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UNDERSTANDING THE EFFECTIVENESS OF THE GOVERNANCE OF TRANSBOUNDARY AQUIFERS: A FRAMEWORK FOR ANALYSIS

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Preface

This research has greatly benefited from the inputs of many people. First and foremost, I would like to thank Frank and Kirstin for their constructive feedback, guidance, and inspiration. The International Groundwater Resources Assessment Centre (IGRAC) deserves a word of appreciation for graciously hosting my research for the full five months. Thanks to my co-workers for reflecting on my preliminary findings and special thanks to Daniela for her help in creating the map. Lastly, I would like to express my appreciation to the people who found the time to share ideas on the case studies.

Abstract

Groundwater is crucial to life in sustaining ecosystems and providing water for domestic, agricultural, and industrial use. Due to the complexity of observing the status of this 'hidden resource', groundwater can be gradually depleted or polluted until impacts are felt. Effective groundwater governance is crucial to averting or mitigating such sustainability problems.

Until a few decades ago, groundwater was neglected in environmental governance on the national, transboundary, and international level. This study focuses on groundwater-bearing geological formations that traverse national boundaries, also known as transboundary aquifers. Currently, approximately 1-2% of the world's transboundary aquifers are the primary subject of some type of institutionalised governance.

This study is the first ever attempt to provide a framework for the comparative analysis of transboundary aquifer governance from the perspective of effectiveness. It pertains to the cross-comparison of eight case studies – three aquifers in Africa, one in Europe, one in the Middle East, two in North-America, and one in South-America – in terms of institutionalisation and four dimensions of institutional design: (a) knowledge and scientific learning; (b) robustness of principles of international law; (c) legality; and (d) monitoring and data-exchange.

The conclusion is twofold. Firstly, there are large variations in both the type of institutions and institutional design. Secondly, institutional design can hardly be linked to effectiveness in terms of problem-solving in the absence of data on the status of the transboundary aquifer. This suggests that institutional effectiveness is influenced by problem structure rather than institutional design. The overall conclusion is thus that a 'one size fits all' solution to effective governance of transboundary aquifers does not currently exist.

Further research may substantiate the hypotheses that link institutional design and impact to contextual factors such as (a) third party involvement, (b) the distribution of the problem and stakes vested in the resource between the country segments, (c) and unilateral groundwater development. The dynamics of power and stakes in transboundary aquifer governance may also be further explored.

Acronyms

ASA	Abbotsford-Sumas Aquifer
CEDARE	Centre for Environment and Development for the Arab Region and Europe
CIC	Intergovernmental Coordinating Committee of the Countries of the River Plate Basin
ESA	European Space Agency
ETH	Swiss Federal Institute of Technology in Zürich
FFEM	Fonds Français pour l'Environnement Mondial
GEF	Global Environmental Fund
GICRESAIT	Project on the Integrated and Joint Management of the Shared Water Resources of the Iullemeden-Taoudeni-Tanezrouft Aquifer Systems and the Niger River Basin
GIS	Geographic Information Systems
FFEM	Fonds Français pour l'Environnement Mondial
IAEA	International Atomic Energy Association
IBWC	International Boundary and Water Commission
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development
JICA	Japan International Cooperation Agency
MERCOSUR	Common Market of the South
MoU	Memorandum of Understanding
NARIS	Nubian Aquifer Regional Information System
NSAS	Nubian Sandstone Aquifer System
OAS	Organisation of American States
OSS	Sahara and Sahel Observatory
SADA	Shared Aquifer Diagnostics Analysis
SADC	Swiss Agency for Development and Cooperation
SAG	Guaraní Aquifer System
SAI	Iullemeden Aquifer System
SAP	Strategic Action Programme
SASS	North-western Sahara Aquifer System
SDGs	Sustainable Development Goals
TBA	Transboundary Aquifer
UNEP	United Nations Environment Programme
UNESCO	De United Nations Educational, Scientific and Cultural Organization
UESEPA	United States Environmental Protection Agency

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1 INTRODUCTION

1.1 Importance of groundwater

Groundwater truly is a life-sustaining resource. Ranging from the provision of water for drinking and sanitation purposes to enabling agricultural activities, groundwater exploitation relates to poverty eradication, human dignity, and other aspects of human development (Moench 2003). When surface water sources are either polluted or limited, groundwater resources have a comparative advantage for drinking water demands (Howard et al. 2006, p.2). Groundwater has a prominent role in the health of many ecosystems in providing water, nutrients, and a relatively stable temperature (Kløve et al. 2011, p.770).

The availability of tube wells and mechanical pumps at increasingly low costs induced rapid groundwater development across the world, particularly in arid and semi-arid regions. Approximately half of the global population relies on groundwater for domestic use (Wijnen et al. 2012, p.2), but on the regional level groundwater dependence may approach 100% (Howard et al. 2006; Howard 2015). Yet groundwater appropriation for irrigation purposes has been increasing in both absolute and relative terms; currently, groundwater accounts for approximately 40% of consumptive irrigation water use (Siebert et al. 2010). The rapid development of groundwater exploitation over the past few decennia has been referred to as a "silent revolution", which was largely credited to the activities of millions of small-scale farmers as opposed to centralised decision-making and planning (Llamas & Martínez-Santos 2005, p.337; Lopez-Gunn & Llamas 2008). Water governance has traditionally prioritised surface water and the attention to the particular characteristics of groundwater is more recent (Mitchell et al. 2012, p.223; Bodart 2014, p.109).

1.2 Linkages between groundwater use, sustainability, and governance

This section explores the linkages between groundwater use, sustainability, and governance. It starts with framing groundwater sustainability problems in terms of depletion and pollution (1.2.1). The human impact on groundwater quantity and quality provide the basis for an argument for achieving sustainability through governance (1.2.2). The section concludes with an exploration of more and less formal types of governance of groundwater resources (1.2.3).

1.2.1 Human impact on groundwater quantity and quality

Although groundwater is estimated to account for 97% of liquid fresh water on Earth, its abundance may well be illusive in light of current exploitation rates (Bodart 2014, p.112; Fitts 2012, p.26). At a global withdrawal rate of 800-1000 km^3/year, groundwater is currently the most extracted raw material in the world; it exceeds oil's rate by a factor of 200 (Jarvis 2012; Margat & Gun 2013). The demand for fresh water continues to increase worldwide – driven by global population growth, the expanse of irrigated agriculture, and economic development (Wada et al. 2010; Siebert et al. 2010, p.1864). On a global level this increasing demand can be met by surface water, but especially those regions that frequently cope with surface water stress resort to groundwater – if available (Wada et al. 2010).

In 2012, Gleeson, Wada, Bierkens & Van Beek estimated that the total area required to sustain both groundwater consumption and groundwater-dependent ecosystem services (i.e. the "groundwater footprint") was roughly 3.5 times the surface area of the world's aquifers. Groundwater depletion has, however, remained geographically uneven. Arid and semi-arid regions are particularly prone to groundwater depletion due to overexploitation, defined as groundwater abstraction in excess of recharge over an extensive area and for a prolonged period of time (Gleeson et al. 2010). Roughly 1.7 billion people live in geographical areas where groundwater depletion is prevalent (Gleeson et al. 2012). Due to the nature of groundwater as a hidden resource, a groundwater reservoir could be gradually depleted before serious impacts are felt (Dingman 2002, p.466). Against the backdrop of the current levels of groundwater exploitation, sustaining the capacity of groundwater resources to supply freshwater for human and environmental needs is a pressing issue.

Groundwater pollution may threaten both human health and the quality of ecosystems. Anthropogenic pollution of groundwater is distinguished from contamination from other sources, such as soluble minerals that are present in the subsurface (Furey & Danert 2014, p.3). Chemical components of personal care products as well as pharmaceutical and industrial compounds comprise a category of emerging drivers of groundwater pollution (Lapworth et al. 2012). Seepage of wastewater into groundwater resources may lead to faecal contamination (Howard 2015, p.2545), threatening the health of those who rely on these resources for drinking water purposes (Howard et al. 2006, pp.4–5). Wastewater return flows also comprise a major driver of salinisation of groundwater, since residues of detergents and washing powders (dissolved ionic salts) are not always removed in conventional treatment. If treated wastewater is reused for irrigation purposes, agricultural return flows may have the same effect (Vengosh 2013, pp.348, 350–352). Salinisation can also be caused or amplified by groundwater over-abstraction (IPCC 2007, p.189).

1.2.2 Towards sustainable groundwater development through governance

Deficient water governance is often held to be the major culprit behind the global water crisis (UNESCO 2003, p.4). Similarly, increased pressure on groundwater resources is (at least partly) attributed to mismanagement of groundwater resources.

Sustainable groundwater development is paramount to intra- and intergenerational equity. Governance mechanisms may avert the 'tragedy of the commons' that would result from excessive exploitation by anyone with sufficient means to construct a pump or drill a well (Brooks & Linton 2011). In the short term, proper groundwater governance may be a means to the development of equitable allocation regimes for aquifers with multiple stakeholders and – ultimately – conflict prevention (Llamas & Martínez-Santos 2005, p.340). In the long term, the sustained availability of groundwater can be safeguarded for future generations. Groundwater governance can thus be a vehicle for achieving sustainable groundwater development, provided that it addresses sustainability issues appropriately.

However, conditions for sustainable groundwater development are often poorly understood. In spite of technological developments in the field of remote sensing and geographic information systems (Garcia et al. 2016), "costly and cumbersome" sampling processes remain necessary to monitor groundwater resources (Knüppe & Pahl-Wostl 2011, p.3390). Apart from regions where comprehensive system of rights, licencing, and pricing are effectively implemented, abstraction volumes also remain poorly understood. Lastly, the dynamic nature of both socio-economic developments and predictions regarding climate change amplifies the complexity and the uncertainty of the water balance (Knüppe & Pahl-Wostl 2011, p.3390; Dawadi & Ahmad 2013). The merits of groundwater governance are thus inextricably linked to the knowledge of the resource.

1.2.3 Groundwater governance on geographic and administrative levels

Groundwater governance can be viewed as a process involving discourses on various geographic levels: the global, regional and/or transboundary, and national levels.

Much like water governance (Pahl-Wostl et al. 2008), groundwater governance could qualify as fragmented. This global 'fragmentation' would imply that norms, institutions, and actors' support of the institutions may be synergistic, cooperative, or conflictive (Biermann et al. 2013, p.19). From the perspective of legal pluralism – a concept resembling governance fragmentation but restricted to (legal) norms – there are two additional implications: firstly, that multiple norms may apply on the same geographic level and secondly, that multiple norms may apply to a single jurisdiction (Conti & Gupta 2014, p.39). The following subsections provide a helicopter's view of the status of groundwater governance on the three geographic levels.

1.2.3.1 Global level

On the global level, groundwater was indirectly touched upon in several multilateral conventions from the 19th century onwards, for instance through referencing wells and springs (Charalambous 2013; Eckstein & Eckstein 2005; Conti & Gupta 2015; Brooks & Linton 2011). Over the past few decades, groundwater has become a more prominent topic in international law. However, most efforts to codify international norms on groundwater focused on transboundary aquifers and aquifers that are hydrologically linked to transboundary surface water (Box 1).

In contrast, the International Law Commission Draft Articles on the Law of Transboundary Aquifers (hereafter: 'Draft Articles') that were adopted by the United Nations General Assembly in 2008 cover all types of transboundary aquifers. Provisions include the principle of reasonable and equitable use of resources and the principle of no significant harm, which are widely considered as part of international water law (Brooks & Linton 2011). Nevertheless, the Draft Articles lack legally binding status as of yet. Indeed, literature suggests that there is insufficient political will to progressively develop the Draft Articles into legally binding norms on a global level, despite the fact that the discussion of their future form has appeared three times on the agenda of the UNGA (Eckstein & Sindico 2014, pp.33, 36).

Box 1 Transboundary aquifers in Public International Law.

The Helsinki Rules on the Uses of the Waters of International Rivers, which were adopted in 1966 by the International Law Association (ILA) acknowledged the groundwater dimension of international drainage basins, but only considered those aquifers that were hydraulically linked to transboundary rivers (Brooks & Linton 2011). This limitation was not addressed until the adoption of the Rules on International Groundwaters in Seoul, Korea, in 1986. The scope of the Convention on the Law of Non-Navigational Uses of International Watercourses (1997), developed by the United Nations International Law Commission (UNILC), excluded those aquifers without links to (transboundary) surface water bodies once again. Despite the extensive support for its adoption in the United Nations General Assembly (UNGA) in 1997, its threshold for ratification has not nearly been reached (Brooks & Linton 2011). Building upon a proposal by the UNILC that followed five years of research, the UNGA adopted Resolution 63/124 in 2008, which contained 19 Draft Articles tailored to transboundary groundwater resources (UNGA 2009).

1.2.3.1.1 The international agenda for sustainable development

The Sustainable Development Goals (SDGs) comprise a global roadmap for sustainable development that is implemented on the national level from 2016 until 2030 (Kanie et al. 2015). Much like the Millennium Development Goals, the SDGs aim to improve human welfare across the world through poverty eradication and economic development. Yet far more than any previous international framework, the SDGs assume linkages between human development and the state of the environment (Griggs et al. 2014; Griggs et al. 2015). The dedicated water goal (Goal 6) is directly relevant in the context of groundwater exploitation: "Ensure availability and sustainable management of water and sanitation for all".

A series of position papers issued by the International Groundwater Resources Assessment Centre (IGRAC) pointed at some level of advocacy for the importance of groundwater in the negotiations leading up to the adoption of the SDG-agenda on 25 September 2015 (Conti 2015). However, the finalised SDG declaration merely includes groundwater protection in one of the targets. Target 6.6 reads as follows: "By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, aquifers and lakes" (UNGA 2015, p.18). Target 6.5 explicitly calls for transboundary cooperation as needed to implement integrated water resources management, which also involves transboundary aquifers by implication (IAEG-SDG 2015).

1.2.3.2 Transboundary, national, and subnational levels

Even though the international law on transboundary aquifers can be considered a tragic tale of what Young (2011, p.19855) has called "arrested development", bilateral and multilateral treaties have been concluded for three independent transboundary aquifers or aquifer systems: the Génévois aquifer in Europe (1978), the Guaraní aquifer system in South America (2010), and the Saq-Ram aquifer system in western Asia (2015). As will be shown in section 3.1.1, merely 1-2% of all transboundary aquifers are the primary subject of regional groundwater agreements of various legal status. Thus the governance of transboundary aquifers is in its infancy compared to the governance of international river basins, 42% of which are the primary subject of international agreements (Dombrowsky 2007, p.95).

On the national level, groundwater legislation exists for less than half of the 196 states (Conti & Gupta 2015, p.3), but the trend is that groundwater is "losing its traditional private property connotation, and that individual rights in it accrue from a grant of user-type rights by the government or the courts" (Burchi & Nanni 2003, p.227). A relevant circumstance is whether the domestic jurisdiction over groundwater issues has been devolved to subnational governmental entities, such as provinces or federal states. This is the case for India, Pakistan, and the United States of America (Burchi & Nanni 2003).

1.2.3.3 Quasi-formal and informal governance

Pragmatic mechanisms that account for the characteristics of a specific groundwater resource may emerge on the subnational- and/or transboundary level, such as arrangements between local governments, water utilities or community representatives (Steenbergen & Shah 2003;

Lopez-Gunn & Cortina 2006). Examples of transboundary aquifers where informal governance arrangements are in place include the Abbotsford-Sumas and the Hueco-Bolsón aquifer.

The informal governance approach "sidesteps the authority of the respective federal governments and places the burden of pursuing cross-border cooperation on the local communities that so depend on these critical fresh water resources" (Eckstein 2013, pp.97–98). In addition to the advantages related to fine-tuning governance in accordance with specific features of local resources, decision-making that is driven by local participation may be perceived as more legitimate by those who are affected by it (Eckstein 2011a). Groundwater markets can be considered a special type of informal governance (Box 2).

"[H]ighly dynamic and complex" groundwater markets have been found in India, Pakistan, Bangladesh and parts of China (Mukherji & Shah 2005, p.335). Oftentimes, well owners sell water for irrigation purposes. Groundwater markets may be more or less institutionalised, depending on the applicable system of rights and allocation of groundwater. There is relative consensus that groundwater markets enhance the accessibility of the benefits of irrigation for those who cannot afford a well, but there are reservations related to the distributional equity (Mukherji & Shah 2005).

Box 2 Groundwater markets.

1.3 Scope of the study

This section explains the focus on transboundary aquifers and defines relevant terminology (1.3.1). A brief overview of previous studies on the governance of transboundary aquifers (1.3.2) is followed by the problem definition and research structure (1.2.3).

1.3.1 Defining the governance of transboundary aquifers (TBAs)

This study focuses on aquifers – i.e. geological formations that contain groundwater (Eckstein & Sindico 2014) – that straddle national borders. To date, 592 of such aquifers have been identified (IGRAC 2015).[1] Parallels exist between the governance of international transboundary aquifers and aquifers that traverse sub-national entities (Blomquist & Ingram 2003), particularly where groundwater is regulated on the subnational level in one or more country segments as discussed in section 1.1.3.2. Nevertheless, this study does not consider aquifers that are exclusively contained within a single country.

Transboundary aquifers (TBAs) thus consist of country segments, divided by international borders. The land overlying these segments is in the jurisdiction of the respective

[1] The number of known TBAs is likely to increase further in the future because continuous research enables hydrogeological delineation on an ever more detailed level. By definition, this number is also subject to a process which has been framed as "reterritorialisation" by Gaines, Feitelson, & Wolf (2003, p. 143), i.e. the rearrangement of administrative boundaries.

countries. These countries are denoted as aquifer states in the Draft Articles, but for the purpose of this research these are called 'riparians' in accordance with the terminology of international river basins.

This study relies on the descriptive definition of governance, which *eo ipso* is not linked to specific normative precepts such as sustainable development or intergenerational equity. Drawing upon the descriptive understanding of global governance (Lockwood et al. 2010, p.987; Biermann & Pattberg 2012, p.4), I define the governance of transboundary aquifers as: '*the constellation of both formal and informal norms and discourses on the national and transnational level that determine the allocation, use, and preservation of the resources of a transboundary aquifer*.'

1.3.2 Previous studies on the governance of TBAs

On a theoretical level, the literature has explored notions that may inform the governance of transboundary aquifers. For example, an analysis of the international law on transboundary aquifers has culminated in the development of six conceptual models of groundwater resources with transboundary implications by Eckstein & Eckstein (2005, p.680), which are "intended to help in assessing the applicability and scientific soundness of existing and proposed rules governing transboundary and international ground water resources".

Literature has paid much attention to the international law on transboundary aquifers as discussed in section 1.2.3.1 (e.g. Stephan 2006; Conti & Gupta 2015; Eckstein & Sindico 2014; Eckstein 2011b). Such approach assumes that progressive development of norms on the global level will modify practises on the local level, reflecting a top-town approach to the analysis of the governance of transboundary aquifers. For example, an analysis of twelve "key international groundwater governance texts" has recently been conducted by Conti & Gupta (2015, p. 18), who concluded that (a) both the scope of groundwater resources and the principles that govern them are inconsistently defined; (b) the documents are lacking critical principles; and (c) underlying notions of sovereignty are conflicting.

Experiential analysis of the emergence and effectiveness of governance of transboundary aquifers has so far been restricted to self-contained studies of single aquifers (e.g. Cobos 2010; Kettelhut 2013; Walter 2015; Alker 2008; Withanachchi 2012; Norman & Melious 2004; Schmidt 2008; Sugg et al. 2015) or on the regional level (Sánchez-Munguía 2011; Eckstein 2011a). Brooks & Linton (2011, p. 458) advocated for the compilation of "information about the nature of institutions developed to manage transboundary aquifers, and about the processes leading to their creation and their successes and failures over time, in different hydrogeological environments, and in different political and economic circumstances" to infer hypotheses on what works on the ground. Such a systematic study of the emergence of effective governance of transboundary aquifers has not yet been conducted.

1.3.3 Problem definition and research structure

Groundwater is markedly different from surface water due to its variable (and potentially negligible) renewability, complex flow regime, and "duality as being both part of and apart from the contemporary hydrologic cycle" (Haddad et al. 2000; Conti & Gupta 2015, p.20). Shallow, unconfined groundwater is often linked to surface water, but the importance of groundwater is often acknowledged "only at a reconnaissance level even in the most studied basins in the world" (Wolf 2007, p.247). Meanwhile transboundary aquifers that lack connections to surface water have been neglected in international discourses altogether (Box 1). This phenomenon, which Jarvis et al. (2005, p.264) labelled as "hydroshizophrenia", calls for studying instances of governance that focus on transboundary groundwater resources in particular.

Section 1.2.2 identified a gap in the existing body of research related to the structured evaluation of the effectiveness of the governance of transboundary aquifers. The primary aim of this exploratory study is to provide hypotheses on the effectiveness of the governance of transboundary aquifers. Thus, it answers the question: *To what extent can the emergence of effective governance of transboundary aquifers be explained by common narratives?* Effectiveness is a central concept in this study that requires further substantiation by means of identifying indicators for evaluation. The secondary aim of this study is therefore to craft a model of effectiveness of the governance of transboundary aquifers. The research question is broken up into the following sub-questions:

- What are the design criteria for evaluating the effectiveness of the governance of transboundary aquifers?
- What is the variation among transboundary aquifers when evaluated according to these design criteria?
- How can the effectiveness of the governance of transboundary aquifers (or clusters of transboundary aquifers) be linked to the context and nature of the specific problems?

Chapter 2 of this thesis outlines the conceptual framework, including four dimensions of effectiveness of the governance of transboundary aquifers. It lays the foundation for defining the design criteria for evaluating the effectiveness of the governance of transboundary aquifers. Chapter 3 describes the methods to defining these criteria and performing the comparative analysis of eight case studies. Chapter 4 systematically describes TBA governance in eight case studies, including the problem structure, history of regional cooperation, and the performance in terms of the design criteria. Each TBA section concludes with a qualitative evaluation of effectiveness. Chapter 5 pertains to a comparative analysis of the case studies in terms of the design criteria. Chapter 6 formulates hypotheses on the emergence of effective governance that create a link between effectiveness and governance design.

The overall structure of the research is visualised in a flowchart in Figure 1. Data-inputs are given in the blue boxes and intermediate analysis steps in turquoise boxes. Arrows connect the answer to sub-questions (green boxes) to the appropriate analysis step.

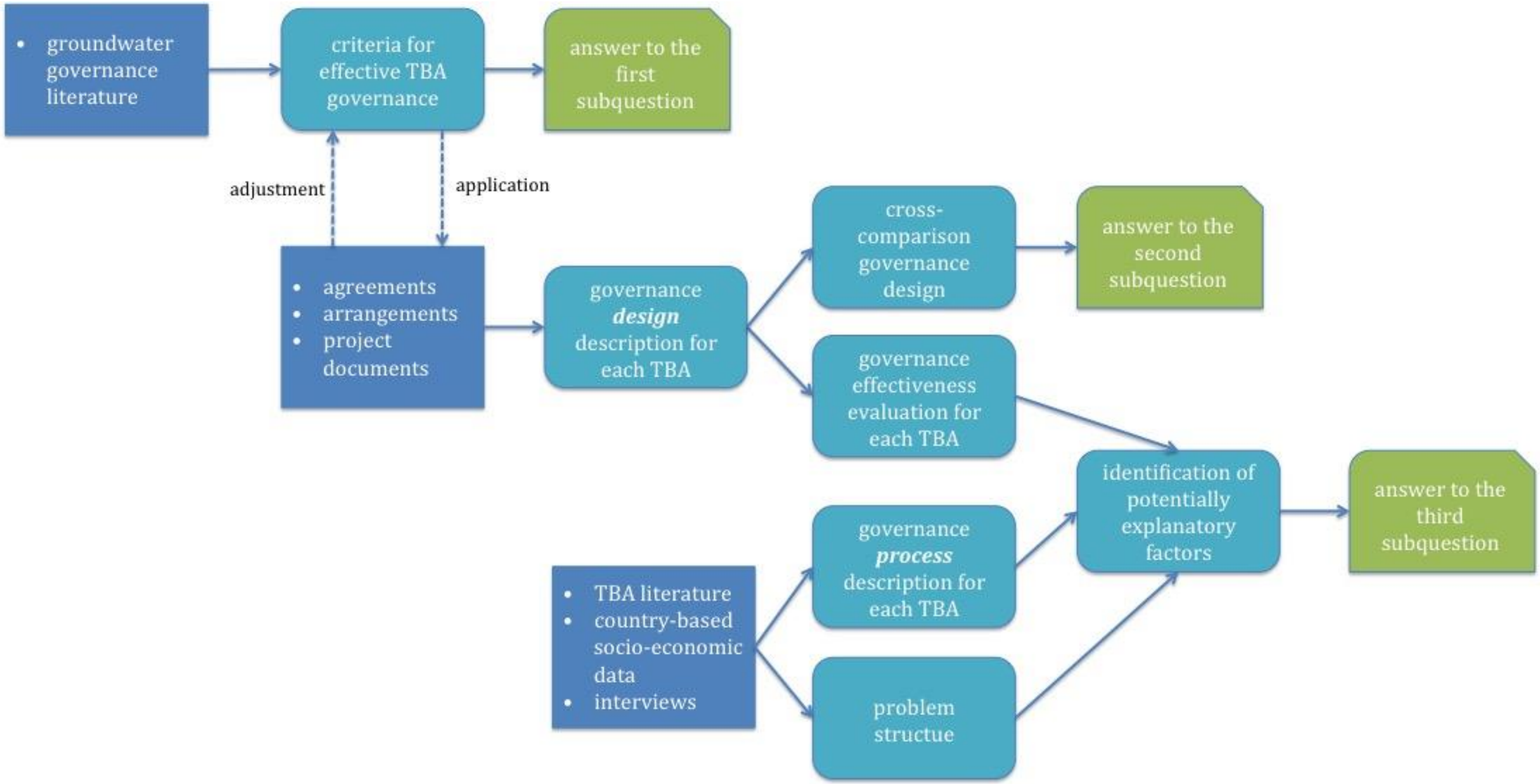

Figure 1 Structure of the research.

