicators to assess the effectiveness of water policy implementation in the KRB may be highly beneficial. The inclusion of scientific policy performance indicators can enhance the accountability of policies implemented in the KRB and to actually assess the effectiveness of the investments and policy responses implemented.

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- It is recommended that the Vice-Ministry of Water Resources and the KRB management unit re-design the governance model currently employed for water policy developments in Bolivia, see Figure 12. This design does not allow an interaction between stakeholders/partners involved. Consequently, this design insulates valuable information and knowledge in clusters. Future participatory designs must include a space for interaction between scientists, public authority, community-based representatives, international cooperation agencies and municipal authorities. Allowing such interaction may be highly beneficial to shift from participation to actual collaboration among partners involved, and to improve the decision-making effectiveness.

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7 Appendices

Table A1. Policy responses implemented during the period 2004–19.

Period/ year	Actor	Type of measure	Description	Spatial allocation
2006	ALT	Project design	Project for infrastructure aiming to instal aerators to increase levels of oxygen and to harvest the vegetation product of the increase in nutrients at Cohana Bay	Cohana Bay
2007–13	State Government of La Paz	Cohana Bay Cleaning Program	Drinking water wells	Pucarani
			De-worming of cattle	Cohana Bay
			Dairy cattle waste ecological management	Laja
			Eco-sanitation services	Puerto Perez
			Drinking water wells	Laja
			Eco-sanitation services	Cohana Bay
			Eco-sanitation services	Puerto Perez
			Eco-sanitation services	Pucarani
			Eco-sanitation services	Puerto Perez
2007	ALT	Bi-national agreement	Binational agreement for the Recovery, Regeneration and Restoration of Cohana Bay and the Surrounding Areas signed by the Bolivian and Peruvian ministries of Foreign Affairs	Cohana Bay
2007	ALT	Consultancy study	The consultancy contract aims to study the potential use of the plants reproduced by the effect of the eutrophication for animal food	Cohana Bay
2008	ALT	Project implementation	'Mechanical removal of duck weed and watercress at Cohana Bay and Pajchiri'	Cohana Bay
2010	ALT	Project implementation	'Economic development of aquatic vegetation of Lake Titicaca'	Cohana Bay
2011	ALT	Project	'Aerator installation'	Cohana Bay
2012	National Deputy Commission	Inspection	National deputies visited the Cohana Bay and the impacted communities	Cohana Bay
2012	ALT	Project design	'Economic development of aquatic vegetation of Lake Titicaca' project design	Cohana Bay

(*Continued*)

Table A1. (Continued).

Period/ year	Actor	Type of measure	Description	Spatial allocation
2012	ALT	Project proposal	Reduction of pollution in the Cohana Bay based on the harvest of aquatic plants and their transformation into earthworm humus	Cohana Bay
2013	ALT	Project proposal	'Aerator installation'	Cohana Bay
2013	National Deputy Commission	Planning meeting	National deputies coordinated a meeting with authorities and mayors of five municipalities	None
2018	UGCK	Water quality study	Lake Titicaca water quality monitoring	Lake Titicaca
2018	UGCK	Water quality study	Implementation of 12 hydroacoustic probes to assess the aquatic fauna present in the lake	Lake Titicaca
2018	UGCK	Solid waste management	Implementation of solid waste containers in 200 schools, seven solid waste recollection campaigns and 91 road signs installed related to the protection of the environment	Rural indigenous region
2018	UGCK	Environmental protection	Two environmental protection campaigns in local radio stations and two audiovisual productions related to the KRDP	Rural indigenous region
2018	UGCK	Environmental protection	Reforestation	Rural indigenous region
2018	UGCK	Project design	Cohana and Pucarani micro-river basin management programme	Cohana Bay
2018	UGCK	Drinking water	Construction of 186 rain-harvesting systems for drinking water	Cohana Bay
2018	UGCK	Project design	Cohana and Puerto Perez micro-river basin management programme	Cohana Bay
2019	UGCK	Municipal policy development	The UGCK supported 23 municipalities with the development of a municipal regulatory framework for the solid waste management at their local jurisdiction. However, El Alto was excluded	Rural indigenous region
2019	UGCK	Waste solid collection	The UGCK implemented seven campaigns to collect solid waste in diverse regions of the river basin	Rural indigenous region
2019	UGCK	Project design	Livestock waste management in order to reduce the contamination produced by dairy cattle	Rural indigenous region

Note: ALT = Autoridad Bi-Nacional del Lago Titicaca/Titicaca Lake Bi-National Authority; KRBDP = Katari River Basin Director Plan/Plan Director de la Cuenca Katari; UGCK = Unidad de Gestión de la Cuenca Katari/Katari River Basin Management Unit.

List of publications

Agramont, A., Van Cauwenbergh, N., van Griesven, A., & Craps, M. (2021). Integrating spatial and social characteristics in the DPSIR framework for the sustainable management of river basins: case study of the Katari River Basin, Bolivia. Water International, 1-22. https://doi.org/10.1080/02508060.2021.1997021

Agramont, A., Craps, M., Balderrama, M., & Huysmans, M. (2019). Transdisciplinary learning communities to involve vulnerable social groups in solving complex water-related problems in Bolivia. Water, 11(2), 385. https://doi.org/10.3390/w11020385

Agramont, A., Peres-Cajías, G., Villafuerte, L. Van Cauwenbergh, N., Craps, M., & van Griesven, A. Framing water policies, a transdisciplinary study of collaborative governance. The Katari River Basin Case (Bolivia). To be submitted to: Water Alternatives.

Integrated Water Resources Management (IWRM) has been worldwide accepted by academics and practitioners as the best water management approach. The IWRM approach recognizes the river basin as the appropriate management boundary and appeals to the multi-stakeholder participation as essential in the decision-making processes and public policy developments. This water management paradigm challenges conventional top-down forms of governance and water resources planning and recalls the need to better understand the interrelations within the hydrological systems. Although IWRM is nowadays widely accepted. Several contexts reflect significant limitations in terms of its implementation, this is mainly attributed to the wicked nature encountered in such socio-hydro-ecological systems. This Ph.D. thesis aims to contribute to the planning and decision-making process within the IWRM paradigm through a better understanding of the intrinsic social and environmental relations encountered in hydrological systems. The first chapter presents an introduction, following, the second chapter suggests the incorporation of social and spatial characteristics within the DPSIR framework, a framework widely employed in water resources management and planning practices. The third chapter presents the transdisciplinary learning communities as a potential approach to deal with the socio-ecological complexities usually present in river basins. At the same time, this chapter suggests the inclusion of vulnerable social groups in the decision-making process to enhance environmental justice to the vulnerable social groups usually influenced by environmental impacts. Considering that the framing process is fundamental in the IWRM and the collaborative water governance, the fourth chapter explores the drivers behind the fragmentation and connection of frames in river basin committees. Finally, the last chapter present the general conclusions.

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