2 THEORY AND CONCEPTS

This chapter explores theory and concepts that are relevant to the study. Paragraph 2.1 introduces two models of institution-building in TBA governance and proposes a framework for categorising institutions. Drawing upon literature on water governance and on the effectiveness of environmental institutions, paragraph 2.2 proposes a conceptual approach to evaluating the governance of TBA governance.

2.1 Institutionalisation of TBA governance

There are different ideas as to the ideal type of institutionalisation in TBA governance: the theoretical model and the evolutionary model. This paragraph starts by describing these two models (2.1.1) and then argues that institutionalisation of TBA governance is captured along two dimensions: depth of integration and the relative importance of facts and values (2.1.2).

2.1.1 Two models of institution-building in TBA governance

Brooks & Linton (2011, pp.451–452) proposed two conceptual groundings of effective governance of transboundary groundwater resources. One focuses on the importance of incremental institution-building processes (evolutionary model), whereas the other focuses on pre-determined institutional design (theoretical model). Although seemingly conflictive, these two approaches have marked overlap.

The theoretical model of institution-building classifies elements of institutional design as either constructive or obstructive in terms of institutional effectiveness (e.g. Wolf 2007; Berardo & Gerlak 2014; Mitchell & Zawahri 2015). In contrast, the evolutionary model of institution-building entails that "the process by which a solution is achieved may be more important than the solution itself", especially when conflicts over groundwater are embedded within wider socio-political conflicts (Blomquist & Ingram 2003, p.162). The step-based and open-ended approach supposedly allows for expansion of the institutional mandate over time based on pre-determined objectives such as "determination of pumpage regimes and rates, drought policies, protection measures, land use, recharge enhancement projects, wastewater treatment standards and reuse policies, and crisis management measures" (Feitelson & Haddad 1998, p.228).

Trust is a central notion in the evolutionary model of TBA institution-building as a "form of social and institutional capital, enabling individuals to tackle the next problem or conflict" (Blomquist & Ingram 2003, p.165). Brooks & Linton (2011, pp.436, 452) link various attributes of the governance of transboundary aquifers to mutual trust such as transparency in data-sharing and monitoring/mediation mechanisms to address the merits of competing knowledge or claims. Dependent effectiveness variables similar to these 'contributors of trust' have been used in literature rooted in the theoretical model (Zawahri et al. 2016; Mitchell & Zawahri 2015; Breitmeier 2006).

2.1.2 Two dimensions of institutionalisation: integration and subjectivity

This section proposes a two-dimensional approach to understanding institutionalisation, which reflects the paradigm shift in (global) governance that included non-state actors in the governance realm (e.g. Biermann & Pattberg 2012, pp.3–4; Mukherji & Shah 2005, p.339). This paradigm shift has concerned (a) private stakeholders including the (transnational) civil society, comprising of profit-oriented actors from the business sector and self-organised advocacy groups (compare: Brand & Reusswig 2006, pp.94–98; Mukherji & Shah 2005, p.339); (b) institutionalised science, since scientific knowledge is called for both in the identification of global challenges and in the design of policies aiming to solve those challenges (compare: Brand & Reusswig 2006, pp.98–102; Gupta et al. 2012, pp.73–82) (c) intergovernmental machineries for decision-making on transboundary matters; and (d) regional or transboundary institutions with a broad mandate.

The first dimension of institutionalisation of TBA governance is based on four generic structures for the governance of a transboundary aquifer that have been listed in the literature (Brooks & Linton 2011, p.450): 1) separately by each state; 2) separately, but with coordination to avoid significant adverse effects; 3) jointly with more or less equal powers granted to each state; and 4) conveying powers to a supranational body. This categorisation reflects varying levels of what I would call '*integration*'. Depth of integration is related to the sacrifice of self-determination regarding groundwater matters (also known as 'sovereignty' in the case of supranational integration) and determined by the number of competences (i.e. legal powers) of institutions.

The second dimension of institutionalisation relates to the relationship between science and politics in environmental governance. According to Underdal (2000), both the essence of environmental governance and its inherent tensions are captured by this very relationship, which is seen as the relative expression of (a) the purported autonomy and integrity of scientists versus (b) the involvement of the scientific community in political decision-making processes. To the extent that these two elements are interdependent, they can be captured by a '*subjectivity*' variable. The relativity of this dimension is emphasised, since many authors have argued that science can never be entirely 'value-free' (e.g. Berardo & Gerlak 2014). Subjectivity is determined by the relative institutional significance of objectively established facts on one hand and the politics of values and interests on the other

2.2 Conceptualising the effectiveness of TBA governance

This section draws on general approaches to measuring effectiveness of environmental institutions (2.2.1), in order to break down the effectiveness of the TBA governance into four dimensions (2.2.2). The section concludes with a schematisation of the conceptual approach to evaluating the effectiveness of TBA governance (2.2.3).

2.2.1 Approaches to measuring effectiveness of environmental institutions

In response to perceived shortcomings of 'compliance' as an indicator of institutional performance (e.g. Mitchell 2007; Young 2011), analysts have increasingly emphasised social-scientific notions of effectiveness in terms of 'problem solving'. Such notions direct attention from *impacts* or quantifiable improvements of the natural environment (2.1.1) to *outputs* or mechanisms and infrastructure that serve to translate a regime from paper to practise (2.1.2); and *outcomes* or changes in the activities of actors that relate to the problem that the institution is meant to alleviate (2.1.3) (Young 2011; Biermann & Bauer 2004).

2.2.1.1 Environmental quality: impact-based effectiveness

The environmental quality dimension pertains to the specification of environmental targets – for example on threshold concentrations of chemical compounds – as well as timeframes for their attainment (Mitchell 2008, p.86). The use of environmental quality indicators for effectiveness is expedient to the extent that anthropogenic drivers determine variation in environmental quality. Yet pollution of water or air, for instance, is subject to flow patterns that may vary considerably in space and time (Mitchell 2008; Biermann & Bauer 2004). Due to the complexity of ecological processes and the strong influence of non-human factors, environmental performance remains therefore a somewhat elusive indicator.

2.2.1.2 Behavioural change: outcome-based effectiveness

Since behavioural change can be seen as the product of constellations of actors, interests, and institutions, effective regimes are those steer the behaviour or interests of actors or in the policies and performance to the benefit of the targeted problem. Public commitments and changes in domestic policy and legislation could be qualified as 'leading' performance indicators in this context, in the sense that they might involve direct and immediate institutional effects and as such be good predictors of ultimate institutional performance (Mitchell 2008, p.95).

2.2.1.3 Inherent quality: output-based effectiveness

A rather different approach to measuring effectiveness involves the induction of the expected impact of institutions from proxy indicators; in this case the institutional properties and features. This involves extensive analysis of supposedly effective institutions to induce such properties and features. An example of the application of this method is the assessment of twenty-three environmental regimes by Helmut Breitmeier, based on an extensive data protocol that consisted of 136 questions (Breitmeier 2006, p.431). Accordingly, the effectiveness of an institution can be evaluated based on the 'inherent quality' of its design; that is the extent to which it exhibits predetermined elements of effectiveness.

2.2.2 The dimensions of effectiveness in TBA governance

Section 2.2.1 discussed three indicators of institutional effectiveness. The utility of these effectiveness indicators is strongly linked to their position in the causal chain (Mitchell 2008); analytical isolation of institutional outputs, outcomes, and impacts is progressively relevant yet increasingly challenging in terms of attribution.

Measuring the impact of the governance of a transboundary aquifer on the status of the resource is complicated. In addition to general issues related to the attribution of outcome, which are due to the presence of "background noise of general political developments" (Biermann & Bauer 2004, p.191), groundwater is governance is inherently complex. Specific obstacles to attributing changes in the status of groundwater to governance include (a) the relatively long residence time of groundwater and (b) its invisibility, which relates to a general lack of understanding of an aquifer's properties, its functions in the hydrological system, and its use (Conti & Gupta, 2015, Mitchell et al., 2012).

In response to attribution issues in environmental governance, the evaluation of outcomes and impacts often involves a counterfactual comparison against reference points. This facilitates the estimation of the scenario had there been no institution or the degree of divergence between the outcome and an ideal-typical institution (Mitchell 2008; Biermann & Bauer 2004). In contrast, application of the 'inherent quality' indicator does not require counterfactual analysis because the indicator itself is somewhat empirically grounded.

Drawing on literature on the effectiveness of international environmental institutions and transboundary water governance, the sections below break down effectiveness of the governance of transboundary aquifers into knowledge and scientific learning (2.2.2.1), robustness of legal principles (2.2.2.2), legality (2.2.2.3), and monitoring and data-exchange (2.2.2.4). These dimensions provide the basis for the formulation of indicators to evaluate the inherent quality of governance of transboundary aquifers in terms of effectiveness.

2.2.2.1 Knowledge and scientific learning

International institutions can be framed as arenas for the evolution of consensual knowledge, in which "consensus regarding the nature, causes, and consequences of the problem, solutions, or which factors should be maximized in the issue area, often only emerges after a lengthy epistemic process […]" (Breitmeier 2006, p.437). Consensus on the nature of the problem and its causes and consequences is considered crucial to effectiveness, because it presumably incentivises attempts to avert environmental change and commitments to the implementation of far-reaching policies (Breitmeier 2006; Mitchell 2008).

While a "complete and comprehensive understanding of transboundary groundwaters" is not a prerequisite to initiating joint governance, "some technical information" is considered necessary at the outset (Blomquist & Ingram 2003, p.165). Presumably, this technical information must be directly related to the nature, the causes, and the consequences of the problem. In addition to preliminary consensus on the nature, causes and consequences of the problem, consensual knowledge may be developed further through joint studies and projects.

The adoption of mechanisms for the production and dissemination of scientific knowledge on the aquifer – 'scientific learning' – is considered crucial to effective governance of transboundary (ground-) waters (Berardo & Gerlak 2014). The effectiveness of the governance transboundary aquifers is often compromised because scientific studies are "conducted independently on each side of the border, use disparate scientific standards, collect dissimilar data, and generate maps and conceptual models that "end" at the border" (Eckstein 2011a, p.287). Thus collaboration in fact-finding and standardisation of meta-data should be a central aspect of scientific learning.

2.2.2.2 Robustness of legal principles

The articulation of principles in interstate agreements is seen as "a necessary but not sufficient condition for regime formation" (Conca et al. 2006, p.265). Abstract and aspirational by nature, the articulation of principles is indicative of a joint ideological foundation for groundwater governance "or at least overlapping interests upon which shared norms might be constructed" (Conca et al. 2006, p.266). In that sense, the principled content of an interstate agreement is not only indicative of the "evidence of the pulling effect of global normative developments" (Conca et al. 2006, p.265), but also an indicator of the effectiveness of groundwater governance.

The 'robustness of legal principles' is defined as the principled content relative to the law of transboundary aquifers. The principles can be subdivided into three categories: principles of International Environmental Law, International Water Law, and Social Justice (compare: Conti & Gupta 2015).

2.2.2.3 Legality

Legality of governance is related to perceptions of credibility and defined as the extent to which governance can induce actors to find ways to reach the policy goals they agreed upon (Spilker & Koubi 2016). From this perspective, legality decreases the actors' freedom to act in exclusively self-serving ways (Spilker & Koubi 2016).

The first factor contributing to legality is the legal status of a groundwater governance document. Formal regional governance instruments, i.e. interstate treaties become legally binding to the parties upon ratification. Informal governance documents may still possess some degree of 'legality' as evidenced by their implementation, if applicable. Legality of treaties and informal governance documents can further be inferred from their design. Precisely stated rights and obligations; strong mechanisms for (compliance) monitoring and enforcement; and dispute resolution procedures are commonly seen as attributes of legality as defined above (Spilker & Koubi 2016; Zawahri et al. 2016; Hearns et al. 2014).

In a way, substantiated water rights can be conceived of as the operationalisation of principles such as 'environmental preservation' or 'reasonable and equitable utilisation of transboundary waters'. Examples are the development of resource protection measures and plans to respond to crises such as a "major groundwater contamination event or a severe and extended drought" (Blomquist & Ingram 2003, p.167). Moreover, Wolf (2007, p.259) claims that "effective institutions must identify clear allocation schedules and water quality standards that simultaneously provide for extreme hydrological events […] and changing societal values". In the same line of argument, the benefits derived from (ground-)water utilisation – such as benefits from "agriculture, economic development, aesthetics, or the preservation of healthy aquatic ecosystems" – must be allocated (Wolf 2007, p.260).

The articulation of rights and obligation has been framed as a "bottleneck" in achieving transboundary groundwater cooperation due to persistent notions of (national) sovereignty over natural resources (Eckstein 2011a). Conversely, the presence of such provisions suggests that parties have been able to make concessions to such notions with respect to specific aspects of groundwater governance.

2.2.2.4 Monitoring and data-exchange

Provisions for monitoring of groundwater resources and data-exchange are considered crucial to effective governance of transboundary aquifers. Not only is the exchange of information strongly linked to building mutual trust and a shared vision regarding the sustainable future of the resource (Timmerman & Langaas 2005; Hearns et al. 2014); it also provides opportunities for continuous evaluation of the effectiveness of institutions in terms of problem-solving (compare: Breitmeier 2006).

Ideally, groundwater monitoring concerns both the state of the resource and developments and practises that are likely to impact their availability and use, such as land use conversion and climatic change (Hearns et al. 2014; Timmerman & Langaas 2005; Brooks & Linton 2011). The governance of transboundary aquifers is further believed to benefit from the presence of a joint mechanism for collecting data or the harmonisation of methodologies and procedures (meta-data), ensuring the compatibility of data-formats and the continuity of data records (Eckstein 2011a).

2.2.3 Schematic conceptual approach to evaluating TBA governance effectiveness

Building upon the literature discussed in 2.2.2, this research conceives of TBA governance effectiveness as being determined by four dimensions: knowledge and scientific learning, articulation of legal principles, legality, and monitoring and data exchange (Fig. 2).

On a more abstract level, this research combines elements of the evolutionary and the theoretical approach to the effectiveness of TBA governance (2.1.1). Respectively, these approaches have a dual focus on (a) the governance process elements that entail convergence of the values and knowledge base of the actors and mutual-trust building; and (b) the inherent quality of the interstate agreements and arrangements as the product of that process (compare: Berardo & Gerlak 2014, p.103). Both the 'process' and 'product' elements are important in terms of effectiveness as defined in 2.2, i.e. promoting change in the activities of actors who relate to the problem that the groundwater governance is meant to alleviate.

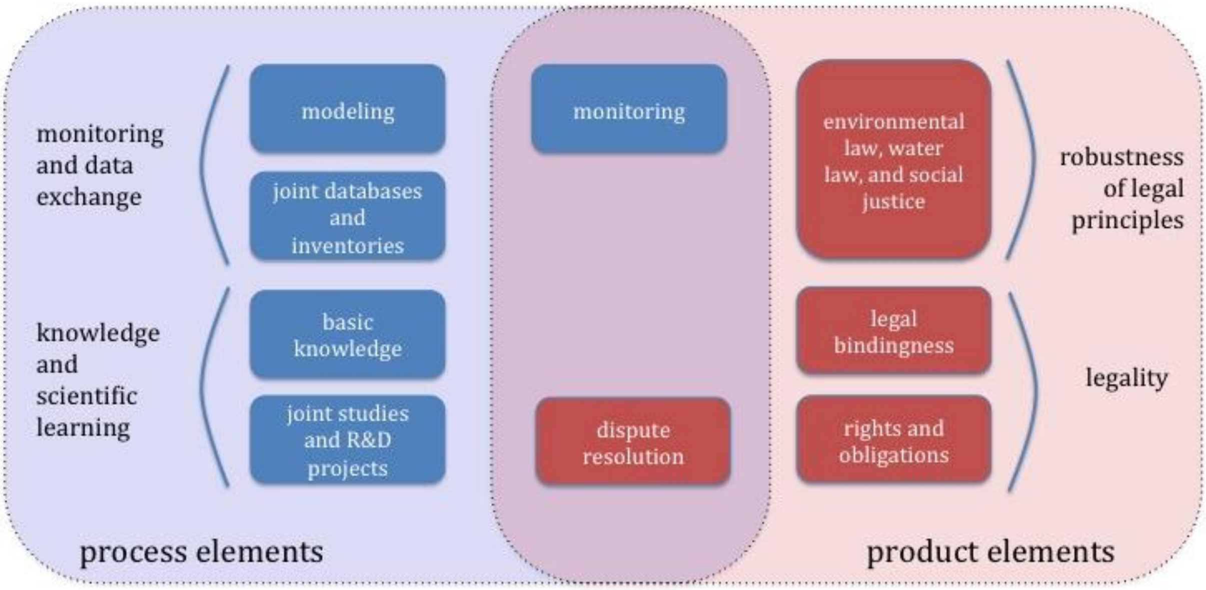

Figure 2 Schematic representation of the dependent variables in the institutional design of effective TBA governance.

3 MATERIALS AND METHODS

This chapter outlines the methods of analysis, which pertains to a cross-comparison of case studies to understand the relationships between institutional design and effectiveness. It starts with the definition of design criteria for effective TBA governance (3.1), followed by a description of the selection and development of the case studies (3.2).

3.1 Defining design criteria of effective TBA governance

As discussed in 2.2, the effectiveness of the governance of TBAs is reflected in four dimensions:

1. The development of consensual knowledge on groundwater resources;
2. the articulation of acknowledged principles of international law;
3. the credibility of its legal obligations; and
4. monitoring and data-exchange.

Relevant elements and associated criteria and coding questions were defined and categorised based on an iterative process involving induction of criteria from governance literature and deductive application of the criteria to governance documents to ensure adequate reflectance of variability between the documents.

The thirty-one coding elements are outlined below, specified for nine categories and four overarching dimensions. Coding schemes entailing a more detailed description of each element and the criteria for its evaluation can be found in Appendix B (Tables 15-24).

Table 1 Overall structure of the coding scheme for evaluating the effectiveness of TBA governance

Dimensions (4)	**Categories (10)**	**Element and associated criteria (36)**
Knowledge and scientific learning	Consensus on the problem	Nature of the problem
		Identification of pressures and drivers
		Risk analysis
	Preliminary knowledge	Aquifer delineation
		Basic hydrogeological features
	Scientific learning	Joint studies
		Joint R&D projects
Robustness of international legal principles	Environmental	Exchange of data
		Precautionarity
		Environmental conservation
		No significant harm
		Notification of planned measures
		Notification accidents and emergencies
	Water	Reasonable and equitable use
		Polluter pays
		User pays
		Integrated Water Resource Management (IWRM)
		Conjunctive use of water resources
	Social Justice	Access to drinking water and sanitation
		Rights of marginalised groups

		Participation / transparency in decision-making
Legality	Legal status	Formality
		Validity
		Implementation
	Rights and obligations	Well design
		Protection zones
		Volumetric abstraction restriction/allocation
		Pollution prevention measures
		Pollution abatement measures
	Dispute resolution	Dispute resolution mechanism
Monitoring and data-exchange	Mechanisms for monitoring and data exchange	Harmonisation of meta-data
		Numerical model
		Well inventory
		Piezometric network
		(web-based) platform for data exchange
		Naming of information to be exchanged

3.2 Development of case studies

The following subsections will discuss the selection of case studies for TBA governance (3.2.1) and types of data that were used (3.2.2). The section concludes with a description on the structure of the analysis of the case studies (3.2.3).

3.2.1 Selection of case studies

The initial selection of case studies comprised six transboundary aquifers that have been identified as being the primary subject of regional governance frameworks in scientific literature (aquifers 2-3 and 5-8 in Table 1). The regional governance frameworks for these six aquifers are generally acknowledged as the formalised outcome of international cooperation, although divergence in legal status and level of comprehensiveness has been observed (Conti & Gupta 2014, p.42; Eckstein & Sindico 2014, p.32). These six regional groundwater governance frameworks may comprise of formal agreements or informal arrangements between two or more riparian countries or subnational entities.

Note that the scope of the analysis excludes groundwater bodies for which regional harmonisation exists as part of the implementation of the European directives – such as the Danube river basin aquifers, the Upper Rhine Aquifer and the lower Rhine aquifer (Conti 2014; Stephan 2006) – or other regional frameworks. However, the analysis extends to two aquifers that are characterised by institutionalised forms of governance, yet lack a formal interstate or interregional agreements (aquifers 1 and 4 in Table 2). Hence the final selection of case studies comprises three aquifers in Africa, one in Europe, one in the Middle East, two in North-America, and one in South-America (Table 2; Fig. 3).

Table 2 Overview of TBAs with regional governance that fall within the scope of the study

	Aquifer	References
1	Abbotsford-Sumas Aquifer	Campana et al., 2006, pp. 8–10; Eckstein & Sindico, 2014, p. 33.
2	Genevese Aquifer	Conti & Gupta, 2014, p. 42; Eckstein & Sindico, 2014, p. 32; Walter, 2011, p. 3.
3	Guaraní Aquifer System	Conti & Gupta, 2014, p. 42; Eckstein & Sindico, 2014, p. 32; Walter, 2011, p. 4.
4	Hueco-Bolsón Aquifer	Campana et al., 2006, pp. 10–13; Eckstein & Sindico, 2014, p. 32; Walter, 2011, p. 5.
5	Illumeden Aquifer System	Conti & Gupta, 2014, p. 42; Eckstein & Sindico, 2014, p. 40.
6	North-western Sahara Aquifer System	Conti & Gupta, 2014, p. 42; Eckstein & Sindico, 2014, p. 32.
7	Nubian Sandstone Aquifer System	Conti & Gupta, 2014, p. 42; Eckstein & Sindico, 2014, p. 32.
8	Saq-Ram Aquifer	Conti & Gupta, 2015, p. 3.

Four of the selected aquifers are among the 5% largest aquifers in terms of surface area (Table 3). The Nubian Sandstone Aquifer System, the Guarani Aquifer System and the Northwest Sahara Aquifer System can be considered extensive, with surface areas exceeding 1 million km^2. By contrast, the Abbotsford-Sumas, Hueco-Bolsón aquifer, and the Genevese aquifer can be considered small, with surface areas below 10.000 km^2. The remaining two, namely the Iullemeden Aquifer System and the Saq-Ram aquifer system are medium-sized.

Table 3 Eight selected aquifers sorted by size and relative size.

Aquifer	Size [km^2]*	Exceedance probability** [%]
Nubian Sandstone Aquifer System	2.892.867	0.35
Guaraní Aquifer System	1.437.799	0.70
North-western Sahara Aquifer System	1.279.963	1.05
Illumeden Aquifer System	577.885	2.11
Saq-Ram Aquifer system	184.518	7.02
Hueco-Bolsón Aquifer	8.548	35.09
Abbotsford-Sumas Aquifer	1.071	65.44
Genevese Aquifer	58	95.79

* Source: IGRAC 2015.
** Calculated as the probability that a randomly chosen aquifer is larger than the selected aquifer.

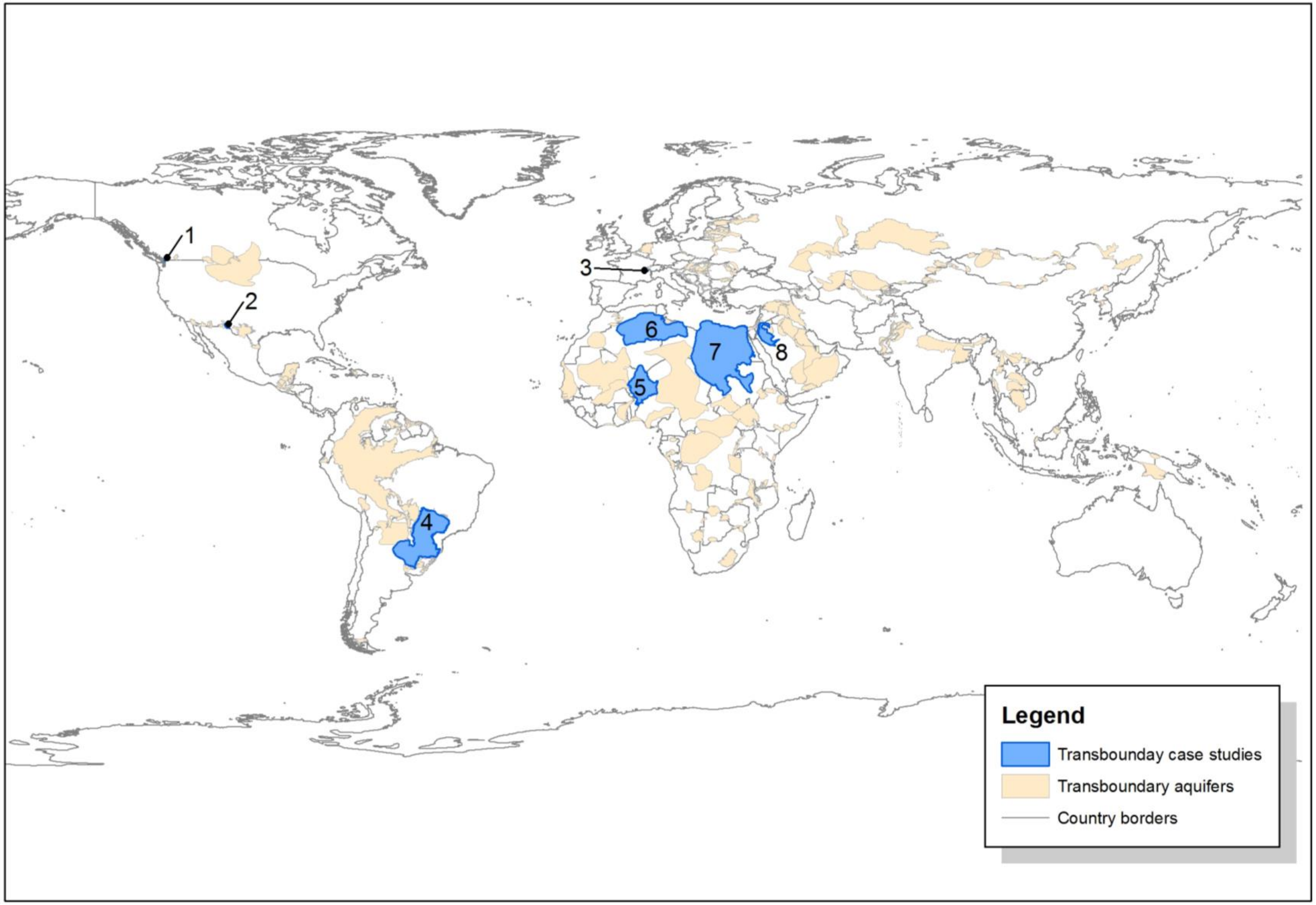

Figure 3 Positioning of the case studies on a map of transboundary aquifers of the world.

3.2.2 Object of analysis and types of data

The primary object of analysis comprises interstate, intergovernmental, interministerial or interagency agreements and informal arrangements. In addition, plans and programme documents were analysed provided that these were formally signed by government representatives. Secondarily, the analysis considers project proposals and evaluations and other cooperation outputs such as joint models and databases. In the absence of a comprehensive databases related to the governance of transboundary aquifers, the first step was to create one for governance documents (3.2.2.1) and projects related to specific transboundary aquifers (3.2.2.2). Interviews were used as a complementary source of information (3.2.2.3).

3.2.2.1 Governance documents

Relevant governance documents were gathered from various locations. A limited number of agreements was found in a FAO/UNESCO compilation of legal instruments on groundwater (Burchi & Mechlem 2005). Some of the more recently concluded agreements were found online, either published on the website of governmental authorities, or as an appendix to project evaluations. The effort to analyse complete governance frameworks involved attempts to locate missing documents by approaching individuals.

The chapter on the case studies contains tables that outline the specifics of the 39 governance components that have been selected for analysis, including 22 aquifer-specific governance documents (Tables 5-12). The tables clearly highlight which documents have not been located.

3.2.2.2 Project documents

Project documents include project proposals and evaluations. The starting point of the creation of a database for international projects was a 2012 synopsis report on transboundary groundwater management (United Nations University 2012). In addition, more recent projects were identified. Fourteen aquifer-specific projects were mapped in terms of duration, project outputs, and involvement of third parties such as international organisations and non-governmental entities.

3.2.2.3 Interviews

Interviews were not intended as a primary source of data, but rather as a means of falsifying hypotheses that emerged after thorough desk research. The interview strategy, including said hypotheses and questions, can be found in Appendix D. Potential interviewees were selected based on their practical expertise in groundwater governance one of the case studies. Nine potential interviewees were contacted; five of whom replied. Eventually, three interviews took place (Skype or email). Reports of the interviews were included in Appendix E.

3.2.3 Structured description of each case study

The case studies are described in a structured way to ensure maximal comparability. The description consists of a brief exploration of the context and structure of the problem (3.2.3.1), the history of regional cooperation (3.2.3.2), the institutional design according to the dimensions of effectiveness (3.2.3.3) and is concluded with the overall evaluation of effectiveness for each case study.

3.2.3.1 Context and structure of the problem

The description of the problem structure consists of the identification of the type of problem – such as groundwater depletion, groundwater pollution, or underdevelopment of groundwater resources – in the broader context of (socio-economic and climatic) pressures and drivers as well as other relevant regional developments.

3.2.3.2 History of regional cooperation

An exploration of the history of regional cooperation is included on the premise that it may serve as a qualitative predictor of the effectiveness of transboundary institutions (Wolf 2007). The history of regional cooperation provides the background for discussion of the regional balance of power and interests, the overall quality of regional relations, and socio-economic obstacles to groundwater governance. For every section, there is a subsection on institutionalisation of the governance of transboundary aquifers, which addresses the emergence of TBA institutions and their mandate.

3.2.3.3 Dimensions of effectiveness

The remaining information on the governance of transboundary aquifers is broken up into a series of separate subsections on institutional design that are aligned with the proposed dimensions of effectiveness, which were identified in 2.2.2. For each case study, these subsections address a) knowledge and scientific learning; b) robustness of legal principles; c) legality; and d) monitoring and data-exchange.

3.2.3.4 Effectiveness

Each TBA section concludes with a qualitative evaluation of effectiveness. Since the four dimensions of effectiveness are mostly concerned with output and outcome, this section focuses on the environmental impact of governance on the status of the transboundary aquifer, if such information is available. The subsection on effectiveness also provides a platform for discussing any perceived changes in effectiveness over time as well as the eventualities of implementation of governance documents.

3.3 Cross-comparison of TBA governance

The cross-comparison of TBA governance builds upon the description of the case studies, focusing on the institutionalisation of TBA governance (3.3.1) and institutional design (3.3.2).

3.3.1 Institutionalisation of TBA governance

The evaluation of the institutionalisation of the governance of transboundary aquifers is grounded in the two-dimensional conceptualisation of institutionalisation as outlined in 2.1. Recalling that this concerns depth of integration (i.e. the sacrifice of self-determination regarding groundwater matters) on one hand and subjectivity (i.e. the relative expression of facts and values), the evaluation methodology is operationalised below.

With regard to integration, the mandate of the institution is an important indicator that can relatively easily be quantified. Drawing on the work of Zawahri, Dinar, & Nigatu (2016), the level of integration is estimated based on the number of competences that the institution has out of the following six options: information-gathering, consultation, regulation, resource monitoring, compliance monitoring, and conflict resolution. The overall structure of the coding scheme can be found below (Table 4) and the criteria for the six coding elements can be found can be found in Table 14 in Appendix B.

With regards to subjectivity, the evaluation is more qualitative. Potential relevant factors include (a) the *aim* of the institution, which may be expressed in the preamble of governance documents; (b) *structure* of the institution, for instance a permanent committee or an intergovernmental mechanism; and (c) *membership*, such as appointment based on scientific merit or political position.

Table 4 Overall structure of the coding scheme for evaluating the institutionalisation of TBA governance

Dimensions (1)	Categories (1)	Elements and associated criteria (6)
Institutionalisation of TBA governance	Institutional competences	Information gathering
		Advice upon consultation
		Regulation
		Resource monitoring
		Compliance monitoring
		Conflict resolution

3.3.2 Dimensions of effectiveness in institutional design

A cross-comparison of the institutional design in the eight case studies relies on the design criteria for the four dimensions of effective governance of transboundary aquifers (3.1). The cross-comparison culminates in a consolidated overview of the similarities and differences between the eight TBAs, in an attempt to distil common narratives and/or clusters in terms of norms, principles and practises.

3.4 Formulation of hypotheses on the emergence of effective TBA governance

The final research step is to develop hypotheses that link the perceived effectiveness (3.2.3.4) to variation in institutionalisation and institutional design of groundwater governance (3.4). These hypotheses are meant to identify facilitating and inhibiting factors. Facilitating factors facilitate the emergence or promote the effectiveness of TBA governance; inhibiting factors inhibit the emergence or effectiveness of TBA governance.

4 GOVERNANCE OF TRANSBOUNDARY AQUIFERS: EIGHT CASE STUDIES

This chapter discusses the governance of eight transboundary aquifers. As discussed in 3.2.3, there is a section for each case study that consecutively describes (a) the context and nature of the specific problem; (b) the institutionalisation of TBA governance in the context of the history of regional cooperation; and (c) the ways in which the four dimensions of effectiveness are reflected in TBA governance. Each section concludes with a qualitative evaluation of effectiveness.

4.1 Abbotsford-Sumas Aquifer (ASA)

4.1.1 Introduction

The Abbotsford-Sumas Aquifer (ASA) underlies some of the most intensively farmed and productive croplands of Northern America and straddles the western part of the international border between the province of British Columbia, Canada and the state of Washington, United States. This unconfined aquifer is highly productive yet intrinsically vulnerable to pollution due to its close proximity to the surface, high annual rainfall, and the permeability of overlying geological formations that are mostly made up of sand and gravel (Zebarth et al. 2015).

4.1.2 Problem structure

Excessive nitrate concentrations have been reported since the 1950s (Zebarth et al. 2015), whilst measured concentrations of pesticides and volatile organic compounds remained below health standards. Agricultural return flows from raspberry fields and dairy/poultry farms in Washington and British Columbia respectively comprise the main source of nitrate pollution; the contribution of leakage from septic fields and urban lawns is relatively small (Norman & Melious 2004, pp.102–103; Rivera 2015, p.628; Zebarth et al. 2015). Due to the net flow southwards, Western Washington is particularly likely to experience the effects of transboundary pollution. Problems related to over-exploitation have remained confined to local instances (Rivera 2015, p.630).

4.1.3 History of regional cooperation

British Columbia and Washington have a long history of environmental cooperation, which has directly involved the ASA since the 1990s. In May 1992, the Environmental Cooperation Agreement established the British Columbia-Washington Environmental Cooperation Council as a symbol of the cooperative relationship between the governments of British Columbia and Washington (Table 4). The ASA's qualitative and quantitative state was listed as one of the region's five highest environmental priorities. This agreement provided for the establishment of Task Forces to address issues of "special or major significance" (Table 5).

4.1.3.1 Institutionalisation of TBA governance

The aforementioned agreement laid the foundations for the creation of the ASA International Task Force, a platform for stakeholder involvement in the governance of the TBA. Although the Task Force was created by informal arrangements between subnational entities, it was later incorporated by the ECC to become one of its first committees (Eckstein 2011b).

The ASA International Task Force consists of governmental representatives from national and subnational governmental agencies and aboriginal and tribal communities. In January 1997, the ASA Stakeholders Group was formally mandated by the City of Abbotsford to give a voice to the civil society, including the agricultural sector (Norman & Melious 2004, p.106). The Task Force has few formal competences. Its working group on legislation and policy advice could, however, be considered as having a competence in consultation.

Table 5 Framework for the governance of the Abbotsford-Sumas Aquifer, shared between British Columbia (Canada) and Washington (United States of America).

	Agreement / arrangement (year)	Parties	Status
2001	Memorandum of Understanding related to Environmental Impact Assessments.	State of Washington (represented by the Director of the Department of Ecology) vis-à-vis the Executive Director of the British Columbia Environmental Assessment Office.	Valid as of 20 June 2001. Does not create binding obligation for either Canada or the U.S.
1996	Memorandum of Agreement Related to Referral of Water Right Applications Related to the Transboundary Abbotsford-Sumas Aquifer.	State of Washington (represented by the Director of the Department of Ecology) vis-à-vis the Province of Britsh Columbia (represented by the Deputy Minister of Environment, Lands and Parks).	Valid as of 15 October 1996, after three years subject to review and renegotiation (unless terminated earlier by either of the parties) ex article 2. Not intended to constitute a contractually binding relationship between parties ex article 4.
1996	Memorandum of Understanding on Environmental Cooperation.	Same as above.	Valid as of 12 April 1996.
1992	Environmental cooperation agreement.	Same as above.	Follow-up: British Columbia/Washington Environmental Initiative has been established.

4.1.4 Institutional design

4.1.4.1 Knowledge and scientific learning

International science forums were held in 2007 and 2012 to promote a shared understanding of the pressures on the ASA (Zebarth et al. 2015). These facilitated the delineation of the aquifer in terms of its spatial extent, catchment area, and hydro(geo)logical boundaries and in identifying issues related to land use and health and the applicable legislation. Moreover, joint studies on land use and nitrate trends have been conducted. The 1996 Memorandum of Agreement provides for the exchange of "relevant water quality information" and consultation regarding (draft) permits on major proposed projects with likely transboundary impacts.

4.1.4.2 Robustness of legal principles

The principled content of the governance of the ASA is low, but its coverage of the principles of social justice stands out. Most strikingly, the rights of aboriginal communities are explicitly acknowledged in the preamble of the 1996 Memorandum of Agreement. The principle of participation and transparency of policy-making is embodied in a platform for stakeholder involvement, which is further discussed below. By contrast, principles of international water law have not been identified in the governance of the ASA.

4.1.4.3 Legality

The governance of the ASA is on the informal side of the legality scale. This is not to say that governmental entities are irrelevant in the policy discourse. Rather, groundwater governance emerges through a 'trialogue' between government, science, and society (Campana et al. 2006). Yet in the absence of legally binding obligations, the legality of the governance of the ASA is low.

4.1.4.4 Monitoring and data-exchange

The Vancouver Sun, a local newspaper, reported that the government of British Columbia has only recently introduced a license system for wells and the obligation to record volumetric abstraction (Sinoski 2015). Monitoring initiatives have been hindered by the elusive relationship between the chemical status of groundwater resources and the use of overlying lands. This is due to the small size of land parcels, the spatial and temporal variability in land use practise, and the permeable composition of the aquifer (Zebarth et al. 2015).

4.1.5 Effectiveness

In spite of the cooperation efforts and a rise in national policies and water quality standards, the quality of the waters of the ASA is still considered poor. Although peak values of nitrate levels are considerably lower compared to the late 1990s, the mean concentrations did not significantly change (Zebarth et al. 2015). Moreover, these concentration levels remained well above the maximum contamination standard for nitrogen of 10 mg/L, which was set independently by both Canada and the United States (Norman & Melious 2004).

The ASA Task Force was set up as an institution with the primary aim of providing a platform for facilitating stakeholder involvement. Nevertheless, stakeholder involvement in addressing transboundary pollution largely happens on an *ad hoc* basis (Zebarth et al. 2015). An example of a successful instance of governance involves British Columbia's plans to use biosolids to re-vegetate a gravel pit, transforming it into a regional park. On both sides of the border, citizens were concerned that the ASA's water quality would negatively be affected. Stakeholders and scientist were involved during all stages of the process and once the citizens were convinced of the project's potential in enhancing local groundwater quality, the project was approved (Campana et al. 2006).

The peak of the Task Force's activity was during the decade that immediately followed its installation. Political interest in transboundary cooperation in the ASA started decreasing from 2008 onwards and the Task Force did not fully resume its activity until January 2013 (Conti 2014). As of 2014, the Task Force reportedly is still hindered by lack of funding and political will (Messa 2014). On paper, the Task Force reports bi-annually on technical, scientific, and political issues related to the transboundary aquifer (Norman & Melious 2004, pp.104–105), but it remains unclear when the most recent report was issued. Perceived obstacles to effective governance include weak implementation mechanisms and competition between user groups (Conti 2014).

4.2 Genevese Aquifer

4.2.1 Introduction

The Genevese Aquifer straddles the border between the France and the Canton of Geneva in the western-most part of Switzerland. This region has a long history of human intervention in hydrological systems and particularly the River Arve, which is hydraulically linked to the aquifer. Through hydraulical engineering, the socio-economic development of the city of Geneva became inextricably linked with water management (Walter 2013).

4.2.2 Problem structure

Following intensive exploitation of groundwater resources for drinking water purposes since the 1940s, the water table dropped by more than 7 m during the 1960s and the 1970s and the aquifer was on the brink of depletion (Cobos 2010).

4.2.3 History of regional cooperation

Diplomatic ties between Switzerland and France have been strong since a failed French surprise attack in 1602. The two countries are important trading partners and more than 150.000 French commuters cross the border on a regular if not daily basis, of which approximately 50.000 come to work in the Canton of Geneva. Geneva is a geographically small canton surrounded by the French countryside. Thanks to a shared language coupled with economic and cultural exchange, Geneva has thus become part of a cross-border metropolitan area characterised by high levels of integration in various policy segments (Sohn et al. 2009).

4.2.3.1.1 Institutionalisation of TBA governance

Groundwater was acknowledged as an issue of transboundary concern shortly after scientist had issued warnings regarding the sustainability of exploitation of the TBA. Since 1972, representatives of the Canton of Geneva and neighbouring French communities held several meetings to agree on preliminary restrictions of groundwater use and to develop a mechanism to share the costs of artificial recharge equitably in mutual benefit of both parties (Cobos 2010). The artificial recharge project would involve the underground storage of 0.015 km^3 under optimal conditions, to be readily available to all users in case other sources of fresh water were to fall short of the demand. Moreover, two established water companies in Geneva would be able to continue exploiting and expanding on previously existing wells and networks as opposed to having to engineer new infrastructure. The French communities would not only be entitled to extract the same volumes as they used to, but they could even abstract supplementary amounts at a small fee (Cobos 2010).

A bilateral agreement was concluded in 1978 and the artificial recharge system was inaugurated two years later. The 1978 agreement established a Joint Commission comprising of three delegates for each party, at least two of whom were technicians specialised in water matters (article 1). The Commission would meet periodically and upon request in the territory of either of the parties to the agreement and on a rotational basis (article 3 paragraph 2-4). The 1978 agreement granted the Commission some advisory and regulatory competences. More specifically, it created the power to advise on planned modification of the waterworks inventory (article 2 paragraph 2) and to determine criteria and measurement intervals for the qualitative analysis of volumes abstracted from or injected in the aquifer (article 16). Lastly, the Commission's mandate comprised the proposal of a yearly aquifer utilisation programme, which included water quality protection measures and pollution mitigation strategies (article 2 paragraph 1).

The three-decade expiration period prompted renegotiation in the 2000s. In addition to small modifications of the provisions, this provided the opportunity to update the text in accordance with developments in international law that enabled local governments to become party to an international agreement. The new agreement entered into force in 2007.

The new agreement entailed refinements as to the convening frequency of the Committee, which was set to be "at least once a year" (article 3 paragraph 3). In an apparent attempt to streamline the decision-making procedures of the committee, the new agreement stipulated that the Commission be co-headed by members with "deliberative powers" assigned by each delegation (article 1 paragraph 1). Lastly, the provision that two-thirds of the members of the Commission shall be technical experts on water related issues was replaced by its power to appoint technicians in a consultative capacity (article 1 paragraph 3).

Table 6 Framework for the governance of the Genevese Aquifer, shared between Geneva (Switzerland) and French communities (France).

Year	Agreement / arrangement	Parties	Status
2007	Convention on the protection, utilisation, recharge and monitoring of the Franco-Swiss Génévois Aquifer. *	Communities of the 'Annemassienne' region and the rural districts of 'Genevois' and Viry (France) vis-à-vis the Republic and Canton of Geneva (Switzerland).	Binding since entry into force as of 1 January 2008.
1985	Convention relative au financement d'un laboratoire d'analyses des eaux de l'Arve. **	Unknown.	Unknown.
1978	Arrangement relatif à la protection, à l'utilisation et à la réalimentation de la nappe franco-suisse.	The State Council of the Republic and Canton of Geneva (Switzerland) vis-à-vis the Prefect of Haute-Savoie (France).	Replaced by 2007 agreement upon expiration.

* Unofficial translation was used.
** Copy has not been retrieved.

4.2.4 Institutional design

4.2.4.1 Knowledge and scientific learning

While exploring the mutual benefits of artificial recharge, the parties continued to map hydrogeological features of the aquifer as well as other water resources in the region. Indeed, the political will to jointly develop a capital-intensive project is believed to have emerged naturally in parallel with the development of consensual knowledge on hydrogeological features of the aquifer and the (Walter 2013). The level of knowledge on the hydrogeological properties of the aquifers is high. However, this is due to independent research as opposed to joint knowledge dissemination projects.

4.2.4.2 Robustness of legal principles

The principled content of the governance of the Genevese is moderate. Coverage of principles of environmental – and water law concerns the more 'pragmatic' principles such as the user-pays principle and the principles of notification of planned measures and accidental pollution. More aspirational principles such as precaution, environmental conservation, and reasonable and equitable use are omitted. Principles of social justice were not at all represented. Much like its predecessor's, the principled content of the 2007 agreement is low.

4.2.4.3 Legality

Within six years after the negotiations were initiated, a legally binding agreement was concluded between the State Council of the Republic and the Canton of Geneva on the Swiss side and the Prefect of Haute-Savoie on the French side.

In addition to regulating artificial recharge installation in terms of financing, exploitation, and liability allocation, the 1978 agreement fixed a maximum allowable volumetric abstraction by the French communities of 5 million m^3 – the first 2 million m^3 of which were free of charge (article 9). The normative character of this restriction is strengthened by provisions pertaining to the monitoring of the aquifer's status, which mandate the equipment of waterworks with recording devices for both water level fluctuations and volumetric abstraction (article 7; article 6). Lastly, the agreement outlined a mechanism for the peaceful resolution of disputes related to its implementation, involving conciliation by the Franco Genevese Regional Committee and consultation by the Franco-Swiss Consultative Commission for Problems of Neighborliness (article 20).

Much like its predecessor, the 2007 agreement shows high level of detail in determining rights and obligations. A new provision assigned the responsibility to resolve disputes on the interpretation of the agreement to the competent authority under Swiss law (article 20, paragraph 1). Moreover, the new agreement confirmed that ownership of the recharge station be transferred from a Swiss company to the Republic and Canton of Geneva (article 8).

4.2.4.4 Monitoring and data-exchange

The 1978 agreement provided for the monitoring of the status of the aquifer in a high level of detail. For instance, it provided for the exchange of the results of obligatory water quality analyses of abstracted volumes (article 16) and the compilation of water level data into national registers that can be consulted upon request by either delegation (article 11). Lastly, it specified the contents of a joint waterworks inventory (article 4).

Yet while the 1978 agreement stipulated that the recording devices shall be sealed upon gauging, the new agreement stressed that gauging entirely occurs at the user's responsibility (article 6 paragraph 1). Similarly, the responsibility to annually report water level recordings to the Commission was replaced by the transparency requirement that all recordings "shall be available to the parties on demand".

4.2.5 Effectiveness

The governance of the Genevese aquifer is considered one of the most successful instances of regional groundwater governance in the world (Cobos 2010). Historical records suggest that groundwater levels have stabilised since the introduction of artificial recharge, despite the fact that pumping rates continue to be high (Geneva 2016).

Despite relatively low ranking in terms of knowledge dissemination and principled content, both the legality and level of institutional integration are high. Groundwater is merely one of many issue areas that are successfully governed in this highly integrated transboundary metropolitan area. As argued by Cobos (2010) and Walter (2013), the shared belief in the mutual benefits of artificial recharge helped align political interests in favour of a cooperative solution, which was another major contributor to the governance effectiveness.

While the 1978 treaty is the oldest known instance of a legally binding interstate agreement on groundwater resources, its recent renewal shows that the preservation of the Genevese resources has remained on the political agenda. The new agreement entailed some refinements but omitted some details of previous provisions as well. In combination, it seems that these small changes served to reduce technocratic and bureaucratic elements of the functioning of the Commission. Despite this apparent concession to institutional integration, the level of institutional integration remains by far the highest among the eight case studies.

4.3 Guaraní Aquifer System (SAG)

4.3.1 Introduction

The Guaraní Aquifer System (SAG by abbreviation of the English and Portuguese names) is among the largest freshwater reservoirs in the world. It underlies part of Argentina, Brazil, Paraguay, and Uruguay in the eastern flank of South-America, and is hydraulically linked to the Paraná River. Due to its large spatial extent, the aquifer system is highly heterogeneous in terms of lithology, thickness, and other hydrogeological features. The SAG is located at more than 1000m depth below surface at some localities in Argentina, but the groundwater table coincides with the ground surface in outcrop areas in Brazil, eastern Paraguay and northern Uruguay (Ferranti et al. 2002). While the overall water quality is well suited for drinking water purposes, local vulnerability to pollution can be high.

The sandstone formation that makes up the aquifer system is predominantly confined by sedimentary rocks below the aquifer and overlying layers of basaltic spill (Wendland et al. 2004). Recharge processes include direct infiltration of excess rainfall in the outcrop zones. The high average rainfall across most of the region (1000-2000 mm/year) results in high potential regional recharge rates, but evaporation rates are high as well and the total recharge area

(150.000 km^2) is small in comparison to the total spatial extent of the aquifer. In addition to direct recharge, there is some leakage at locations where the basalt is thin or fractured. The total recharge is estimated to be within the range of 45-55 km^3/year on average, which amounts to less than 0.2% of the total storage (Foster et al. 2009, p.5; Wendland et al. 2004).

4.3.2 Problem structure

Regional groundwater demand is increasing due to socio-economic dynamics coupled with the degradation of surface water. Groundwater resources also have the comparative advantage to be less sensitive to regional climatic variability and particularly occasional droughts (Foster et al. 2009). Nevertheless, annual withdrawal is estimated at merely 2% of recharge rates and seems negligible compared to total fresh water storage. The majority of groundwater withdrawals is appropriated for domestic use (Foster et al. 2009). Provided that agricultural use of groundwater remains modest, pollution and depletion problems are likely to be confined to 'hot-spots'. Yet these problems might intensify in the face of rapid population growth and urbanisation. The severe drought and water-shortage crisis that plagued the metropolitan area of Sao Paulo in 2015 demonstrates the potential gravity of localised groundwater problems in the region, even though this megacity itself does not rely on the SAG (Sugg et al. 2015).

4.3.3 History of regional cooperation

The four countries that share the SAG have a long-standing tradition of cooperation as members of the Organisation of American States (OAS) and the Common Market of the South (MERCOSUR), institutions that focus on a range of issues (Conti 2014). A major step in the field of environmental cooperation was the 1969 Treaty of the La Plata Basin, in which the four countries and Bolivia agreed to join forces to promote the harmonious development and physical integration of the basin and its zones of "direct and measurable influence", specifically the improvement of road, rail, river, air, electrical and telecommunications interconnections (article l sub *d*). The 1979 Paraná agreement continued this trend through promoting the construction of hydroelectric dams to the benefit of economic development across the region (Walter 2015). The 1969 treaty is believed to have "dramatically" changed the tenor of international dynamics in the La Plata basin, which had previously been characterised by "conflicts over water use and management"(Berardo & Gerlak 2014, p.106), but Box 3 illustrates that regional cooperation has not been frictionless since then.

Box 3 Bilateral tensions in the region of the Guaraní.

Argentina and Uruguay were caught in a dispute regarding the construction of pulp mills on the Uruguay River as recently as 2005. The International Court of Justice (ICJ) ruled in 2010 that Uruguay had breached its obligation of prior notification of planned measures in the Statute of the Uruguay River (Mello Sant' Anna & Villar 2015). The construction of the Guaira-Itaipu hydroelectric power plant on the border between Brazil and Paraguay was another source of tension that has loomed for decades, although Dinar (2009, p.340) is convinced of the benevolence of Brazil's hydrohegemony in promoting mutual "benefits of joint cooperation". Unable to absorb its entire share, Paraguay was allowed to sell its energy surplus to a electricity corporation owned by the Brazilian state at a price fixed "well below international rates and […] with no adjustment for inflation" (Lamber 2016, p.40). Moreover, the treaty prohibits that the surplus be sold to third parties. Brazil was initially reluctant to renegotiate the terms of agreement, but gave in due to concerns that a procedure at the ICJ might harm its international reputation. The countries returned to the negotiation table in 2009, but the conflict does not seem to be entirely resolved to date (Lamber 2016; Mello Sant' Anna & Villar 2015).

4.3.3.1 Institutionalisation of TBA governance

Groundwater did not receive much special attention in regional cooperation until the 1990s, when academics from the region realised that the SAG is indeed an aquifer-system (as opposed to three separate aquifers) (Conti 2014). Two decades of extensive research and project activity followed. This culminated in the formulation of a Strategic Action Programme in 2009 and the conclusion of a multilateral agreement in August 2010, shortly after the formulation of Draft Articles for Transboundary Aquifers (Box 1).

The agreement provides for the creation of a Joint Commission comprised of governmental representatives of the four parties (article 15). The most notable role of the Commission is its envisaged competence to give recommendations on the resolution of disputes regarding the interpretation of the agreement (article 17). Its set-up and operation are otherwise not specified, aside from the practicality that the permanent Intergovernmental Committee of the River Plate Basin (CIC) would host it. Since the overall objective of the Committee is only broadly defined as coordinating the cooperation among parties for complying with the principles and objectives of the agreement (article 15), the level of institutional integration is moderate.[2]

[2] Proposed objectives of the Commission include the harmonisation of abstraction permit systems and other legal instruments; the design of a methodology for a shared groundwater database; and the coordination of a groundwater information system (Villar & Ribeiro 2014). Furthermore, the Commission could be charged with the monitoring of change in land-use patterns, particularly in recharge zones (OAS 2009).

Table 7 Framework for the governance of the Guaraní Aquifer System, shared between Argentina, Brazil, Paraguay, and Uruguay.

Year	Agreement / arrangement	Parties	Status
2010	Guarani Aquifer agreement. *	Argentina, Brazil, Paraguay, Uruguay.	Entry into force remains subject to ratification by Brazil and Paraguay.
2009	Strategic Action Programme.	n/a	Policy document negotiated by national and subnational governments of the four riparians. Implementation status unknown.
2001	Framework agreement on the environment of Mercosur.	Argentina, Brazil, Paraguay, Uruguay.	Binding since entry into force as of 23 June 2004. Valid indefinitely.
1975	Statute of the River Uruguay	Argentina, Uruguay.	
1973	Paraná River Agreement		
1973	Itaipú Treaty	Military dictatorships of Brazil and Paraguay	Valid for 50 years.
1969	Treaty of the River Plate basin.	Argentina, Bolivia, Brazil, Paraguay, Uruguay.	Binding since entry into force as of 14 August 1970.

* Unofficial translation was used.

4.3.4 Institutional design

4.3.4.1 Knowledge and scientific learning

Shortly after the 'discovery' of the aquifer system, a joint study on the scientific issues was initiated with the support of the International Development Research Centre (IDRC) in Canada (1997-1998). The public university of Uruguay had a leading role in this joint scientific endeavour. Driven by the concerns of local stakeholders regarding the status of the SAG, follow-up anticipatory projects were initiated with the primary aim to collect and analyse data (Walter 2015; Ferranti et al. 2002). Data was gathered on hydrogeology, geophysics, hydrogeochemistry, socio-economics, and use of the SAG (OAS 2009).

The World Bank initiated a project on the protection and sustainable development of the SAG in 2003. In addition to knowledge-dissemination, this project aspired to (a) lay the foundations for a joint management framework of the SAG, including mitigation measures within identified "hot-spots", (b) promote the involvement of the public and specific stakeholders, including indigenous peoples, and (c) explore the potential of thermal energy from low and medium enthalpies of the SAG for "a variety of economic and agro-industrial activities, aside from current use for spas" (OAS 2009, p.19). Renewed for a period of two more years in 2007, this project culminated in the adoption of a Strategic Action Programme (SAP) for the SAG in 2009.

The project was executed by the OAS with financial support of the Global Environmental Fund (GEF); riparian states were not directly involved (OAS 2009). In drafting the SAP document, however, representatives of national and local governments of Argentina, Brazil, Paraguay and Uruguay were involved along with technical experts. The conclusion of this joint research effort was that potential transboundary effects of uncontrolled use of the groundwater resources provide a compelling argument for devising adequate management strategies for vulnerable zones (OAS 2009).

Lastly, local transboundary committees were set up to support pilot projects in the regions of Concordia-Salto (Argentina-Uruguay) and Rivera-Santana do Livramento (Uruguay-Brasil). The first region thrives on thermal use of groundwater, and the committee came up with a registration system for deep borehole drilling and wastewater quality control. The second region is an urbanised recharge zone where (according to Ferranti et al. 2002) tensions related to the decline of the water table had been identified. The committee drafted an agreement on shared water resources (Foster et al. 2009). However, it is unclear to what extent these transboundary committees have remained active to date.

4.3.4.2 Robustness of legal principles

The principled content of the Guaraní-agreement is high and its wording strongly echoes the Draft Articles, which were referenced in the preamble. The agreement refers to the principles of international cooperation (article 11 paragraph 2), peaceful dispute resolution (article 16-19), environmental conservation (article 4), aversion of significant harm (article 6-7), notification of planned measures that may have transboundary effects (article 9), the principle of reasonable and equitable use of groundwater resources (article 4), and the exchange of information on those resources (article 8 and 12). Interestingly, the agreement also strongly emphasises the premise of sovereignty over natural resources in its territory.

The principle of public participation and transparency of policy-making was not explicitly included in the Guaraní-agreement itself, yet strongly embodied in the governance process. For example, leaders of indigenous communities of Argentina, Paraguay and Brazil were involved in meetings in the preparation period of the SAP.

4.3.4.3 Legality

The Guaraní agreement excited the groundwater governance community, since it was the first TBA treaty to be concluded after the Genevese agreement in 1978. Yet while Argentina and Uruguay ratified the multilateral treaty in that same year of conclusion, its validity remains subject to entry into force. Despite the low level of detail of the provisions in specifying mutual rights and obligations, Brazil and Paraguay seem to be reluctant to ratify. The agreement is under consideration at Brazil’s Ministry of the Environment; Paraguay has made clear that it is refusing to ratify (Sugg et al. 2015).

In contrast, SAP entails more concrete proposals for strengthening the institutional and technical framework of the SAG. This includes specific targets and indicators for the monitoring and implementation of the programme. The SAP distinguished three large zones for which groundwater governance may be differentiated: the outcrop zones, the confinement zones, and the highly confined zones. Nevertheless, its implementation status remains unknown and the time window for implementation is unclear.

4.3.4.4 Monitoring and data-exchange

Numerical models have been developed for four regions (Concórdia-Salto, Itapúa, Ribeirão Preto, and Rivera-Santana do Livramento). In addition, a monitoring network as established and monitoring procedures were harmonised in terms of frequency and modality (OAS 2009). Lastly, wells were inventorised; location and geographic coordinates were specified. A (web-based) hydrogeological database has, however, not yet been developed for the SAG.

4.3.5 Effectiveness

The governments of Argentina, Brazil, Paraguay and Uruguay and local stakeholders made great strides in developing hydrogeological knowledge on the SAG, including the development of "regional hydrogeological assessment and maps, hydrodynamic models of the aquifer system, surveys and geo-referencing of water-wells, and a piezometric monitoring system to identify 'hotspots'" (Sugg et al. 2015, p.384).

The pinnacle of two decades of cooperation was the conclusion of the Guaraní agreement in 2010, which exhibits richness in principles of international environmental and water law. With regards to their expressed intention of institutional integration, the parties have neither established a multilateral commission, nor drafted its statutes outlining its objectives, competences and financing (Villar & Ribeiro 2014; Sugg et al. 2015). The Joint Commission is not likely to take office until all parties have ratified the treaty.

Despite the apparent deadlock concerning the agreement, the momentum that was brought about by projects seems to have translated into action at the national and subnational level. For instance, Brazil's National Water Agency has completed a study on an outcrop zone's vulnerability to pollution (Sugg et al. 2015). As part of the implementation of the SAP, some subnational governments harmonised drilling regulations, set minimum buffer zones between wells, and took steps to designate and protect recharge areas (Sugg et al. 2015). Nevertheless, it remains unclear to what extend such local activities were continued after the project's completion.

Practicalities related to (lack of) implementation of governance aside, the development of a "common base for groundwater management" is considered a "considerable achievement" in light of its anticipatory nature; it was developed in the absence of international tensions related to groundwater (Villar & Ribeiro 2014, p.74). Since the problem that the governance of the Guaraní responded to was related to the development of knowledge rather than the sustainability of the resource, it can be considered effective in terms of problem-solving.

4.4 Hueco Bolsón Aquifer

4.4.1 Introduction

The Hueco Bolsón aquifer is located in the northern part of the Chihuahuan desert in North America, bound by mountain ranges to the east and the west. The spatial extent of the aquifer comprises mostly Texas, United States and Chihuahua, Mexico, but a small stretch of the aquifer extends into the state of New Mexico. It consists of a) an unconfined alluvial layer that interacts with the Rio Grande River, and b) a confined layer below. Recharge in the top layer is generally low, although the hydraulic conductivity is highly variable in space (Mace et al. 2001).

4.4.2 Problem structure

Many citizens have relied on the aquifer as a primary source of fresh water for several decades, including the inhabitants of El Paso (Texas), Dona Ana County (New Mexico) and Ciudad Juárez (Mexico) (Mace et al. 2001; Sanchez et al. 2016, p.111). Largely due to employment programmes, the border region's population has been increasing at a higher rate than average in Mexico and the United States and is expected to reach 20 million by 2020 (Marston & Lloyd 2005, p.243; Eckstein 2013; Eckstein 2011a; Sánchez-Munguía 2011). Urban sprawl has brought about environmental impacts and problems related to water supply, distribution and quality (Sánchez-Munguía 2011). While regional dependence on groundwater for domestic use continues to increase, irrigated agriculture accounts for three quarters of the total fresh water demand in the production of cotton, alfalfa, chilli peppers, and pecans.

The average pumping rate exceeded (natural and artificial) recharge since the 1920s – in 2001, both rates differed by a factor of 30 (Marston & Lloyd 2005, p.244; Eckstein 2011a). As a result, the water table fell by 45 m between 1940 and 1999 (Eckstein 2013). The aquifer historically discharged into the Rio Grande River, but the latter now loses water to the aquifer at the expense of surface water flow. The direction of seepage between the semi-confined and unconfined layer has also reversed due to excessive pumping, resulting in downward leakage of alluvial groundwater of poor quality into the bolson aquifer (Marston & Lloyd 2005, p.247). While natural salinity increases with depth, agricultural groundwater return flows and pumping-induced lateral mixing of saline water and fresher water are amplifying salinity problems for users (Sanchez et al. 2016, p.111; Eckstein 2013; Mace et al. 2001).

4.4.3 History of regional cooperation

The (at least) sixteen aquifers that traverse the border between Mexico and the United States of America – including the Hueco Bolsón – are undeniably important to the inhabitants of the region, but there is no bilateral agreement on the management and protection of transboundary groundwater resources to date (Sanchez et al. 2016). The only formal instrument that refers to groundwater in the border region is Minute 242, which was issued by the International Boundary and Water Commission (IBWC) in 1973 and became binding to both countries upon approval by the federal governments (Eckstein & Hardberger 2006).[3]

Minute 242 primarily addresses salinity problems of the Colorado River, but also encourages cooperation in the management of transboundary aquifers. The immediate motive for the inclusion of groundwater was the conflict related to the transboundary flow of agricultural drainage water from the U.S. into Mexico; to compensate for the loss of quality of local surface water, groundwater pumping in Mexico intensified (Sánchez-Munguía 2011). The resulting provision entails a general obligation to consult the neighbouring country prior to the development of groundwater resources that could have detrimental, transboundary effects (Eckstein 2013; Eckstein & Hardberger 2006).

Many authors have advocated for a U.S.-Mexico groundwater agreement (Eckstein 2013), but such an endeavour is complicated by conflicting notions of groundwater appropriation, high number of regional stakeholders, and disparities as to the administrative level (e.g. national or federal) where competence to regulate on groundwater on the national level is vested. Legal considerations aside, groundwater management arguably ranks relatively low on political agendas compared to other issues in the border region, such as migration and drug violence (Eckstein 2013).

4.4.3.1 Institutionalisation of TBA governance

Groundwater governance was considered important enough by local communities to take matters in their own hands. Shortly after a technical report was issued by the IBWC, representatives of the local water utilities of the City of Juárez and El Paso signed a Memorandum of Understanding (Table 8). Article 1 of this 1999 MoU established an Executive Committee comprising of personnel from both water utilities, with the immediate objective to complete the feasibility study mentioned in section 4.2.4.5. Institutionalisation of the governance of the Hueco Bolsón has primarily involved joint fact-finding and monitoring.

[3] The IBWC is a bi-national commission that was formally charged with the enforcement of water treaties and the settlement of border disputes by the 1944 'Treaty between the United States of America and Mexico relating to the utilization of waters of the Colorado and Tijuana Rivers and of the Rio Grande'.

Table 8 Framework for the governance of the Hueco Bolsón Aquifer, shared between Chihuahua (Mexico), New Mexico (United States), and Texas (United States).

Year	Agreement / arrangement	Parties	Status
2009	Joint Report of the Principal Engineers regarding the Joint Cooperative Process United States – Mexico for the Transboundary Aquifer Assessment Program.	n/a	Recommendation to the International Boundary and Water Commission (IBWC); no legal status.
1999	Memorandum of Understanding.	City of Juárez Utilities (Mexico) and the El Paso Water Utilities (United States)	Does not create binding obligations for either Mexico or the U.S. May be revoked "at any time through written notification" (article 4).
1998	Transboundary Aquifers and Binational Ground Water Database For the City of El Paso / Ciudad Juárez Area Report – a Binational Publication.	IWBC, U.S. Environmental Protection Agency ,Texas Water Development Board, New Mexico Water Resources Research Institute. Estados Unidos Mexicanos Comisión Internacional de Limites y Aguas, Comisión Nacional del Agua. Junta Municipal de Agua y Saneamiento de Ciudad Juárez.	Output of informal cooperation; no legal status.
1997	Joint Report Of The Principal Engineers Regarding Information Exchange And Mathematical Modeling In The El Paso, Texas And Ciudad Juárez, Chihuahua Area Aquifer. **	Unknown.	Output of informal cooperation; no legal status.
1973	Minute 242.	n/a	Binding to the governments of the United States and Mexico.

** Copy has not been retrieved.

4.4.4 Institutional design

4.4.4.1 Knowledge and scientific learning

The heads of the national sections of the IBWC, the 'principal engineers', issued two statements on transboundary aquifers. In 1997, the Mexican and Texan principal engineers jointly submitted a report to the IWBC, containing recommendations on information exchange and mathematical modelling in two contiguous communities in the largest metropolitan area along the border: El Paso, Texas and Ciudad Juárez, Chihuahua Area. Such a database was accordingly developed and described in a report jointly drafted by nineteen individuals from agencies in the United States and five individuals from Mexican agencies (Moore et al. 1998).

The database has advanced the joint understanding of the spatial variability of the problem, more specifically drawdown and groundwater pollution. For example, the researchers found a pattern of salinisation in wells with significant long-term drawdown. The report also includes (a) delineation of the spatial extent of the aquifer; (b) hydrogeological cross sections; and (c) geo-electrical cross-sections. After a peak of activity in the late 1990s, political interest in transboundary groundwater governance seems to have dropped. It was not until 2009 that the principal engineers issued their second statement. Intending "to improve the knowledge base" of regional TBAs, they advocated the adoption of a joint cooperative process to be hosted at the IBWC (Merino & Mendoza 2009, p.2). It is unclear to what extent this recommendation to institutionalise cooperation was adopted and implemented.

4.4.4.1.1 Project activity led by U.S. entities

While the financing of activities of the IBWC is based on the principle of equitable cost-sharing (IBWC n.d.), the federal government of the United States has independently taken steps in the funding of two projects in the region. The Environmental Protection Agency (USEPA) initiated a two-year project in 2005. Objectives of this project included the formulation of methodological and policy recommendations on the design of a binational groundwater management model and the promotion of joint requests for funding (EPA n.d.). Evaluation reports for this project have not been located. In 2007, the U.S. – Mexico Transboundary Aquifer Assessment Programme was initiated with the objective to advance hydrogeological knowledge of the Hueco Bolsón (among other transboundary aquifers). The on-going implementation of this initiative primarily involves U.S. initiatives but also indirectly involves Mexican experts through collaboration with the IBWC (Alley 2013).

On the local level, The El Paso Water Utilities (EPWU) has explored alternative water resources since the 1980s. This includes managed aquifer recharge, which involves the injection of treated wastewater into recharge wells and, more recently, infiltration basins (Sheng 2005). With ten recharge wells and one pilot recharge basin, the Fred Hervey Water Reclamation Plant was designed to process an influx of 38.000 m^3/day and it was operationalised in 1985.[4] This location was chosen because underground storage is sufficiently large that the water table could be raised by up to 5m and the proximity to pumping wells is close enough that distribution costs are low, yet the residence time is long enough (>5 years) to diminish microbial contamination. Prior to injection, the wastewater is treated to meet drinking water standards that were issued by USEPA and the Texas Department of Health (Sheng 2005). The city of El Paso has also been operating a desalinisation plant for brackish groundwater (Sánchez-Munguía 2011).

[4] Annual injection peaked at 7 million m^3 in 1990 – which is only 50% of volumetric capacity – and has since then declined due to increases in other uses, especially cooling purposes at the El Paso Electric Company (Sheng 2005).

4.4.4.2 Robustness of legal principles

The MoU highlights that "significant opportunities exist for sharing technologies between both utilities" and that the impact of water conservation and reuse is "severely limited" without transboundary implementation. Apart from mentions of the merits of exchange of data, technology and best practises in the field of water conservation, the principled content of the MoU is low.

4.4.4.3 Legality

The MoU announced a study on the feasibility of diversion to other sources of fresh water in Mexico in order to alleviate the pressure on groundwater. This would involve the joint treatment of surface water at the amount of 74 million m^3/year, corresponding to Mexico's fresh water share as stipulated in a 1906 U.S.-Mexico agreement. Even though the MoU itself did not create new rights and obligations, it embodies the shared belief that the joint management of groundwater resources may benefit all users.

4.4.4.4 Monitoring and data-sharing

Objectives of the Joint Committee include data-sharing (pumping records, sources of water, and water quality); sharing of knowledge and best practises regarding the acquisition of funding (grants and loans); developing plans to extend the lifespan of the aquifer; and jointly inventorying issues related to socio-economic development of the region (article 3). In the MoU, the local water utilities of the City of Juárez and El Paso referred to a joint mathematical model and claimed to have shared technical information (e.g. well locations, ownership and pumping data) during the past decade. Lastly, the technical report issued by the IBWC reveals that the joint database (MS Excel 7.0 Workbooks) consists of tabulated groundwater level recordings, pumping records, and TDS measurements, which were organised by country/state. This implies that if meta-data were not harmonised, these were at the very least compatible.

4.4.5 Effectiveness

While groundwater cooperation has remained limited on the international level, local authorities have taken up a leading role in the governance of the Hueco Bolsón aquifer. Community-based groundwater governance seems to have emerged around 'hot-spots' where groundwater issues are most pressing, i.e. focal points of drawdown beneath El Paso in Mexico and Ciudad Juárez in Texas (Moore et al. 1998). Even though the intensity of the groundwater depletion problem was found to be relatively low in New Mexico, it is questionable whether the users in this state would have included if the governance process were more formal. The emergence of informal arrangements in the late 1990s draws the attention to the strong historic, cultural, and socio-economic ties between these 'sister communities' of Ciudad Juárez and El Paso (Eckstein 2013).

In disseminating knowledge on such (hydrogeological) properties of the aquifer, the principal engineers of the IBWC developed a framework of reference for groundwater governance. Researchers from either side of the border have made considerable progress in developing the knowledge-base of the Hueco Bolsón aquifer especially given that knowledge on the delineation, storage capacity, flow direction, renewability and quality of groundwater resources along the U.S.-Mexico border has been called "limited at best" (Eckstein 2011a, p.275). However, it remains unclear to what extent the second report from the Principal Engineers, dating from 2009, was followed up on.

It seems that after a few years of relative effectiveness, the interest in joint governance waned. A striking example is that federal and local governmental entities of the United States of America decided to develop projects from 2005 onwards, which only marginally involved Mexican institutions. There are two explanations for this: the first one being that unilateral initiatives were considered more effective compared to cooperation, the second one that a change in circumstances (for example a hydrological drought) shifted the benefits for cooperation between the parties.

Lastly, the evaluation of governance effectiveness in terms of problem solving is inhibited by the lack of (public) historical recordings of the groundwater level. The El Paso Water Utilities have published pumping records that show a negative trend from the early 1990s to the mid-2000s (EPWU 2015). Pumping was at a historic low around 2008, after which it started to increase again. However, the utilities attribute this dip to full river allocation as part of their overall water supply strategy rather than reduced demand. This illustrates that the governance of the Hueco Bolsón must be understood within the wider context of water governance, including agreements on the allocation of surface water and resilience strategies for times of drought.

4.5 Iullemeden Aquifer System (SAI)

4.5.1 Introduction

The Iullemeden aquifer system (SAI) extends across Algeria, Benin, Mali, Niger, and Nigeria. It is defined by mountain ranges in the north, the northwest and the south (Wallin et al. 2005). The aquifer system consists of two large aquifers: the low-lying cretaceous Continental Intercalaire and the overlying Complexe Terminal, both predominantly made up of sedimentary deposits

(OSS 2008).[5] The region is characterised by high aridity, and the Niger River is the only source of permanent surface water runoff. The interaction between surface water and the aquifer system is complex and dynamic (Dodo & Baba Sy 2004; Hearns 2009). The SAI is also a weakly connected to confined aquifers in the Chad basin (Saradeth & Weissman 2008).

4.5.2 Problem structure

This groundwater resource and related ecosystems are increasingly stressed due to loss of groundwater resources and groundwater depletion, driven by rapid population growth and climatic variability. Although calculation of annual recharge is hindered by the hydrogeological heterogeneity of the aquifer system, the threshold of overexploitation is believed to have been crossed in 1995 (Dodo & Baba Sy 2004; Wallin et al. 2005). Withdrawals exceeded estimated recharge by 25% in 2009 (Hearns 2009).

Meanwhile, a persistent Sahelian drought has come with reduced precipitation and increased evaporation. The abstraction of (highly-mineralised) groundwater from ever-deeper locations has induced a surge of water-related diseases such as skeletal and dental fluorosis. Other pressures on groundwater resources include pollution, salinity intrusion, and land degradation (Vrba et al. 2009; Saradeth & Weissman 2008; OSS 2008).

4.5.3 History of regional cooperation

A Niger River commission was established over five decades ago and its successor, the Niger River Commission, was granted additional competences in 1980. However, groundwater historically received little attention in regional environmental cooperation (Adenle 2004) until the Niger Charter entered into force in 2010. This agreement promotes the principles of integrated water resource management (article 12 sub 3 and 5) and conjunctive use of water resources (article 12 sub 4) and provides for the creation of standards on wastewater effluent to prevent pollution of groundwater and surface water resources (article 12 sub 5).

4.5.3.1 Institutionalisation *of TBA governance*

The development of shared knowledge on the SAI that was spurred by projects, called for the design of "decision-making support tools for a sustainable development and a rational and concerted exploitation of their shared water resources". Mali, Niger and Nigeria agreed to install a consultative mechanism for the joint management of SAI resources at the premises of the FAO headquarters in 2006. Subsequently, they requested additional assistance from FAO to formalise the mechanism. In the meantime, a temporary solution emphasised the role of the OSS in

[5] Along the northern fringes of the system, it is overlain by a marine cretaceous aquifer extending into Algeria (Saradeth & Weissman 2008). This segment is not included on maps of the aquifer system that were produced by the 'riparian' countries, but it is considered part of the aquifer system as delineated by IGRAC (TBA map).

gathering and processing new data and sharing the revised database with all countries involved (Hearns 2009).

Within three years after the first FAO meeting, the competent ministers of Mali, Niger and Nigeria signed a MoU related to the setting up of a consultative mechanism for the management of the Iullemeden Aquifer System. Rather than implementing this MoU, however, the countries embarked on an exploration of the linkages between the aquifer system and the Taoudeni-Tanezrouft basin on one hand and the Niger River Basin on the other. This culminated in the conclusion of a second MoU in 2014, which also involved representatives of Algeria, Benin, Burkina Faso, and Mauritania.

Article 5 of both MoUs assigned various advisory and regulatory powers to the respective consultation mechanisms. Such powers include advising on the likely impacts of planned projects on the groundwater resources in the region and on the harmonisation of national legislation; the identification of vulnerable zones; the dissemination of a monitoring programme; and the coordination of integrated development plans that promote the preservation of groundwater resources. The MoUs also explicitly identified the mobilisation of financial resources as one of the functions of the mechanisms.

Table 9 Framework for the governance of the Iullemeden Aquifer System, shared between Algeria, Benin, Mali, Niger, Nigeria.

Year	Agreement / arrangement	Parties	Status
2014	Memorandum of Understanding for the Establishment of a Consultation Mechanism for the integrated management of water resources of the Iullemeden, Taoudeni/Tanezrouft Aquifer Systems.	Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger, Nigeria.	Ministerial declaration; not legally binding. Unclear whether the consultative mechanism has been established as intended.
2008	Niger Basin Charter.	Benin, Burkina Faso, Cameroon, Guinea Ivory Coast, Mali, Niger, Nigeria, Chad.	Binding since entry into force as of 19 July 2010.
2009	Memorandum of Understanding related to the setting up of a consultative mechanism for the management of the Iullemeden Aquifer System.	Mali, Niger and Nigeria.	Ministerial Declaration; not legally binding. It remains unclear whether the consultative mechanism has been established as intended.
2009	Bamako Declaration of the Ministers in charge of Water resources of the countries sharing the Iullemeden aquifer system.	Mali, Niger and Nigeria.	Follow-up: a MoU on the establishment of a consultation mechanism for the SAI was issued in 2009.
2006	Minutes of the closing seminar of FAO project TCP/RAF/3001 on "Establishment of a tripartite consultation mechanism for the management of the Iullemeden Aquifer System held at FAO headquarters in Rome on 19-20 October 2006. **	Unknown.	Minutes of a meeting; no legal status.

1980	Convention creating the Niger Basin Authority.	Benin, Cameroon, Chad, Ivory Coast, Guinea, Mali, Niger, Nigeria, and Upper Volta.	Binding since entry into force as of 3 December 1982.
1964	Agreement concerning the Niger River Commission and the navigation and transport on the River Niger.	Cameroon, Chad, Dahomey, Guinea, Ivory Coast, Mali, Niger, Nigeria, and Upper Volta.	Binding since entry into force as of 12 April 1966.

** Copy has not been retrieved.

4.5.4 Institutional design

4.5.4.1 Knowledge and scientific learning

The riparians of the SAI have engaged in joint knowledge development efforts such as research on the hydrogeologic properties of the resource and pilot projects. This has also involved the application of innovative techniques in the field of remote sensing and isotope dating. The countries have succeeded delineating the aquifer, scoping the problem, and understanding groundwater level and groundwater use.

The first step in the governance of the Iullemeden Aquifer System consisted of an analysis of transboundary risks or 'Transboundary Diagnostic Analysis'. Upon proposal of the governments of Mali, Niger and Nigeria, a project called "Managing hydrological risks in the Iullemeden Aquifer System" was initiated by the Global Environmental Fund (GEF) and the United Nations Environment Programme (UNEP) in 2004. This followed a preparatory phase that involved the partners of the Internationally Shared Aquifers Resources Management (ISARM) initiative, the International Atomic Energy Association (IAEA), and the Swiss Federal Institute of Technology in Zürich (ETH) (GEF, 2003).

Executed by the Sahara and Sahel Observatory (OSS), this project pertained to technical training in database development and hydrogeological modelling. This also involved the creation of digital maps. In 2008, the project had culminated in the identification of transboundary risks (groundwater overdraft, pollution, and the impact of climate change) as well as their direct causes and root causes (OSS 2011). Simulations run with the SAI mathematical model have enabled the identification of zones at high risk of overexploitation with greater precision than before and fostered the understanding of hydrological connections between the aquifer system and the Niger river (OSS 2008).

In parallel to the GEF/UNEP project, cutting-edge technologies were applied to develop the physical-hydrological understanding of the aquifer system. Firstly, IAEA-led pilot studies in Niger and Nigeria served to estimate recharge rates using isotope dating techniques (Wallin et al. 2005). Secondly, land-use patterns were mapped using innovative methods involving remote sensing and satellite imagery under the umbrella of the "Earth Observation for Integrated Water

Resources Management in Africa" AQUIFER initiative of the European Space Agency (ESA), also known as TIGER (2007-2008). The latter project involved extensive capacity development and cooperation with a regional partner, namely AGHRYMET – a regional institution of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS). The AQUIFER project was funded by ESA's Data User Element programme and co-funded by the OSS and the African Water Facility, which is management by the African Development Bank.

While led by a German company in the geo-spatial service market (GAF AG), the IAEA project's implementation involved other actors from the private sector (SCOT, France; Telespazio, Italy; Vista Geowissenschaftliche Feernerkundung, Germany) and from academia (Joanneum Research, Austria; University of Jena, Germany) as well (GAF n.d.). Project outputs included maps of land use and land cover; digital elevation models; estimates of actual evapotranspiration and precipitation; and the monitoring of land subsidence in relation to groundwater abstraction (Saradeth & Weissman 2008).

Upon the initiative of the member countries, the OSS launched a project on the integrated and joint management of the shared water resources of the Iullemeden-Taoudeni-Tanezrouft Aquifer Systems and the Niger River Basin in 2011 (better known as the GICRESAIT project by abbreviation of its French name). The objective was to analyse and manage transboundary risks of regional groundwater resources, to devise a framework for dialogue between the riparian countries and to develop capacity in the use of GIS (OWAS/AWF 2014). The African Water Facility provided financial support OSS member countries (Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger and Nigeria) were primarily responsible for its implementation, with non-regional entities (GEF and FFEM) only involved in supplementary funding.

The IAEA initiated a technical cooperation project in 2012 on the integrated and sustainable management of shared aquifer systems and basins of the Sahel region, among which the Iullemeden and Taoudeni basins. The aim of this on-going project is to provide a scientific basis for the preparation of a Strategic Action Programme by 2017 to support the establishment of the legal-institutional framework for multipartite management and rational use of the shared water bodies. To this end, IAEA is partnering with UNESCO, JICA and the OSS and receives financial support from Australia, Japan, Sweden, New Zealand and the United States.

4.5.4.2 Robustness of legal principles

The principled content of the 2009 MoU is high. It resembles the Draft Articles, with references to a) general principles of international law such as international cooperation and peaceful dispute resolution (article 3; article 29 paragraph 31); b) principles of environmental law such as the precautionary principle (article 16), notification of planned measures that are likely to have transboundary effects (article 24), and the principle of ecosystem preservation (article 21 sub *a*); and c) principles of water law such as the principle of reasonable and equitable use of groundwater (article 13), the principle of non-detrimental use (article 15), the principles of integrated water resource management and conjunctive use of water resources (article 20), the user-pays principle (article 18), and the polluter-pays principle (article 17). Lastly, transparency and participation in decision-making is encouraged (article 14).

Much like its predecessor, the 2014 MoU is rich in principles and similar to the Draft Articles. Moreover, the latter resembles the first in terms of both structure and wording. Therefore, the governance of the SAI ranks high in terms of principled content.

4.5.4.3 Legality

The two key agreements that contribute to the legality of the governance of the SAI are the MoUs from 2009 and 2014. The 2009 MoU provided for the exchange of data on SAI resources and their use (article 19 sub *a*; article 22 sub *a* and *c*) and the establishment of a consultation mechanism, which would be responsible for the identification of vulnerable zones that require special measures (article 5 sub *l*; article 11 sub *g*). Other provisions involve the avoidance of "excessive abstraction" (article 19 sub *c*) and the promotion of harmonised standards of groundwater quality (article 20 sub *e*). Although its provisions are broadly formulated, the MoU is comprehensive in scope. Again, both MoUs are very similar in terms of structure and wording.

The formality of the MoUs is low in the sense that unlike international treaties, these are not potentially legally binding. Nevertheless, much progress would be entailed by their implementation. Yet neither of the two MoUs appears to have been been implemented. Instead of implementing the 2009 MoU, Mali, Niger and Nigeria directed their attention to the governance of the Iullemeden, Taoudeni/Tanezrouft Aquifer Systems. The resulting 2014 MoU has only been signed by Benin and Niger.

4.5.4.4 Monitoring and data-exchange

As discussed in section 4.2.5.3, project outputs included the creation of a mathematical model on the hydrogeology of the SAI was created and a database comprising data on climatology, hydrology, hydrogeology, administrative districts and water use (Dodo & Baba Sy 2004). Through linking the database to the model, thematic maps were made Geographical Information System of the SAI. Such maps included water distribution, lithological cross sections of the aquifer system, and piezometric maps of both aquifer segments. In addition, an inventory for wells was made (OSS 2007).

4.5.5 Effectiveness

There are no indications of abatement of issues related to groundwater depletion and pollution. Nevertheless, the riparians of the Iullemeden aquifer system made great strides in developing knowledge and understanding of pressures on the system and associated socio-economic drivers. In doing so, they opted for a participatory approach involving regional stakeholders (Dodo & Baba Sy 2004). In generating the right 'climate' for knowledge-development, the role of third parties – and most strikingly the IAEA and the ESA – appears to have been paramount. The role of national governments and the OSS, however, grew over the course of the past decade as evident by the self-initiated GICRESAIT project and follow-up for the TIGER project.

More importantly, the riparians embarked on an ambitious effort to formulate norms and principles for the governance of shared groundwater resources. The resulting MoUs are elaborate and comprehensive and their incorporated principles were substantiated compared to the governance of other aquifers, yet remained too abstract to be of any practical significance. The countries appear to have failed to operationalise any transboundary groundwater institution to date. The on-going preparations of a Strategic Action Programme, supported by IAEA, may prove beneficial for the governance effectiveness; the formulation of concrete targets and a timeframe for implementation may provide the guidance that countries need to effectively govern shared groundwater resources.

4.6 North-western Sahara Aquifer System (SASS)

4.6.1 Introduction

The North-western Sahara Aquifer System (SASS as abbreviated by its French name) underlies parts of Algeria, Libya and Tunisia. This multi-layered system of aquifers has large fresh water storage, which is mostly fossil in origin. The upper layer (the so-called Complexe Terminal) occurs at varying depth (400-1000m) below surface and consists mostly of limestones and sandy and clayish formations, intermittedly overlain by shallow (phreatic) aquifers. The underlying Continental Intercalaire extends further towards the west.

4.6.2 Problem structure

The SASS provides the primary source of drinking water for approximately 5 million people but is depleted at a high rate due to land use change, particularly the rapid expansion of irrigated agriculture (Vrba et al. 2009; Mechlem 2014). Transboundary drawdown effects are felt in Tunisia and Libya (Schmidt 2008). Other pressures include salinity intrusion along the coast and deterioration of water quality along the national borders (Saradeth & Weissman 2008; Schmidt 2008).

4.6.3 History of regional cooperation

There are longstanding relationships between the neighbouring Maghreb states. Algeria's Treaty of Fraternity and Concord with Tunisia led to a temporary cooling of bilateral relationships between Algeria and Libya, since the first had long shunned the latter's inclinations for a political union. This changed with the establishment of the Arab Maghreb Union (AMU) in 1989, which marked the start of an economic collaboration involving all three riparians. The union was seen as very effective until 2008. More recently, the friendly regional relations are overshadowed by post-Arab Spring tensions.

4.6.3.1 Institutionalisation of TBA governance

The first phase in the governance of the SASS was knowledge dissemination induced by international projects from the late 1990s onwards. Attempts for institutional integration followed shortly afterwards. During a meeting at the FAO premises in 2002, the three countries expressed their intent to establish a 'consultation mechanism' for the TBA, which was operationalised six years later. This intergovernmental mechanism would be responsible for the promotion of coordinated studies in the region and the processing, analysis and validation of data related to the state of groundwater resources and socio-economic aspects of water use.

Within a few years after the minutes of this meeting where endorsed by all three countries, two subsequent Ministerial Declarations were apparently signed to formally establish the mechanism (2005) and to determine its structure, operation and funding as well as the allocation of liability (2007). The fact that these declarations have not been located (Table 10) may imply an underestimation of institutionalisation of the governance of the SASS.

Table 10 Framework for the governance of the North-western Sahara Aquifer System, shared between Algeria, Libya and Tunisia.

Year	Agreement / arrangement	Parties	Status
2007	Agreement on the structure, operation and funding of the consultation mechanism and on the allocation of accountability (2007). **	Algeria, Libya and Tunisia.	Unknown.
2005	Accord pour la création d'un mécanisme tripartite permanent de concertation pour la gestion commune du SASS (2005). **	Algeria, Libya and Tunisia.	Ministerial Declaration; not legally binding.
2002	Establishment of a consultation mechanism for the North-western Sahara Aquifer System - Excerpts of the procès verbal (Minutes) of a meeting held at the Headquarters of the FAO in Rome, Italy, on 19 and 20 December 2002.	Algeria, Libya and Tunisia.	Endorsed by Algeria on 6 January 2003 and Tunisia on 15 February 2003 and Libya on 23 February 2003 (ratification equivalent).
1989	Treaty Establishing the Arab Maghreb Union	Algeria, Libya, Mauritania, Morocco, and Tunisia.	Signed by all member states in Marrakech on 17 February 1989.

** Copy has not been retrieved.

4.6.4 Institutional design

4.6.4.1 Knowledge and scientific learning

The SASS has been subject to intensive project activity between 1999-2014. The three-stage UNEP/OSS SASS project was funded by the GEF, FFEM, and the Swiss Agency for Development and Cooperation (SADC). The first project phase (1999-2002) identified loss of artesian pressure, depletion, and salinisation of groundwater as major challenges. It culminated in the development of a multi-layer water balance model for the aquifer system, in which vulnerable zones were highlighted. However, the hydrological relationships between some parts of the SASS (namely the Chotts/Sebhas and the underlying aquifers) remained not fully understood (Puyoô 2010). The second phase focused in particular on the vulnerable zones that were identified in the first phase. The third phase culminated in the publication of three OSS reports on the socio-economic aspects of irrigation in the region.

The SASS was also part of ESA AQUIFER - TIGER initiative, discussed in the previous section on the SAI. While the project set-up was largely the same as for the SAI, the regional partners were naturally different: the Centre National de Télédétection (Tunisia), Centre National des Techniques Spatiales (Algeria), and the Libyan Center for Remote Sensing and Space Science (GAF n.d.). Project outputs included maps of estimated water abstraction for irrigation for two demonstration sites in the SASS (UNESCO 2010). Furthermore, the IAEA, FAO, and the government of Libya conducted a case study on groundwater potential of the Gefara basin using isotope dating, with technical support from Japan and Italy (Wallin et al. 2005).

4.6.4.2 Robustness of legal principles

The principled content of the governance of the SASS is very low; the principle of exchange of information is the only one coded for, as it is implicit in the monitoring agreement.

4.6.4.3 Legality

The legality of the governance of the SASS is on the low end of the spectrum. No provisions entailing rights and obligations have been identified. Provisions on adjudication and dispute resolution are also lacking. Moreover, none of the negotiated governance documents are formal in the sense of potentially legally binding. The informal governance documents seem to have been successfully implemented.

4.6.4.4 Monitoring and data-exchange

As discussed above, outputs of the SASS project also involved hydrogeological modelling, more specifically the construction and calibration of the Djeffara model and the Biskra model (north of the Chotts zone). In addition, a conceptual model for the Western Basin was constructed. Boreholes and so-called foggaras have been inventorised and a piezometric network was completed (Puyoô 2010). Furthermore, the minutes provided for the development of a reference observation network for groundwater monitoring (article iv).

4.6.5 Effectiveness

The countries of the SASS have made great strides in developing knowledge on the aquifer system, particularly the quantitative aspects (water balance). The use of remote sensing techniques has proven to be fruitful in the absence of regulation and control on groundwater abstractions. In addition to knowledge dissemination, the aquifer system ranks moderately high in terms of monitoring and data-exchange. With the establishment of its coordination unit at the OSS premises in 2008, an intergovernmental concertation mechanism became operational.

Nevertheless, the convening frequency of this mechanism is unknown and the last governance update was related to the closing meeting of SASS III project on 20 and 21 October 2014 (OSS 2015). As suggested in section 4.1.6.2, political interest in the joint governance of the SASS may have waned in the context of post-Arab Spring tensions. This is exemplified by the fact that both Algeria and Tunisia have reportedly started to build walls at the border with Libya. Meanwhile, volumetric abstraction has continued to increase (Puyoô 2010).

4.7 Nubian Sandstone Aquifer System (NSAS)

4.7.1 Introduction

The Nubian Sandstone Aquifer System extends to over two million km^2 in northeast Africa below the desert lands of Egypt and Libya and the sparsely vegetated lands in Chad and Sudan. The Mediterranean Sea defines the northernmost boundary of the aquifer system, including a stable salt-fresh water interface. The system is bound by a mountain range and the Nile in the east and southeast respectively (Alker 2008; IAEA 2010; Wallin et al. 2005).

The aquifer system can be divided into two main segments that are hydraulically linked through upward leakage: 1) the extensive Nubian Sandstone Aquifer and 2) the overlying Post-Nubian Aquifer in the northern part. It comprises sedimentary sequences that range in thickness from less than 100 m (in Chad and Sudan) to more than 5000m (in Egypt and Libya) and rest on basement rocks. The bulk of the water in storage is of fossil origin. Modern-day recharge may take place, but only at a low rate (Wallin et al. 2005; Alker 2008).

4.7.2 Problem structure

The aquifer is of importance to the inhabitants of in supplying water for domestic and irrigation purposes (Alker 2008; Wallin et al. 2005). Small communities and nomadic groups comprise the main user group in the sparsely populated country segments of Chad and Sudan, but rural dwellers are being pushed further south in the face of progressive desertification (Wiese 2010; Kornfeld 2006). Moreover, there is some "cultivation of date palms and cereals in the oasis, wadis and interdunal depressions" in northern Chad (Wiese 2010, p.56) whilst an "unprecedented upsurge in land acquisitions" by foreign investors is promoting an increase in groundwater abstractions in Sudan (Ferragina & Canitano 2014, p.105).

In Egypt, small-scale farms used to account for the bulk of the abstraction for decades until they were outnumbered by large irrigation development schemes in the southwestern part of the country. More recently, Libya started exploring opportunities for large-scale exploitation as well (Box 3). Despite the vastness of the NSAS storage, it is suspected that the aquifer system has been unstable since the economic development of Egypt and Libya accelerated in the early 1960s (Alker 2008; Sefelnasr et al. 2015).

Box 4 The 'Great Man-Made River Project'.

Libya's 'Great Man-Made River Project' is the world's largest groundwater transfer scheme to date, involving five large well fields with more than 1300 boreholes of 500-800m in depth. Approximately 2.2 km^3 is transferred annually over distances of 300-600 km to the highly densely populated coastal strip of Libya where local groundwater is of inferior quality. The preparations for the project started in 1983 and the first water was delivered to Benghazi in 1991 and to the capital of Tripoli in 1996 (Charalambous 2013). The project was meant to enable irrigation of 250.000 hectares across the country, but its implementation slowed down due to the civil war and most irrigation sites have never become operational (Ferragina & Canitano 2014) .

4.7.3 History of regional cooperation

The geopolitical history of the Nubian region is characterised by high volatility. International tensions and border conflicts have marked the 20th and 21st century. More recently, the stability of the region at large is increasingly at risk in aftermath of the so-called "Arab Spring" (Zandee et al. 2016). Neighbouring states to Chad and particularly Sudan have long felt the cross-border migration effects of poverty, domestic political turmoil and cross-ethnic violence (Kornfeld 2006; Giroux et al. 2009), but destabilisation in the Middle East and the MENA has spill-over effects across the Sahel and Sub-Saharan Africa.

4.7.3.1 Institutionalisation of TBA governance

International interest for the use of groundwater to combat desertification arose in the 1970s, but joint knowledge dissemination was not initiated until after Egypt and Libya had commenced large-scale exploitation of the NSAS. Project activity led to a declaration on monitoring and data-sharing (2000) and two negotiated policy documents: the Shared Aquifer Diagnostic Analysis (SADA) and the Strategic Action Programme (SAP) (Table 11).

The Joint Authority (JA) for the study and development of the NSAS is among the oldest institutions for groundwater governance and evolved organically. The JA was created in 1992, shortly after Libya celebrated the first transfer of groundwater to the city of Benghazi (Box 2). Its constitution concerned a bilateral agreement, where Libya's large-scale groundwater development appears to have been a major incentive for Egypt to engage in cooperation. After third parties got involved in the region (section 4.7.3), the scope of the JA was expanded to include the other riparians. Sudan acceded in 1996, Chad in 1998.

Composition of the Joint Authority, meeting frequency, funding, and financial compensation of its members were determined in great detail in the agreement on the Joint Authority. The SAP further stipulates that the privileges and immunities necessary for carrying out its mandate be granted to the JA. By contrast, the Authority's objective and powers were more broadly defined; the agreement granted the JA the competence to collect and to analyse "all relevant information, data, and results of studies" (article 3). Strikingly, the JA may formulate plans for the development and utilisation of groundwater resources, which explicitly includes embarking on the rationing of their consumption (article 3). The list of targets to "strengthen existing cooperation through the JA and explore new areas of cooperation" also provides for the expansion of its mandate to ecosystem monitoring and management (p.45). Article 24 of the agreement provides for further regulation of its competences, but no by-laws have been located.

Table 11 Framework for the governance of the Nubian Sandstone Aquifer System, shared between Chad, Egypt, Libya and Sudan.

Year	Agreement / arrangement	Parties	Status
2013	Regional Strategic Action Programme for the Nubian Aquifer System.	Signed by representatives of Chad, Egypt, Libya, and Sudan and the Chair of the Joint Authority.	Implementation phase.
2010	Shared Aquifer Diagnostics Analysis	Presumably signed by country representatives.	Issued upon completion.
2000	Terms of reference for the monitoring and exchange of groundwater information of the Nubian Sandstone Aquifer system (Agreement No. 1).	Chad, Egypt, Libya and Sudan.	Ministerial Declaration; not legally binding.
2000	Terms of reference for monitoring and data sharing (Agreement No. 2).	Chad, Egypt, Libya and Sudan.	Ministerial Declaration; not binding.
1992	Constitution of the Joint Authority for the study and development of the Nubian Sandstone Aquifer Systems.	Bilateral agreement concluded between Egypt and Libya. Accession of Sudan in 1996. Accession of Chad in 1998.	Joint Authority is operational. Its competences are elaborated in Bylaws. **
1963	Act regarding navigation and economic co-operation between the states of the Niger basin.	Cameroon, Chad, Dahomey (Benin), Guinea, Ivory Coast, Mali, Niger, Nigeria, and Upper Volta (Burkina Faso).	Entry into force 1 February 1966.

** Copy has not been retrieved.

4.7.4 Institutional design

4.7.4.1 Knowledge and scientific learning

The NSAS was discovered as part of oil exploration efforts in the southern part of Libya in 1953. Joint research on the NSAS started in the 1970s, with UNESCO sponsoring two subsequent meetings in Cairo, in which Egypt, Libya and Sudan agreed to make plans to assess the groundwater resources. After the United Nations Conference on Desertification in 1977 in Nairobi, UNEP, and the Danish government backed projects to use groundwater for afforestation and development of the extremely arid areas near the border between Egypt and Sudan (Iskander 1985).

Project activity was revived in 1995 but the focus shifted to the dissemination of knowledge on groundwater resources. The Centre for Environment and Development for the Arab Region and Europe (CEDARE) and the International Fund for Agricultural Development (IFAD) had a major role in facilitating a research project that involved the governments of Egypt, Libya and Sudan were involved from the beginning. After a preparatory phase of two years, the 'NSAS Regional Strategy Programme' was initiated in 1997 and completed one year later. This endeavour reportedly culminated in the establishment of a Nubian Aquifer Regional Information System (NARIS) database.

Between 2005 and 2011, the GEF/UNDP 'NSAS Project' was conducted with major involvement of the IAEA. Objectives included the agreement of a Shared Aquifer Diagnostic Analysis; the establishment of a framework for a legal-institutional mechanism for four-partite management and rational use of the NSAS; and the application of isotope technology to address methodological, data, and capacity gaps (UNDP/IAEA 2005).

One of the negotiated outcomes of the GEF/UNDP project was the Regional Shared Aquifer Diagnostics Analysis (SADA) report. The SADA report was the product of a process that revolved around "joint fact-finding" to agree on transboundary issues (IAEA 2010, p.8). The report suggested that transboundary effects in drawdown are not anticipated in light of current pumping levels and distance from the border. While this conclusion was allegedly based on a model developed through rigorous calibration, sparse data were used for calibration. The risk of transboundary pollution was also considered low, due to the low transmissivity of the aquifer and the distance of water discharge locations from international borders (IAEA 2010). As a follow-up to the SADA, the Strategic Action Programme (SAP) was signed by national representatives in 2013. The SAP outlines targets and a timeline of process indicators that relate to the achievement of these targets.

In addition to joint studies, pilot projects have been developed for the NSAS. The IAEA piloted its isotope technology in Kharga and Toskha in Egypt, Kufra and Jaghbaub in Libya, and Wadi Hawar and Dongola in Sudan (Wallin et al. 2005). The SAP includes a timeline for the implementation of pilot programmes on water conservation, wastewater disposal, and climate change adaptation by 2015 and the establishment of a pilot protected area between Chad and Sudan by 2018.

4.7.4.2 Robustness of legal principles

The principled content of the governance of the NSAS is moderately high. Coverage of principles of International Environmental Law is particularly high, including the principles of exchange of information, precaution, environmental conservation, aversion of significant harm, and notification of planned measures. Most of these principles can be found in the SAP. Striking is the inclusion of the user-pays principle with the statement that the "cost of preventing and eliminating pollution, including clean-up costs, shall be paid by the polluter" (p. 21). In the category of principles of Social Justice, the omission of references to rights of marginalised groups is striking.

4.7.4.3 Legality

The governance of the NSAS is ranks in the middle segment in terms of legality. Some clearly outlined rights and obligations contribute to its legality. More specifically, the SAP provides for the development of waste disposal quality standards and guidelines as wells as standards on the use of chemicals in agriculture and disposal of industrial and municipal waste. As mentioned in section 4.7.4.1, the SAP also includes a timeline for the implementation of a pilot no-drilling zone between Chad and Sudan.

On the other hand, the governance of the NSAS does not involve a dispute resolution mechanism and formal governance instruments are lacking. It seems like none of the informal arrangements have been implemented so far; the status of the 2000 ministerial declarations is unknown and the implementation of the SAP is planned to continue until 2018 at the earliest.

4.7.4.4 Monitoring and data-exchange

The declaration on terms of reference for monitoring and data sharing (2000) outlined the types of monitoring data, providing for measurements of the groundwater table and abstraction taken twice a year in "selected locations" and yearly measurements of electric conductivity as an indicator of salinity. It also provided for the harmonisation of monitoring parameters and the creation of an inventory for wells and boreholes. Lastly, it expressed the intention to further develop NARIS and upload hydrogeological, meteorological and socio-economic data to a protected online environment. Complementarily, the SAP provides for the establishment of harmonised monitoring of biological parameters.

4.7.5 Effectiveness

The identification of pressures on the NSAS and associated drivers was central in the emergence of governance of the aquifer system. In spite of extensive knowledge dissemination, gaps in knowledge on the hydrogeology and utilisation of the NSAS remain. Overall, "scarcity, discontinuity, and the scattered distribution of data" still prevails, as the presence of observation wells is exclusively confined to Libya and Egypt (Sefelnasr et al. 2015, p.51). As a result, little is known about groundwater dependence of nomadic groups in Chad and Sudan and the extent to which their livelihoods are likely to be affected by changes in exploitation patterns across the Nubian.

Despite the high involvement of third parties, the governance of the NSAS seems to have started to emerge before the peak in project intensity. An institution was installed in an early stage. Although operational, this institution seems to be coping with lack of funds as the SAP calls for the provision of "financial means to the JA including country contributions" (p.24).

The governance of the NSAS ranks relatively high in terms of the dimensions of effectiveness with average to moderately high levels of knowledge-dissemination, principled content and institutional integration Yet there are no indications of improvements in terms of the four problems identified by the riparians, i.e. declining water levels, water quality deterioration, changes in groundwater regime, and damage or loss to ecosystems and biodiversity. Moreover, transboundary terrorism, human trafficking and illegal arms trade stand unhindered by porous international borders and have directed political attention away from groundwater governance (4.7.3.).

4.8 Saq-Ram Aquifer System

4.8.1 Introduction

The Saq-Ram aquifer system extends from the Tabuk-Tayma region in the northern borthers of Jordan and Saudi Arabia and beyond. The Tabuk-Mudawwara-Disi segment stretches from Wadi Rum in Jordan to the Tabuk Plain in Saudi Arabia and is underlain by a deep sandstone aquifer, called the Saq layer in Saudi Arabia and the Disi layer in Jordan. The Saq-Ram aquifer system is "composed of medium to coarse grained sandstones with thin shale intercalations" and ranges in thickness from several hundreds of metres in the outcrop areas to over 2.000 m in the east and northeast (ESCWA 2013; Wagner 2011, p.231). Depth-to-surface ranges from 400m in Mudawwara to more than 2.000m in Wadi Sirham.

The Saq-Ram aquifer system is unconfined in the outcrop areas on its western flank, where groundwater tables are relatively shallow. Large areas are confined by shale aquitards of the Tabuk-Khreim formations, especially in the Tabuk-Mudawwara-Disi segment. Precipitation levels are generally low and actual evaporation exceeds 90% of all precipitation. Despite the large spatial extent of the aquifer system, a total recharge volume of merely 0.31 km^3 has been calculated. Recharge is almost exclusively confined to the outcrop areas (ESCWA 2013; Wagner 2011); groundwater in the Disi/Saq layer is most probably of fossil origin.

4.8.2 Problem structure

Exploitation of the aquifer has increased dramatically since the 1980s, when both Jordan and Saudi Arabia started utilising groundwater to turn the desert into arable land in order to achieve food security. This strategy was "more political than economic, since it was launched in a period […] when western countries threatened to use the food weapon against oil producers by reducing their cereal exports" (Ferragina & Canitano 2014, pp.104–105).

Increased awareness of impending depletion problems was reflected in new national policies, which curbed agricultural abstraction in more recent years. Policy interventions have included the announcement by the Jordanian government involving the discontinuation of pumping concessions to large agro-businesses after 2011 and the cuts of agricultural subsidies by the government of Saudi Arabia in 1994 (Barham 2012). Saudi Arabia's irrigation programme will be discontinued in 2016 (Ferragina & Canitano 2014). As a result, municipal use is increasingly prioritised over agricultural use (ESCWA 2013; Charalambous 2016)

While Saudi Arabia traditionally consumed a lion's share of the shared groundwater resources, the balance has shifted recently with the construction of the 'Disi-Mudawarra to Amman Water Conveyance System' (Box 5). Jordan had reportedly been seeking cooperation with the states that secure alternative fuel sources to desalinate water (Partrick 2013), but the country proceeded to securitise the shared groundwater resources of the Saq-Ram nonetheless.

Box 5 The 'Disi-Mudawarra to Amman Water Conveyance System'.

The construction of the 'Disi-Mudawarra to Amman Water Conveyance System' involves a scheme to annually transfer 0.1 km^3 of water from a wellfield at Dubaydib the Southern Desert of Jordan 325 km to the north, to the capital of Amman, providing water to the cities of Ma'an, Talifah, Karak and Madaba on the way (satisfying approximately 40% of Jordan's water demand). This megaproject comprises 55 boreholes of 500-600 m in depth, 46 of which now operate continuously. Construction of the wells, the pipeline and the pumping stations was initiated in 2008, but suspended on several occasions as local communities were protesting against the implementation of the project. The first water reached Amman in 2013 with a travel time of 20 days. In 2014, the water conveyance involved the volumetric abstraction of 98 million m^3 of groundwater in 2014, approximating the planned annual average. With previous agricultural use and domestic supply to Aqaba and localities amounting to 40 million m^3 and 14 million m^3 respectively, the total volumetric abstraction of groundwater from the Southern Desert has increased to 150 million m^3 on Jordan's end, which is approximately 15% of estimated consumption by Saudi Arabia (ESCWA 2013; Charalambous 2013; Charalambous 2016). However, Jarvis (2014) indicates that high levels of natural radioactivity have reduced Jordan's planned abstraction rates by 30%.

4.8.3 History of regional cooperation

The bilateral relationship between Jordan and Saudi Arabia is characterised by complex geopolitical dynamics. According to Partrick (2013, p.2-3), "[t]he cliché is that the historical fallout between the house of Saud and the house of Hashem over the Hijaz, and responsibility for the two holiest places in Islam in Mecca and medina specifically, continues to sour relations and raise suspicions" between the two neighbouring Sunni Arab monarchies of Saudi Arabia and Jordan. However, the current bilateral relationship is arguably dominated by their mutual concerns about domestic security vulnerabilities (Partrick 2013). For example, Jordan and Saudi Arabia are united in their concerns political change in the Arab world that favour the Muslim Brotherhood, in part due to "possible ramifications" for their own security (Partrick 2013, p.8).

In 1965, Jordan and Saudi Arabia concluded a bilateral agreement that re-delineated the international border. This land swap allowed Jordan to expand the port of Aqaba and to protect the (pastoral) water rights of nomadic tribes. Since this agreement stipulated that the natural resources of the exchanged lands are the joint property of both countries, it follows that unilateral exploitation of the water resources by either Jordan or Saudi Arabia is prohibited (Haddadin 2006, p.19). Nevertheless, specific bilateral arrangements for environmental governance were lacking and it would take decades for the governance of shared groundwater resources to emerge.

4.8.3.1 Institutionalisation of TBA governance

Regional cooperation on groundwater-related issues appears to be confined to Disi/Saq layer below the western end of the border between Saudi Arabia and Jordan (Tabuk-Mudawwara-Disi area). For example, the Ministry of Water and Irrigation of Jordan and the Ministry of Water and Electricity of Saudi Arabia concluded a Memorandum of Understanding (MoU) in 2007. This MoU was a major step in groundwater governance, but presumably too non-committal.

The impending completion of the water conveyance project was seen as a turning point in determining the cooperative versus conflictive nature of the bilateral relations regarding groundwater (Allen 2010). This contentious project now appears to have been a catalyst of negotiations as opposed to an accelerator of what could be characterised as a 'silent pumping race' between Saudi Arabia and Jordan, since a bilateral agreement for the management and utilisation of the groundwaters in the Al-Saq/Al-Disi layer was concluded in 2015.

The agreement provides for the establishment of a Joint Technical Committee, composed of five members from each party and headed by representatives of the respective ministries responsible for water resources (article 3 paragraph 1).

Table 12 Framework for the governance of the Saq-Ram Aquifer System, shared between Jordan and Saudi Arabia.

Year	Agreement / arrangement	Parties	Status
2015	Agreement between the Government of the Hashemite Kingdom of Jordan and the Government of the Kingdom of Saudi Arabia for the Management and Utilization of the Ground Waters in the Al-Sag/Al-Disi Layer. *	Jordan, Saudi Arabia.	Unknown (subject to ratification by both parties ex article 4).
2007	Memorandum of Understanding. **	Jordanian Ministry of Water and Irrigation and the Saudi Arabian Ministry of Electricity and Water.	Ministerial Declaration.
1965	Agreement regarding the Delimitation of the Boundary between the Hashemite Kingdom of the Jordan and the Kingdom of Saudi Arabia	Jordan, Saudi Arabia	Entry into force on November 7, 1965.

* Unofficial translation was used.
** Copy has not been retrieved.

4.8.4 Institutional design

4.8.4.1 Knowledge and scientific learning

The parties have barely made attempts to jointly disseminate knowledge. Notably, the map of the protection zone in the appendix to the 2010 agreement does not delineate of the aquifer relative to their respective territories – arguably one of the most crucial elements that require consensus in TBA governance from the start.

4.8.4.2 Robustness of legal principles

The 2015 agreement does not explicitly acknowledge principles of international water and – environmental law and social justice. Some principles are, however, implicitly mentioned. These include the principles of exchange of information and notification of planned measures, which are relatively pragmatic in nature compared to principles such as reasonable and equitable use. All in all, the principled content of the governance of the Saq-Ram aquifer is low.

4.8.4.3 Legality

The legality of the governance of the Saq-Ram aquifer is high. The 2007 MoU reportedly prohibited the construction of production wells and agricultural expansion within 10 km from either side of the international border (between the Dubaydib and Tabuk wellfields) in the Tabuk-Mudawwara-Disi segment. Jordan committed to take steps to reduce agricultural abstractions in this protected area. Both states agreed on the necessity of a mechanism for cooperation through monitoring and data-sharing (ESCWA 2013; Jarvis 2014). Much like the MoU, the 2015 agreement has a territorial focus on the Al-Sag/Al-Disi layer, which is defined as extending from the "end of the fields of the water wells project of central Tabuk" in Saudi Arabia to the “end of the fields of water wells of the Al-Disi project in the Dabeidab area” in Jordan (article 1).

As an appendix to the 2015 agreement, a map was included that outlines transboundary quadrilateral protection zones (in which only observatory wells may be drilled) and management zones (within which abstractions are restricted to municipal use). The agreement provides for a transition phase to terminate all abstraction in the protection zone, that is five years after its entry into force. It also prohibits the digging of horizontal wells and provides for the formulation of supplementary technical standards for abstraction wells (article 2 paragraph 4), presumably regarding pumping capacity. Moreover, the construction or modification of waterworks is subjected to the Committee’s non-binding, technical advice (article 5).

The exact degree of overlap in substance between the 2015 agreement and the 2007 MoU remains unclear since the latter has not been located. A major difference between the two is, however, that the agreement will bind both parties under international law after ratification.

4.8.4.4 Monitoring and data-exchange

The Committee is competent to monitor both the implementation of the agreement and the status of groundwater resources in terms of volumetric abstraction, quality, and level (article 3 paragraph 4). The Committee may facilitate the collection and exchange of information, statements and studies; to this end, it may appoint experts and advisors (article 3 paragraph 2). Hydrogeologic models appear to exist, but have boundary conditions that coincide with the national border of the respective countries or assume and large uncertainties as to the abstraction rates.

4.8.5 Effectiveness

Groundwater governance in the Saq-Ram aquifer system has only recently started to emerge, if only for a very small part of the system near the international border. After having ‘skipped’ the usual step of jointly disseminating knowledge, Saudi Arabia and Jordan proceeded to define no-drilling zones and management zones that restrict pumping to municipal use. These clearly defined mutual rights and obligations are strengthened by the procedural integration of monitoring. However, the success of previous efforts of data exchange has been questioned. Reportedly, Saudi Arabia has been particularly reluctant to share data on groundwater abstractions (Allen 2010).

In the absence of a joint hydrogeological model that is grounded in a shared body of knowledge, it is difficult to determine the merits of these provisions in terms of the preservation the groundwaters of the Saq-Ram for future generations. National hydrological models take abstractions of the neighbour-state into account in assessing the potential impact of groundwater abstractions (Charalambous 2016, p.90). Considerable gaps in data and large diversions between various datasets are observed in the historical groundwater abstraction records that were compiled by ESCWA (ESCWA 2013, p.309). The recently concluded agreement certainly is a step in the right direction but its success will greatly depend on the implementation of monitoring and the level of prudence in sharing data. As long as the status of the resource is not monitored across the border, the effectiveness of governance in terms of problem-solving will remain unknown.

5 CROSS-COMPARISON OF THE GOVERNANCE OF EIGHT TRANSBOUNDARY AQUIFERS

This chapter entails a cross-comparison of institutional design of the governance of the case studies. It starts with a discussion of the types of institutions, according to the methodology in 3.3.1, and then discusses the dimensions of effectiveness in institutional design, according to the methodology in 3.3.2. Recalling that the cross-comparison is based on an extensive coding scheme (Tables 14-24 in Appendix B), the visualisation of the similarities and differences between the case studies is based on the coding results in Appendix C (Tables 25-29).

5.1 Institutionalisation

All eight aquifers are characterised by some degree of institutionalisation of transboundary governance as implied by the criteria for the selection of case studies (section 3.2.1). However, the institutions differ in terms of membership, competences, and the relative importance of science and politics. This section addresses the similarities and differences in terms of territorial scope relative to the spatial extent of the aquifer (5.1.1), structure and membership of the institution (5.1.2), and institutional competences (5.1.3), with in-line references to the respective governance documents outlined in Tables 5-12.

5.1.1 Territorial scope

The institutions for the Hueco Bolsón aquifer and the Abbotsford-Sumas aquifer are limited in territorial scope, due to the informal nature of governance of these aquifers. The jurisdiction of the institution for the Disi layer is restricted to the management- and protection areas surrounding the border, which covers less than 1% of the spatial extent of the Saq-Ram aquifer system. An institution with aquifer-wide coverage exists – at least on paper – for all other case studies. Complementarily, local transboundary committees have been established for the Guaraní aquifer system.

5.1.2 Structure and membership

Permanent committees have been operationalised or proposed for the Genevese, Hueco-Bolson, Nubian and Saq-Ram (Disi layer). These committees may operate in relative independence from political leadership. In contrast, intergovernmental mechanisms have been installed or proposed for the Guaraní, Iullemeden, and North-western Sahara. Such structures are characterised by the complexity of the political machinery of decision-making, in which multiple entities take part.

The ASA International Task Force is also inherently political, although its workings are less structured by comparison.

Large variation occurs in terms of the composition and membership of the committees. The composition and membership of the proposed Intergovernmental Committee for the Guaraní remain unspecified. The Juárez-El Paso executive committee for the Hueco Bolsón consists of six members in equal numbers for each locality, whom are appointed based on their position in the water utilities of both localities. The Disi committee consists of ten appointed technical experts and is headed by the representatives of the responsible ministries (article 3 paragraph 1 of 2015 agreement). Similarly, the committee for the Genevese consists of six appointed members, two of whom are granted "deliberative powers" (article 1 of 2007 agreement). Much like the Genevese's the committee for the Nubian consists of three representatives for each member country (article 5 of the 1992 agreement).

As mentioned above, the workings of the intergovernmental mechanisms are complex. The Consultative Mechanisms for the Iullemeden aquifer system consist of a) the Council of Ministers, who have decision-making authority; b) the National Technical and Scientific Committees, who have an advisory role towards their respective governments; c) an Executive Secretariat, which is responsible for coordination and administration; and d) the *ad hoc* Technical Committee of Experts, which provides technical advice preceding a meeting of the ministerial council according to the theme of the session (articles 7-12 of the 2007 MoU). The Consultation Mechanism for the Iullemeden-Taoudeni/Tanezrouft aquifer system is very similar in workings, except its scientific committee is permanent and it has an additional Coordination Unit (articles 7-12 of the 2014 MoU). The Consultation Mechanism for the North-western Sahara comprises a) a Steering Committee consisting of governmental representatives; b) a coordination unit; and c) an *ad hoc* scientific committee, "to be convened when the need arises" (paragraph II of the 2002 MoU). Lastly, the ASA International Task Force appears to be open to participation of any stakeholder as it consists of an unspecified number of representatives from (local) governmental entities, NGOs, and communities.

5.1.3 Competences

The power to gather information for the purpose of joint knowledge-dissemination and scientific learning was explicitly or implicitly assigned to five out of eight institutions. For the committees, this competence is generally very broadly defined but is sometimes accompanied with specific privileges such as the power to appoint experts. For the intergovernmental mechanisms, such as the Iullemeden – and North-western Sahara aquifer system institutions, the power to gather information can lie in the power to establish networks for processing data and information in a way that facilitates exchange of such information between the national entities.

The power to give advice (spontaneously or upon consultation) was explicitly or implicitly assigned to four out of eight institutions. In the case of the committees for the Disi and the Genevese this relates to non-binding advice on the construction of waterworks. The ASA Task force has a working group that may spontaneously advice on policy issues and the intergovernmental mechanism for the Iullemeden may give advice on any issue submitted to it.

The power to regulate on matters that concern the transboundary groundwater was explicitly or implicitly assigned to three out of eight institutions. This generally concerns the ability to draft plans or action programme such as for the Iullemeden and the Nubian. For the Genevese, this is complemented with the power to establish chemical criteria and well design.

The power to monitor the status of shared groundwater resources was explicitly or implicitly assigned to four out of five institutions, two of which also have competences in compliance monitoring. This competence mostly related to quantitative data such as water level and volumetric abstraction and may asserted passively (e.g. Nubian institution monitors data and information submitted to it), actively (e.g. the institution for the Genevese has the power to demand water level recordings) or unspecified (e.g. Saq-Ram institution). The power to monitor compliance with the agreed provisions was explicitly or implicitly assigned to the Disi and Genevese committee. Lastly, competences in conflict resolution were assigned to the Guaraní committee and the Iullemeden mechanism.

Figure 4 shows the institutional competences that were coded for in the eight case studies; Table 25 in Appendix C provides the justification for assigning the codes. The institutions for the Genevese aquifer and the Iullemeden and Saq-Ram aquifer systems stand out as having a broad mandate; the institution for the Abbotsford-Sumas, the Hueco-Bolsón and the Guaraní stand out as having a narrow mandate.

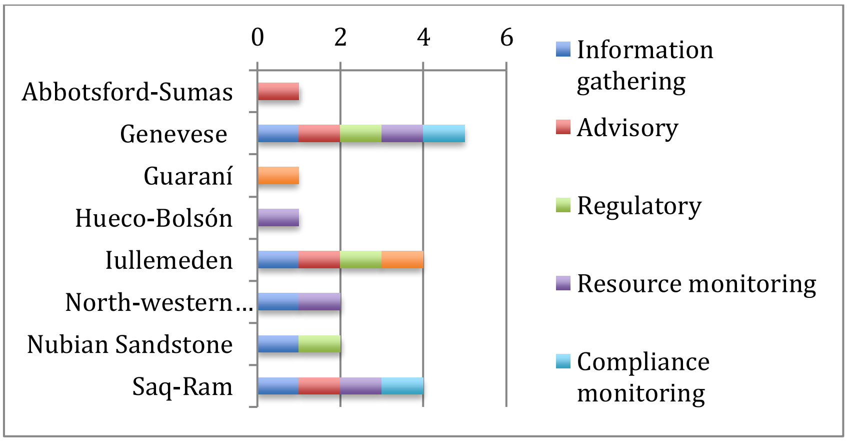

Figure 4 Number of competences assigned to the TBA institutions as a proxy for the relative depth of integration of TBA governance in the case studies.

5.2 Institutional design

This section provides an overview of the relative ranking of the case studies in terms of the four dimensions of effectiveness in institutional design: knowledge and scientific learning (5.3.1), robustness of legal principles (5.2.2), legality (5.2.3), and monitoring and data-exchange (5.2.4).

5.2.1 Knowledge and scientific learning

The following subsections give an overview of way in which knowledge and scientific learning is embodied in the institutional design of TBA governance in the eight case studies, disaggregated for consensus regarding the problem (5.2.1.1), preliminary hydrogeological knowledge (5.2.1.2), and mechanisms for scientific learning (5.2.1.3). Figure 5 visualises the relative ranking of the case studies in terms of knowledge and scientific learning. Table 26 in Appendix C provides the justification for assigning codes.

5.2.1.1 Consensus regarding the problem

The nature of the problem (e.g. overexploitation, pollution, underdevelopment, and/or lack of data) has only been explicitly identified for four out of eight aquifers, of which two have also identified pressures and drivers.

Policy problems include the quality of the Abbotsford-Sumas (ASA Task Force website) and the expected pressure on water supply and –quality for the Hueco-Bolson (1999 MoU). Lack of system knowledge was identified as an additional problem in the 2009 report by the principal engineers. The MoUs for the Iullemeden and the governance documents for the Nubian are thorough in their analysis of the nature of the problem. The first identify the conservation of natural resources and the protection of the environment; the latter specify four major problems: declining water levels, water quality deterioration, changes in groundwater regime, and damage or loss to ecosystems and biodiversity.

Consensual drivers in the Iullemeden are socio-economic developments and regional integration. The SADA for the Nubian mentions the demands related to the expansion of agriculture, and intensified by issues of efficiency and conservation; population growth; pollution, salinisation and disturbed water balance due to agricultural and industrial development, related to the combination of increased population and national decisions related to food security priorities.

An analysis of (transboundary) risks appears to have been done for two out of eight aquifers, namely the Nubian Sandstone aquifer system and the Iullemeden aquifer system. For the Nubian, this involved verbal account of a risk assessment that was rooted in the joint model.

In contrast, the Tranboundary Diagnostics Analysis for the Iullemeden visualises major (transboundary) risk on a map.

5.2.1.2 Preliminary hydrogeological knowledge

This section discusses the level of hydrogeological knowledge, i.e. the delineation of the aquifer, hydrological connections (recharge discharge). There is consensual delineation for seven case studies. This involves the inclusion of maps in the governance documents for most aquifers, but is limited extensive verbal accounts of spatial extent and hydrogeological boundaries for others. The Saq-Ram is the only case study that lacks spatial delineation of the aquifer system. There is consensus on basic hydrogeological features for four aquifers, namely the Guaraní, the Hueco-Bolsón, the Iullemeden and the Nubian aquifer systems. Indications include hydrogeological cross-sections and the specification of recharge zones and rates.

5.2.1.3 Mechanisms for scientific learning

Mechanisms for conducting joint studies have been included in the institutional design for five out of eight case studies. This involves the regular organisation of international science forums for the Abbotsford-Sumas, and the involvement of scientific committees in decision-making for the Genevese, the Hueco- Bolsón, the Iullemeden and the North-western Sahara.

Joint pilot projects have been provided for in the governance documents of three of the case studies. This involves pilot studies in problem-intense regions of the Guarani (i.e. Concordia-Salto and Rivera-Santana do Livramento); a joint feasibility study on diversifying the mix of water sources in the Hueco-Bolson (e.g. managed aquifer recharge; desalinisation); and various pilots on water conservation, wastewater disposal and climate change adaptation in the Nubian.

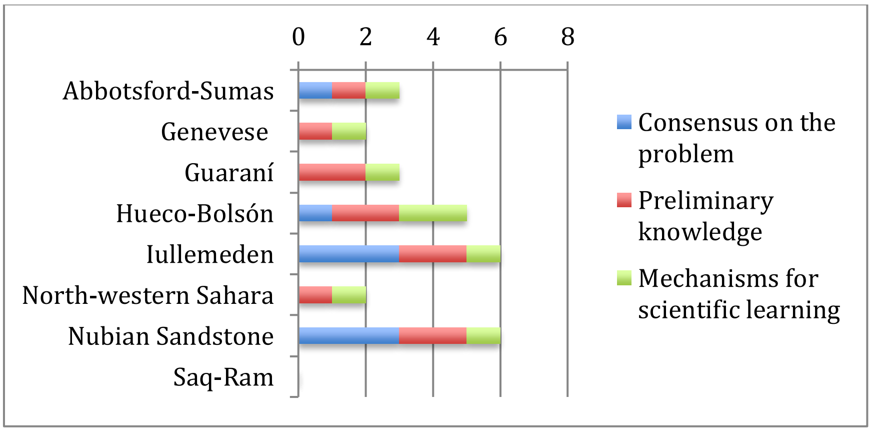

Figure 5 Relative ranking of the case studies in terms of the number of coded elements of the knowledge dimension. Disaggregated for the consensus of the problem, preliminary knowledge, and mechanisms for scientific learning.

5.2.2 Robustness of legal principles

There is large variation between the case studies in terms of in the robustness of legal principles. The governance of the Iullemeden is rich in principles of public international law. With five principles of International Environmental Law, five principles of International Water Law and two principles of Social Justice, its score approximates the maximum of respectively six, six, and three. The governance of the Guaraní and the Nubian Sandstone aquifer systems also scores high, but the principles of Water Law are less represented by comparison. The Hueco-Bolsón and the North-western Sahara rank low in terms of principled content. Figure 6 visualises the relative ranking of the case studies in terms of robustness of legal principles. Table 27 in Appendix C provides the justification for assigning codes.

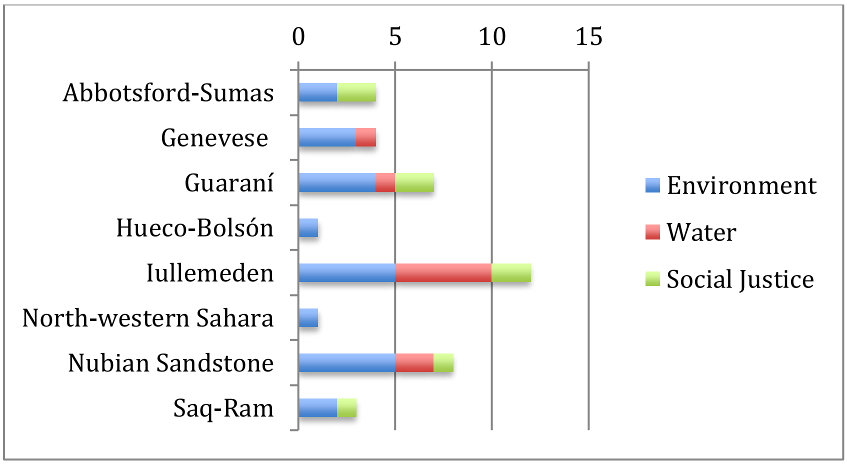

Figure 6 Relative ranking of the case studies in terms of the number of coded elements for the robustness of principles of international law. Disaggregated for Environmental Law, Water Law and principles of Social Justice.

5.2.3 Legality

The following subsections provide an overview of the legality of TBA governance in the eight case studies, which combines the extent to which rights and obligations are defined (5.2.3.1), the credibility of the provisions given the legal status of the governance documents (5.2.3.2), and the availability of mechanisms for the resolution of disputes related to the interpretation of the governance documents (5.2.3.3). Figure 7 provides an overview of the comparative legality of the case studies. Table 28 in Appendix C provides justification for the assigned codes.

5.2.3.1 Rights and obligations

Overall, few rights and obligations are clearly defined in the case studies. Provisions on well design exist for two TBAs. The Genevese agreement prescribes the equipment of wells with recording devices. Horizontal drilling is prohibited in the Saq-Ram and its committee has the power to issue technical standards for abstraction wells.

Provisions on protection zones exist for three TBAs. For the Guaraní, this merely concerns a provision related to cooperation in the identification of (boundary) areas that require specific treatment. For the Nubian, this concerns the establishment of a no-drilling zone between Chad and Sudan, although the location and spatial extent are not specified. For the Saq-Ram, however, the size and location of the no-drilling zone are clearly delineated on a map as an appendix to the agreement.

Provisions on the allocation and/or restriction of volumetric abstraction exist for two aquifers. For the Saq-Ram this simply concerns a categorical prohibition of drilling in the protection zone, i.e. restriction. The Genevese agreement is unique in that it specifies the annual allowable volumetric abstraction for the French communities, i.e. allocation.

Provisions on the prevention of pollution exist for three aquifers. For the Genevese, this concerns a rather detailed obligation; the agreement mandates the chemical analysis of water that is to be injected in the aquifer recharge plant, according to quality standards. The SAP on the Nubian provides for the formulation of joint standards and guidelines on the use of chemicals in agriculture as well as the disposal of municipal and industrial waste. For the Saq-Ram this concerns the rather self-evident statement that the injection of pollutants in the aquifer is prohibited as well as a prohibition of horizontal drilling.

Provisions on pollution abatement only exist for one aquifer: the Genevese. However, these provisions are not very detailed and it is not entirely clear that it focuses on *abatement* indeed; the agreement provides for the identification of measures that remedy the possible causes of pollution (article 2 paragraph 1).

5.2.3.2 Legal status

Overall, few of the governance documents are binding. As to formality, there are only three aquifers for which there is an agreement that counts as a treaty under international law: the 1978 Genevese agreement (renewed in 2007), the 2010 Guaraní agreement, and the 2015 agreement on the Disi layer (Saq-Ram). Of these, only the agreement for the Genevese has become binding to the parties upon ratification. Although most informal documents have not been implemented, some have (as exemplified by the operationalisation of institutions for the North-western Sahara and the Nubian sandstone aquifer systems).

5.2.3.3 Dispute resolution mechanisms

A procedure for the resolution of disputes has only been defined for three aquifers: the Genevese, the Guaraní, and the Iullemeden. The Genevese agreement prescribes resolution according to Swiss domestic law prior to international consultation. The Guarani agreement outlines a tiered procedure entailing negotiation, consultation, and arbitration. The MoUs for the Iullemeden describe mediation, conciliation and adjudication by the International Court of Justice.

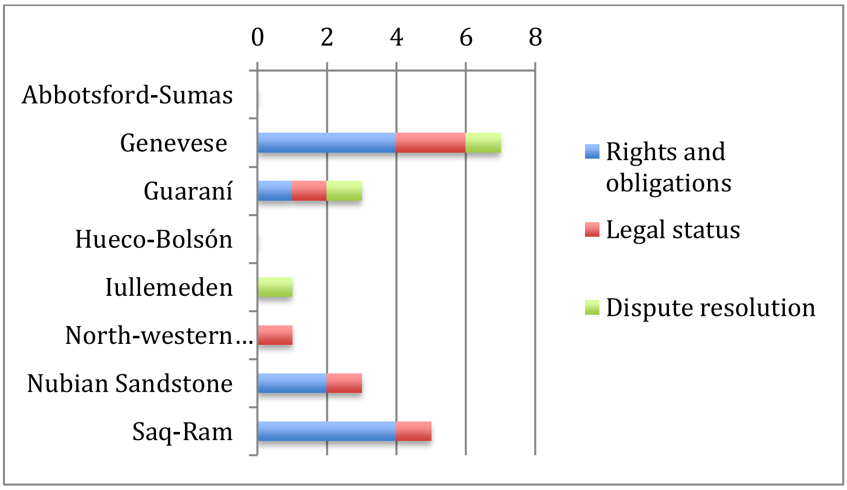

Figure 7 Ranking of the case studies in terms of number of coded elements of the legality dimension. Disaggregated for the articulation of rights and obligations, legal status, and dispute resolution mechanisms.

5.2.4 Monitoring and data-exchange

A numerical model is known to exist for all aquifers besides the Genevese and the Saq-Ram. In the case of the Genevese, the understanding of the hydrogeology of the aquifer was already high at the onset of transboundary governance, which may explain the apparent lack of a joint model. However, the utility of numerical models is limited in the absence of relevant data.

Types of information to be exchanged were specified in five aquifers, ranging from best practices to electric conductivity. Harmonisation of meta-data appears to exist for five out of eight aquifers, as claimed in governance documents or implied by the fact that there is a joint database. Wells have been inventorised in all case studies apart from the Abbotsford-Sumas and the Saq-Ram. Moreover, a piezometric network purportedly exists for three of these, which implies that water level measurements are periodically updated. Since the frequency of monitoring and data-sharing is rarely specified, the practical merits of the infrastructure remains unknown.

Figure 8 provides an overview of the comparative performance of the case studies in terms of monitoring and data-exchange. Table 29 in Appendix C provides the justification for the assigned codes.

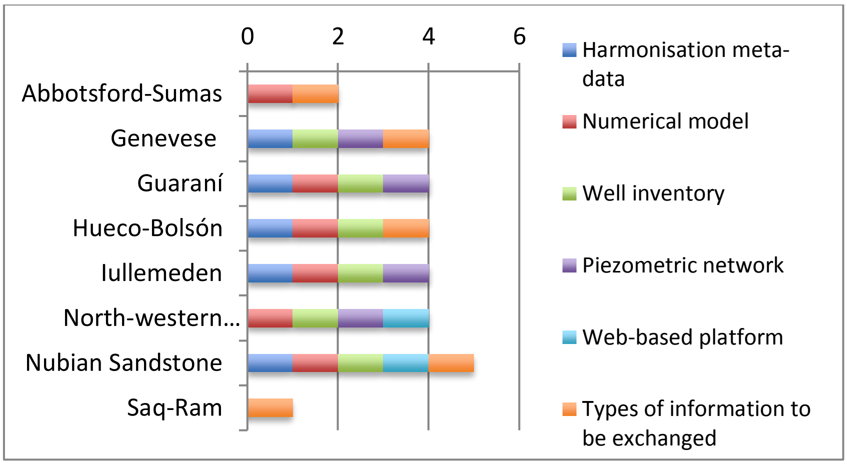

Figure 8 Ranking of the case studies in terms of number of coded elements of the monitoring dimension.

6 HYPOTHESES ON THE EMERGENCE OF EFFECTIVE GOVERNANCE OF TRANSBOUNDARY AQUIFERS

The cross-comparison showed that the case studies differ widely in terms of institutional design, which raises the question whether contextual factors may explain variation in effectiveness of TBA governance. The aim of this chapter is to formulate hypotheses that link the problem context to institutional design and effectiveness. Consecutively, these hypotheses relate to third party involvement (6.1), the homogeneity of the perceived problem (6.2), parity of stakes (6.3), unilateral development (6.4), and competing national and regional priorities (6.5).

6.1 Third party involvement

As discussed in §4.1, project activity was prevalent in four TBAs: the Guaraní, the Iullemeden, the North-western Sahara, and the Nubian Sandstone aquifer systems. Along with national governments of the riparian countries, such projects involved (a) international organisations such as IAEA, UNEP and UNESCO; (b) regional intergovernmental organisations such as CEDARE, IBWC, OAS and OSS; (c) international development funds such as GEF and IFAD; and (d) European companies specialised in remote sensing and GIS. Table 13 summarises the findings on project activity in terms of number and total duration of projects with third party involvement.

Table 13 Third party involvement in eight TBAs – number of aquifer-specific projects and total duration.

No.	TBA	Project activity with third party involvement	Total duration (years)
1	Abbotsford-Sumas Aquifer	n/a	n/a
2	Genevese Aquifer	n/a	n/a
3	Guaraní Aquifer	IDRC Canada (1997-1998) GEF/OAS (2003-2007) GEF/OAS (2007-2009)	7
4	Hueco-Bolsón Aquifer	n/a	n/a
5	Iullemeden Aquifer System	ESA (2004-2007) GEF/AWF (2004-2008) GICRESAIT AWF/OSS (2011-2013) IAEA (2012-2017)	14
6	North-western Sahara Aquifer System	SASS I (1999-2002) SASS II GEF/UNEP (2003-2006) ESA (2004-2007) ESA/AWF GEO AQUIFER (2006-2010) SASS III GEF/UNEP (2007-2014)	20
7	Nubian Sandstone Aquifer System	CEDARE/IFAD (1995-1998) GEF/IAEA (2005-2011)	9
8	Saq-Ram Aquifer	n/a	n/a

Whilst intensive project activity in the NSAS was developed only after the conclusion of the 1992 agreement on the establishment on a Joint Authority, governance documents for the other three aforementioned TBAs must be seen as the product of project activity with third party involvement. This is not to say that governance requires project activity; for instance, the treaties for both the Genevese and the Saq-Ram emerged in the absence of project activity.

> **Hypothesis 6.1.1**: Third party involvement increases the likelihood of institutionalisation of the governance of transboundary aquifers.

Even if intensive project activity promotes the emergence of TBA governance, it does not appear to be related to all dimensions of effectiveness. For example, the Guaraní agreement was not ratified and the SAI MoUs were never implemented. It is crucial to discern the reasons and motivations that may explain why international discourses may culminate in deadlock and to determine whether obstacles are related to lack of political will, capacity or funding. Nevertheless, the three aforementioned aquifers with prominent involvement of third parties also stood out in terms of principled content (Table 13).

It is also notable that the four aquifers that have been subject to large international funding schemes are among the 5% largest aquifers in the world in terms of spatial extent (Table 3). It is possible that the contribution of project activity to governance effectiveness would be different if TBAs were selected based on problem intensity instead of spatial extent.

> **Hypothesis 6.1.2**: Third party involvement is likely to increase the articulation of legal principles in the governance of transboundary aquifers.

6.2 Homogeneity of the perceived problem

Aquifer-wide problem homogeneity is associated with aquifer-wide institutionalisation in some of the smallest aquifers in the world such as the Abbotsford-Sumas (pollution) and the Genevese (depletion) (Table 3). Thus the relative homogeneity of the perceived problem across the border in terms of depletion or pollution may help to align interests towards institutionalisation of transboundary aquifers governance around a common objective.

By contrast, issues of groundwater quality and quantity appear to be more localised in the Guaraní-, Iullemeden-, and the Nubian Sandstone aquifer systems. The heterogeneity of the problem across the aquifer might slow down implementation and follow-up of agreements and as such undermine the effectiveness of attempts of aquifer-wide governance, which is particularly likely for the larger aquifers. Nevertheless, effective governance may emerge for parts of larger aquifer systems where the perceived problem is most intense such as in the Guaraní and the Saq-Ram.

> **Hypothesis 6.2a**: Scoping of the institution in accordance with the spatial extent of the transboundary problem, enhances its effectiveness.
> **Hypothesis 6.2b**: Homogeneity of the problem across the border helps align interests towards problem-based institutionalisation of the governance of transboundary aquifers.

6.3 Parity of stakes

The parity of the stakes is related to, yet different from the homogeneity of the problem. When an aquifer is homogeneous across the border in terms of e.g. depth below surface and thickness, the costs of drilling are likely to be homogeneous as well; however, great disparities of stakes may occur depending on available capacity and infrastructure in the country segments.

The extent of groundwater development and dependence are the two main variables related to the parity of stakes. The extent of exploitation is not only subject to the proportion of storage that underlies the respective territories of the country segments, but also the availability of financial capital required to exploit the groundwater. Groundwater dependence relates to the availability of sources of fresh water in the country segments of the transboundary aquifer, other than the transboundary aquifer itself.[6] Options include other groundwater bodies and surface water, if available, or alternative sources such as desalinisation or wastewater recycling. Large divergence in groundwater dependence and/or exploitation between the country segments implies large disparity of stakes.

Asymmetry in the stakes related to the development of a transboundary aquifer may translate into asymmetry in the dissemination of scientific knowledge. For example, whilst Egypt and Libya pump enormous quantities from the fossil Nubian sandstone aquifer in order to sustain their economic development, pastoral wells in Chad and Sudan often fall short of reaching the deep groundwater table (Wiese 2010; Kornfeld 2006). The first two countries appear to have been more influential than the latter in the emergence of transboundary governance and the dissemination of scientific knowledge in particular. Another example relates to the disproportionate distribution of datapoints in the Iullemeden database: while Nigeria is considered responsible for the bulk of groundwater withdrawal, it only accounts for about 2% of the datapoints in the database (Hearns 2009).

[6] Note that the term groundwater dependence is commonly used in the context of ecosystems and ecosystem services (e.g. Kløve et al. 2011). Here it is defined as the proportion of fresh water demand that is satisfied using groundwater in a particular area, where the unit of measurement is an administrative entity such as a country.

Disparity in stakes can also be associated with the pursuit of mutual benefits by the major stakeholder. For example, the Genevese aquifer largely underlies the Canton of Geneva, where most of the abstraction is generated. By comparison, the French communities operate fewer exploitation wells. Geneva has proven to be influential in the emergence of governance by taking a leading role in developing an artificial recharge plant to the benefit of all users. It is important to emphasise that the prospect of benefits of mutual joint engineering solutions such as managed artificial recharge is by itself not decisive. For example, a local water utility in Texas developed such solutions to mitigate depletion issues in Hueco Bolsón, but appears to have been unwilling or unable to involve its cross-border counterpart in such capital-intensive endeavour. This suggests a role for other variables in the emergence of joint groundwater policy or – measures that are in the interest of both parties.

Hypothesis 6.3a: Those actors that have the highest stakes vested in the transboundary aquifer are most influential on the effectiveness of governance.
Hypothesis 6.3b: The influence of the major stakeholder can be focused towards maximising either individual interests or mutual interests.

6.4 Unilateral development

The unilateral development of major groundwater transfer schemes in Jordan and Libya appears to have been a major factor in regional groundwater governance – although this applies more to the timing of negotiations than the design of resulting agreements. In both cases, a key governance document came into being within one year after the completion of (parts of) the transfer scheme. These documents were characterised by high legality. Somewhat surprisingly, this suggests that unilateral development may contribute to the emergence of TBA governance – even if this has only been observed in two cases.

Hypothesis 6.4: Unilateral development of a transboundary aquifer for the benefit of the domestic population in one of the riparian countries increases the willingness of the other riparians to commit to high-legality governance.

6.5 Urgency of groundwater governance relative to other national and regional priorities

Preservation of groundwater availability and quality may compete with other policy issues on both the national and regional level. In the Iullemeden-, Nubian-, and North-western Sahara aquifer systems, competing policy priorities comprise a major obstacle to TBA governance. In the following subsections, three examples of competing priorities are discussed: national and regional stability (6.1.4.1); food security and irrigated agriculture (6.1.4.2), and poverty eradication and quality of life (6.1.4.3). In addition, interrelations may exist. For example, the combination of (a) the increase of food prices on the global market in 2008 and 2011, (b) the high percentage of the population under or near the poverty line, and (c) the large share of family expenditures on food played its part in triggering social unrest that led to the Arab Spring (Ferragina & Canitano 2014).

6.5.1 National and regional stability

Many countries that share the NSAS and the SASS are subject to destabilisation in terms of their political, economic, and security situation. After the fall of Qaddafi in 2011, Tuareg militants who were in the dictator's deploy had taken up arms and returned to Mali, spurring concerns of potential spill-overs in Niger. Meanwhile, Libya has become a gateway for illegal arms to be smuggled to extremist groups in at least fourteen countries across the continent and particularly in Mali, Niger and Nigeria (Larémont 2013; Rood et al. 2015; Zandee et al. 2016).

Moreover, transboundary terrorism organisations are likely to divert attention away from groundwater governance – and not just in Libya, where the so-called Islamic State effectively controls territory. Political stability is compromised in large parts of Sub-Saharan Africa due to activity by Al Shabaab in Mali and Boko Haram in Chad, Niger and Nigeria (Zandee et al. 2016).

6.5.2 Food security

Irrigated agriculture comprises a major water user in many regions. In the regions of high aridity, groundwater is often the water source designated to sustain irrigation demand. Egypt, Libya, Jordan and Saudi Arabia have all employed the idea of 'greening the desert' by using extensive quantities of fossil groundwater to facilitate agricultural practises. This practise accelerated in the 1980s, when national strategies to achieve food security were developed in response to decreasing food prices on the global market (Box 6; section 4.8.2).

> International financial institutions promoted trade liberations in the early 1980s. Conversion to high-value irrigated agricultural production for export such as fruits and vegetables coupled with the purchase of basic foodstuffs on the international markets was employed to achieve food security. In combination with the effects of European and American subsidies, the liberation process led to a 53% drop in food pries on the global market. This "widened the production-consumption gap of cereals, which are the staple food of the most vulnerable segments of the population"(Ferragina & Canitano 2014, p.97).

Box 6 Historical intermezzo on trade liberation and food prices

6.5.3 Poverty eradication and quality of life

Given the prevalence of poverty in Sub-Saharan Africa (Ogilvie et al. 2010; Batana 2008), the countries that share the Iullemeden and some of the riparians of the Nubianare likely to prioritise poverty eradication and improvements of quality of life over groundwater preservation. Examples may include the improvement of structures for sanitation in Chad, reducing the burden of the rural poor in Sudan (Alker 2008).

Hypothesis 6.5: Competing national and regional priorities impede the effectiveness of the governance of transboundary aquifers.

7 DISCUSSION

7.1 The validity of the framework

The proposed framework for cross-comparison of case studies is suited to denote variation between instances of governance. While acknowledging the complexity of measuring effectiveness, the output-based approach to governance effectiveness entails both conceptual and practical limitations that question the adequacy of institutional design as a predictor of effectiveness.

The problem structure is arguably more significant to institutional effectiveness than institutional design. Interest-based arguments direct the attention from institutional design to the underlying constellations of riparian interests (Lindemann 2008). In the case of collective problems (e.g. cross-border pollution problems in the Abbotsford-Sumas aquifer) interests/stakes tend to be symmetric and such cross-border homogeneity may enhance the effectiveness of TBA governance, as hypothesised in 6.2. However, in the case of cross-border externalities (e.g. transboundary drawdown as a result of intensive groundwater pumping near the border) interests/stakes are unevenly distributed. Such complex problems do not have an 'easy fix' (Underdal 2000; Mitchell 2006), which may inhibit the effectiveness of their governance.

Institutional design is not merely the product of deliberation, but shaped by the negotiation context. In the words of Hearns et al. (2014, p.98), institutional design is "highly dependent on political, social, economic and ecological drivers". Research has proposed numerous contextual factors that influence the design of transboundary water institutions, including the number of negotiating states (Zawahri et al. 2016). Warner & Zawahri 2012 cited literature that suggests that democratic countries engage differently in transboundary water cooperation from their non-democratic peers, particularly in terms of data-sharing, and that the institutional output varies accordingly. Moreover, interests (or 'stakes', as hypothesised in section 6.3) and power are thought to be crucial elements that contribute to regime formation and institutional design (Brooks & Linton 2011, p.452). Since stakes and power influence institutional outcome in terms of behavioural change, the mere presence of a transboundary institution for water governance does not necessarily translate into behavioural altering cooperation in terms of problem solving (Warner & Zawahri 2012).

Regional power dynamics may be reflected in the politicisation of one of the dimensions of effectiveness in the proposed framework, i.e. knowledge and scientific learning. In their analysis of conflict and cooperation along international rivers, Berardo & Gerlak (2014, p.105) emphasised that "parties with differing goals in a decision-making process often bring their own science to the table of negotiations". As put by Jarvis (2014, p.154), "[t]he tensions between the political and technical arenas are palpable, especially when it comes to debating how to place boundaries around the hidden resource of groundwater. Defining boundaries around groundwater resource domains is very political and polarizing". Two instances of conflictive information may illustrate the reality of politicisation of scientific knowledge on respectively the substantive and spatial scope of the problem, namely 1) the appreciation of transboundary depletion risks in the Nubian Sandstone aquifer system; and 2) the delineation of the spatial extent of the Iullemeden aquifer system (Box 8).

The politicisation of knowledge and scientific learning raises the question whether notions of social justice should be included in the measure of effectiveness. In the words of Mitchell & Zawahri (2015, p.187), "treaties do not guarantee a future of stable cooperation because these contracts can solidify power imbalances between and give the illusion of cooperation". In parallel to the disparities in impact of environmental problems between different societal groups, the impact of institutions that target those problems may also vary disproportionately between the rich and the poor (Mitchell 2008, pp.101–102; Adger et al. 2005, p.2; Bosselmann 2008, p.184) and possibly between country segments overlying transboundary aquifers. Although such observations do not challenge the merits of consensual knowledge in contributing to governance effectiveness, these do call for consideration of what Young & Levy (1999, p.5) framed as the "normative approach to effectiveness". However, inclusion of notions of social justice would inevitably imply politicisation of the comparative tool itself.

The case-study approach allows for the in-depth exploration of the effectiveness of transboundary aquifer governance on the ground, but the assumptions that underlie the proposed framework cannot (yet) be tested. The causal link between institutional design in the governance of transboundary aquifers and problem-solving remains poorly understood. From the qualitative evaluation of governance effectiveness in the respective case studies (Chapter 4) the Genevese aquifer emerged as arguably the only one where significant improvements of the status of the resource (i.e. abatement of depletion) could be attributed to governance. Acquiring a more quantitative understanding of the relationship between institutional design in the governance of transboundary aquifers on one hand and effectiveness in terms of problem-solving on the other would serve to test and refine the framework. Such quantitative approach could help to 'break the circularity' inherent in defining effectiveness in terms of the same criteria that are used to measure it.

Two on-going trends appear promising in terms of acquiring a more quantitative understanding of the relationship between institutional design and the effectiveness of the governance of transboundary aquifers. Firstly, the increasing interest in groundwater governance and the rapid development of the governance of transboundary aquifers across the globe. The continued emergence of governance for the remaining 98-99% of transboundary aquifers of the world would allow for studying instances of transboundary aquifer governance in larger numbers, similar to what has been done for river basin agreements (e.g. Zawahri et al. 2016; Mitchell & Zawahri 2015). The second trend relates to the increasing interest in groundwater monitoring and assessment, particularly by large international organisations such as the World Bank and GEF. In the face of the continued development of groundwater monitoring- and information networks, the governance performance in terms of design criteria may in time be linked to effectiveness in terms of problem solving.

The relative utility of desk research in the chosen methodological approach is a major advantage. The chosen approach, which assumes that effectiveness is reflected in institutional design, is considered the most adequate approach given the time available for this research. Even if not all governance documents were located despite repeated attempts (3.2.2.1), information related to any international projects in the case studies was readily available online. Yet even though institutional design is broadly conceived as comprising of both 'process' and 'product' elements (2.2.3), desk research has limitations in that it serves to understand effectiveness only surficially.

The chosen methodology is not suitable for the purpose of understanding effectiveness on a deeper level, i.e. to uncover the riparians' motivations for observed behaviour. The interview strategy of this research was partly meant to do just that, for example to understand the apparent reluctance to ratify in the case of the Guaraní and waning political interest in the Hueco-Bolsón (Appendix D). However, the interviewees found themselves occasionally speculating as to such motivations because despite their extensive expertise in the governance of the case studies, they were not directly involved in the decision-making. For the purpose of understanding effectiveness on a deeper level, interviews would have to be had with government officials and others who have been at the negotiation table or otherwise involved in governance 'on the ground'. However, there are numerous reasons why such a strategy might still fail to fully capture the complexity of governance effectiveness; it is conceivable that individuals are not willing or able to talk openly about all aspects of governance and its effectiveness. Although discourse analysis may help in suggesting what motivates actors, the conclusions would therefore remain speculative.

The first example of the politisation of scientific knowledge relates to the assertion in one of the negotiated policy documents for the Nubian aquifer system that, although sufficient to merit diligence in monitoring, transboundary risks were “low enough that each country can exercise their sovereign right to use their resources as they see appropriate” (IAEA 2010, p.33). In contrast, geologists from a German and an Egyptian institute simulated that if pumping in East Oweinat in Egypt is to continue at its current rate, the cone of depression will extend up to 50 km beyond the Sudanese-Egyptian border by 2100 (Sefelnasr et al. 2015). If this were true, the establishment of a no-drilling zone between Sudan and Egypt would be intuitive. Instead, the countries negotiated a no-drilling zone on the border between Sudan and Chad, even though there are currently no indications of intensive exploitation on either side on the border nor the presence of nearby outcrops or recharge zones. Therefore, the perceived transboundary risks appear to be inconsistent with considerations in scientific literature.

The second instance of the politisation of scientific knowledge relates to the spatial extent of the Iullemeden Aquifer System. The consensual delineation on the maps in governance documents negotiated between Mali, Niger, and Nigeria roughly follows the border between Mali and Niger on one hand and Algeria on the other. On the map of transboundary aquifers of the world issued by IGRAC, an internationally active organisation that does not have interests in the delineation of aquifers, the aquifer system extends more to the north into Algeria amounting to additional surface area of 30.000 km^2 (section 4.5.1). Interestingly, Algeria has not been part of the negotiations. The terminal evaluation of the UNEP/GEF project conceded that Algeria and Benin are part of the groundwater basin, although relatively small, and recommended that the two countries be formally invited to participate by Mali, Niger and Nigeria “when there is sufficient momentum” (Hearns 2009, p.51).

Box 7 Two instances of politicisation of science in TBA governance

7.2 Findings

The hypotheses in Chapter 6 overlap address variables that were also identified in analyses of adaptive water governance. These include the overall quality of international relations, including historical collaborative projects; the rate of environmental change; the rate and distribution of population growth; and the rate of economic development and distribution of wealth (Feitelson & Haddad 1998; Gupta et al. 2013; Blomquist & Ingram 2003; Wolf 2007). While such variables have generally been intuitively defined, this study has taken a systematic approach to do so.

The role of third parties in the institutionalisation of the governance of transboundary aquifers limits the generalisability of the findings. As elaborated in 6.1, intensive project activity had taken place in half of the case studies. The fact that these four transboundary aquifers are among the 5% largest transboundary aquifers of the world, suggests that international organisations and donors might have an agenda of selecting those aquifers that are most significant in terms of spatial extent, as opposed to e.g. problem intensity.

The involvement of the international community in four case studies might explain the similarity between their governance and the international law on transboundary aquifers in terms of principled content. International organisations and non-governmental organisations appear to turn to the international discourse for inspiration in drafting agreements on specific transboundary aquifers. This finding is consistent with hypotheses in literature on policy convergence, also known as 'diffusion', in environmental governance (Conca et al. 2006; Tews & Busch 2001; Busch & Jörgens 2005; Busch 2005).

The findings suggest that the *extent of transboundary* effects of groundwater development on either side of the border should be decisive in scoping the governance of transboundary aquifers. This has implications for global discourses on TBA governance, including the Sustainable Development Goals. As mentioned in section 1.2.3.1.1, target 6.5 explicitly calls for transboundary cooperation to implement integrated water resources management, which also involves transboundary aquifers by implication. Indicator 6.5.2 is measured as the "proportion of transboundary basin area with an operational arrangement for water cooperation" (IAEG-SDG 2016, p.26). This approach does not reflect the differences between groundwater and surface water such as the potential that transboundary effects of groundwater development remain confined to a few hundred kilometres on either side of the border, depending on the characteristics of the aquifer and the flow regime.

7.3 Further research

While firmly rooted in literature and inductive analysis of governance documents, the underlying assumptions of the proposed framework require testing (7.1). This would require that the relationship between institutional design and effectiveness could be studied at a higher level of detail. As a next step, further refinements of the framework could consist in exploring the effects of the relative weighting of the indicators on the measures of effectiveness.

The exploration of contextual factors to effectiveness requires further substantiation. The validation of hypotheses formulated in Chapter 6 benefit from the two trends outlined in 7.1, i.e. the continued emergence of TBA governance and increased interest in monitoring. Such endeavour could also help clarify the similarities and differences in the best practises of the governance of groundwater and surface water respectively.

The interplay between power and interests in the governance of transboundary aquifers could be further explored. The findings suggest that power and stakes are important in TBA governance, but the dynamics remain unclear. For international watercourses, the concept of 'hydrohegemony' has been combined with the upstream-downstream distinction. Transboundary cooperation, in this view, arises only in the presence of a hegemon (i.e. the riparian that is most influential on the governance discourse) in the downstream position, "since only the latter has both an interest to secure its water supply and the power resources to compensate for its geographically disadvantageous situation" (Lindemann 2008, p.120; Zeitoun & Warner 2006). Future research may address how this translates to transboundary aquifers, where relevant variables may include (a) the spatial extent of the respective aquifer segments;

(b) the extent of exploitation for each of the country segments (6.1.3); (c) the transboundary flow direction; and (d) the position of (natural) recharge zones relative to the international borders.

8 CONCLUSION

The aim of this study was to provide hypotheses on the effectiveness of the governance of transboundary aquifers. Both design and impact of institutions in transboundary aquifer governance were evaluated in eight case studies: three aquifers in Africa, one in Europe, one in the Middle East, two in North-America, and one in South-America.

The proposed framework for evaluating the effectiveness of transboundary aquifer governance builds on the assumption that institutional design provides proxy information on institutional effectiveness, where institutional design is broken down into four dimensions: (a) knowledge and scientific learning, (b) robustness of legal principles, (c) legality, and (d) monitoring and data-exchange. The dimension of knowledge and scientific learning relates to consensus on the problem, knowledge on basic hydrogeological features, and mechanisms for knowledge dissemination and scientific learning. The articulation of legal principles is a measure of the similarity of the principled content of TBA governance on one hand and the international law on transboundary aquifers on the other. The legality measure involves the articulation of rights and obligations, including groundwater resource preservation standards (e.g. no-drilling zones) and allocation. In addition to rights and obligations, the legality-dimension considers the 'legal bindingness' of governance documents and the presence of dispute resolution mechanism. The dimension of monitoring and data-exchange considers mechanisms and platforms for monitoring the status of the shared resource. A structured description of governance of the eight case studies provided the basis for a cross-comparison.

Six observations were made in the cross-comparison of the case studies.

1. Firstly, the institutions differ greatly in terms of competences and the relative importance of facts and values. Permanent committees – installed or proposed for the Genevese, Hueco-Bolsón, Nubian and Saq-Ram – operate in relative independence from political leadership and are often focused on joint knowledge dissemination or monitoring. Intergovernmental mechanisms – operationalised or proposed for the Guaraní, Iullemeden, and North-western Sahara – are characterised by the complexity of the political decision-making making machinery. As to their mandate, the institutions for the Genevese, Iullemeden and the Saq-Ram appear most integrated, whereas the institutions for the

Abbotsford-Sumas, Guaraní, and the Hueco-Bolsón have few predetermined competences.

2. Secondly, few of the governance documents are binding. Out of the 22 aquifer-specific governance documents that were selected for analysis, only three count as a treaty under international law: the 1978 Genevese agreement (renewed in 2007), the 2010 Guaraní agreement, and the 2015 agreement on the Disi layer (Saq-Ram). The agreement for the Genevese is currently the world's only agreement on the governance of a transboundary aquifer that has become binding to the parties upon ratification. Other governance documents included memoranda of understanding and informal arrangements.
3. Thirdly, there are large differences in the level of knowledge and the mechanisms for scientific learning. For example, the Iullemeden and the Nubian sandstone rank high, which is partly due to the countries' thoroughness in analysing the pressures, drivers, and risks related to the aquifer. In the absence of joint studies and projects, the Saq-Ram ranks very low in this regard.
4. Fourthly, the robustness of principles of international law differs between the case studies. The Iullemeden, Nubian Sandstone, and Guaraní aquifer systems rank high in terms of principled content. The pragmatic tone of the governance documents for the Hueco-Bolsón, North-western Sahara, and the Saq-Ram is reflected by the lack of articulated principles in TBA governance.
5. Fifthly, the overall number of rights and obligations is low. Governance documents on the Genevese and the Saq-Ram provide for the regulation of well design and provisions on protection zones exist in decreasing level of detail for the Saq-Ram (delineated no-drilling zone), Nubian (planned pilot no-drilling zone), and the Guaraní (cooperation in the identification of protected areas). The Genevese agreement is unique in that it allocates the annual volumetric abstraction for the French communities. Moreover, the governance of the Genevese and the Nubian provides for the establishment of joint standards on the chemical groundwater quality.
6. Lastly, infrastructure for monitoring and data-exchange appears to be present for all case studies, except for the Abbotsford-Sumas and the Saq-Ram. However, since the modality and frequency of monitoring were described in varying levels of detail, the practical merits of the infrastructure could not be assessed for the case studies.

However, linking the institutional design to the effectiveness in terms of problem-solving appears to be difficult. The governance of the Genevese was found to be effective in mitigating the problem (i.e. depletion) (4.2.5). The governance of the Guaraní has been anticipatory in nature rather than responsive to a sustainability problem; since governance was primarily related to the development of knowledge, it can be considered effective in terms of problem-solving (4.3.5). The governance of the Abbotsford-Sumas and the North-western Sahara aquifers is not considered effective in respectively addressing pollution (4.1.5) and depletion (4.6.5). Indications of impact in terms of problem-solving are lacking for the other aquifers. The evaluation of governance effectiveness in the Hueco-Bolsón is inhibited by the lack of (public) historical recordings of the groundwater level (4.4.5). There are no indications of improvements in terms of the four targeted sustainability problems of the Nubian – i.e. declining water levels, water quality deterioration, changes in groundwater regime, and damage or loss to ecosystems and biodiversity (4.7.5) – or the issues related to groundwater depletion and pollution in the Iullemeden (4.5.5). Lastly, the effectiveness of governance of the Saq-Ram will remain unknown as long as the status of the resource is not monitored on a transboundary level (4.8.5).

As discussed above, TBA governance was evaluated as effective in two case studies, appeared to be ineffective in two case studies, and the effectiveness in the four remaining case studies remains unknown. Hypotheses were formulated to link the perceived effectiveness of TBA governance to both institutional design and contextual variables.

1. Firstly, given that intensive project activity occurred in half of the case studies, third party involvement is presumed to increase the likelihood of institutionalisation of TBA governance.
2. Secondly, the facts that the four project-intensive aquifers are among the 5% largest of the world and rank relatively high in terms of the articulation of principles of international law, suggests a role for third parties in the diffusion of legal principles.
3. Thirdly, problem-based institutionalisation of TBA governance (i.e. scoping governance in accordance with the spatial extent of the problem) is presumed to enhance effectiveness.
4. Fourthly, those riparians with the highest stakes vested in the resource (e.g. stakes related to the extent of exploitation and the availability of alternative sources of fresh water) are presumed to assert the most influence on governance effectiveness.
5. Fithly, large-scale unilateral development (e.g. the implementation of major groundwater transfers) is presumed to increase the willingness to commit to

high-legality governance among those actors who do not benefit from the infrastructural development.

6. Lastly, and perhaps most intuitively, competing national and regional priorities such as food security and political stability are presumed to decrease the perceived urgency of TBA governance and thus impede its effectiveness.

Three aspects are crucial to answering the research question: 1) the observed large variations in both the type of institutions and institutional design; 2) the observation that institutional design can hardly be linked to effectiveness in terms of problem-solving in the absence of data on the status of the resource; and 3) the implication that institutional effectiveness in the governance of transboundary aquifers is influenced by problem structure rather than institutional design.

In conclusion, this study did not identify common narratives that explain the effectiveness of TBA governance, beyond the hypothetical relationships between contextual factors and institutional design. Further research may substantiate the hypotheses that link such contextual factors to institutional design and impact as well as the dynamics of power and stakes in transboundary aquifer governance.

Appendix A: Map of Transboundary Aquifers of the World

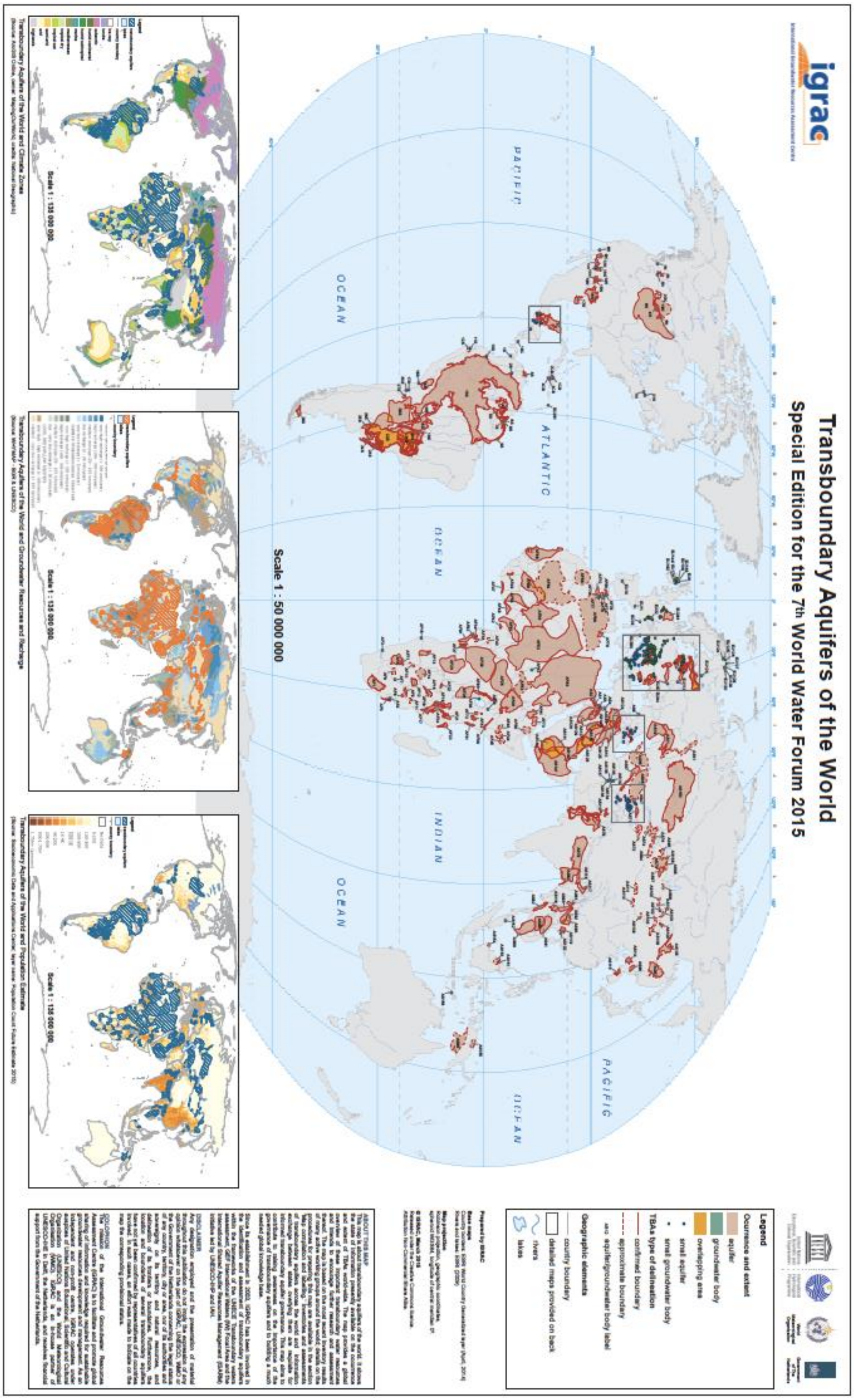

Figure 9 Map of transboundary aquifers of the world (IGRAC 2015)

Appendix B: Coding scheme

B-1: Institutionalisation

Table 14 Coding scheme – Competences of TBA institutions

	Competence	Coding question	Code	Criteria and examples
1	Information	Does the institution have the power to gather information?	0 = not specified	n/a
			1 = yes	The institution may gather documents and data; the institution may appoint experts for the purpose of studies and joint research.
2	Advice upon consultation	Does the institution have the power to advise on certain matters?	0 = not specified	n/a
			1 = yes	Certain activities are subjected to the technical opinion of the institution (e.g. the construction of waterworks).
3	Regulation	Does the institution have the power to regulate human activity in the aquifer?	0 = not specified	n/a
			1 = yes	The institution may establish groundwater quality criteria; the institution may formulate a yearly aquifer management programme.
4	Resource monitoring	Does the institution have the power to monitor the status of the groundwater resources?	0 = not specified	n/a
			1 = yes	The institution monitors groundwater levels, abstraction, and quality submitted by the countries.
5	Compliance monitoring	Does the institution have the power to monitor compliance with groundwater-related agreements?	0 = not specified	n/a
			1 = yes	The institution monitors compliance with agreed upon allocation rules.
6	Conflict Resolution	Does the institution have a role in conflict resolution?	0 = not specified	n/a
			1 = yes	The institution has a role in mediation or adjudication; the institution may give its (technical) opinion related to a conflict.

B-2: Knowledge and scientific learning

Table 15 Coding scheme – Consensual scope of the problem

	Scope of the problem	Coding question	Code	Criteria and examples
7	Nature of the problem	Is there consensus on the nature of the problem?	0 = not specified	n/a
			1 = yes	The nature of the problem is identified as overexploitation, pollution, underdevelopment, and/or lack of data.
8	Pressures and drivers	Is there consensus on the pressures and drivers related to the problem?	0= not specified	n/a
			1 = yes	The actors have identified pressures and drivers related to the problem such as agricultural development, population growth, and climate change.
9	Risk analysis	Have the actors estimated or projected consequences of the problem?	0 = not specified	n/a
			1 = yes	Identification of high-risk areas, e.g. through scenario development where the scope of the problem is linked to pressures and drivers

Table 16 Preliminary hydrogeological knowledge

	Consensus on the problem	Coding question	Code	Criteria and examples
10	Delineation	Is there consensus on the spatial extent and delineation of the aquifer?	0 = not specified	n/a
			1a = implicit	Implicit in the boundary conditions of a joint model.
			1b = explicit	Presence of a map; Detailed (verbal) account of the spatial extent.
11	Basic hydrogeological features	Is there some understanding of the role of the aquifer within the hydrogeological system (i.e. natural recharge and discharge)	0 = not specified	n/a
			1 = yes	Natural recharge and discharge are identified and rates are estimated. This requires some knowledge of aquifer properties such as permeability, transmissivity, etc.

Table 17 Coding scheme – Joint knowledge-development efforts in Groundwater Governance

	Joint knowledge-development efforts	Coding question	Code	Criteria and examples
12	Joint studies	Has the groundwater governance process included the conduction of joint studies?	0 = no	n/a
			1 = yes	Studies have been conducted by teams consisting of experts from the countries involved.
13	Joint R&D pilot projects	Has groundwater governance involved joint R&D pilot projects?	0 = no	n/a
			1 = yes	Design and/or implementation of transboundary pilot projects meant to explore best practises, e.g. pollution prevention measures.

B-3: Principled content

Table 18 Coding scheme – Principles of International Environmental Law applied to Groundwater Governance

	Principle	Coding question	Code	Criteria and examples
14	Exchange of data	Is groundwater governance implicitly or explicitly based on the principle of exchange of data?	0 = not specified	n/a
			1a = implicit	Statement that countries shall share information related to the groundwater resource; Enumeration of types of data that shall be shared between countries.
			1b = explicit	Mentions of 'principle' AND 'sharing/exchange' AND 'information/data'.
15	Precautionary principle	Is groundwater governance implicitly or explicitly based on the precautionary principle?	0 = not specified	n/a
			1a = implicit	Statement that countries shall not refrain from preventing transboundary impacts in the absence of a conclusive evidence of a causal link between activity and impact.
			1b = explicit	Mentions of 'precautionary' AND 'principle'/'approach'
16	Environmental conservation	Is groundwater governance implicitly or explicitly based on the principle of environmental conservation?	0 = not specified	n/a
			1a = implicit	Environmental conservation is implicit in a preamble or in the cooperation objectives.

			1b = explicit	Mentions of 'environmental' OR 'environment', OR 'ecosystem' AND 'conservation' OR 'protection' OR 'preservation' AND 'principle'.
17	No significant harm	Is groundwater governance implicitly or explicitly based on the principled obligation to avert significant harm?	0 = not specified	n/a
			1a = implicit	Statement that countries shall refrain from the use of harmful techniques; statement that countries conduct environmental impact assessment prior to undertaking activities on their territory.
			1b = explicit	Mentions of principle of 'do no harm', 'non-detrimental use', OR 'non-damaging use'.
18	Notification of planned measures	Is groundwater governance implicitly or explicitly based on the principle of notification of planned measures that are likely to have adverse impacts beyond the border?	0 = not specified	n/a
			1a = implicit	Statement that the construction of waterworks is subject to consultation of the neighbouring state or a third party
			1b = explicit	Mentions of 'notification' AND 'project' OR 'proposal' OR 'activity' AND '(adverse) impacts'
19	Notification of accidents and emergencies	Is groundwater governance implicitly or explicitly based on the principle that countries notify neighbouring countries in the case of accidental impacts on the groundwater resource?	0 = not specified	n/a
			1a = implicit	Referral to a groundwater quality monitoring network intended to issue warnings
			1b = explicit	Mentions of 'accident' OR 'emergency' AND 'notification' AND 'adverse/negative impact'

Table 19 Coding scheme – Principles of International Water Law applied to Groundwater Governance

	Principle	Coding question	Code	Criteria and examples
20	Reasonable and equitable use	Is groundwater governance implicitly or explicitly based on the principle of reasonable and equitable use?	0 = not specified	n/a
			1a = implicit	Statement that countries shall share groundwater resources in a fair way.
			1b = explicit	Mentions of 'reasonable' AND 'equitable' AND 'use'.
21	Polluter pays	Is groundwater governance implicitly or explicitly based on the principle that the polluter pays?	0 = not specified	n/a
			1a = implicit	Referral to taxes and/or fees for wastewater purification.
			1b = explicit	Mentions of 'cost' AND 'pollution' AND 'borne by/paid by polluter'.
22	User pays	Is groundwater governance implicitly or explicitly based on the principle that the user pays?	0 = not specified	n/a
			1a = implicit	Statement that water rates are dependent on use; statement that the costs of measures are shared between beneficiaries.
			1b = explicit	Mention of 'user' AND 'pays'
23	IWRM	Is groundwater governance implicitly or explicitly based on the principle that water management is integrated with policy in the social and economic domains?	0 = not specified	n/a
			1a = implicit	Statement that water development is coordinated with the development of e.g., land and employment
			1b = explicit	Mentions of 'integrated' AND 'management' AND 'water resources'

24	Conjunctive use of water resources	Is groundwater governance implicitly or explicitly based on the principle that the management groundwater of groundwater use is coordinated with the management of other water resources?	0 = not specified	n/a
			1a = implicit	Statements that groundwater policy is coordinated with policy related to the water cycle and/or water resources inventories
			1b = explicit	Mentions of 'conjunctive' AND 'use'

Table 20 Coding scheme – Principles of Social Justice applied to Groundwater Governance

	Principle	Coding question	Code	Criteria and examples
25	Access to drinking water and sanitation	Does groundwater governance implicitly or explicitly recognise the human right of access to drinking water and sanitation?	0 = not specified	n/a
			1a = implicit	Restriction of agricultural abstractions for the benefit of municipal use.
			1b = explicit	Mentions of '(human) right' AND '(drinking) water'.
26	Rights of marginalised groups	Does groundwater governance implicitly or explicitly recognise the rights of marginalised groups, such as women, youth and indigenous people?	0 = not specified	n/a
			1a = implicit	Concessions for members of specified societal groups; referrals to inclusive groundwater management.
			1b = explicit	Mentions of 'rights' AND 'minorities' OR 'vulnerable/marginalised' OR naming group in question.
27	Participation / transparency of policy-making	Is groundwater governance implicitly or explicitly based on the principle of public participation and transparency of policy-making?	0 = not specified	n/a
			1a = implicit	Presence of a stakeholder involvement platform.
			1b = explicit	Mentions of 'public participation' OR 'right to be informed' OR 'access to information' OR 'stakeholder involvement'.

B-4: Legality

Table 21 Coding scheme - Level of detail in rights and obligations of Groundwater Governance

	Right/ obligation	Coding question	Code	Criteria and examples
28	Well design	Does groundwater governance regulate (or provide for the regulation of) groundwater wells?	0 = not specified	n/a
			1 = yes	Certain features are specified (e.g. well depth or capacity) or the competence to regulate on such features is assigned.
29	Protection zones	Does groundwater governance delineate (or provide for the delineation of) protection zones?	0 = not specified	n/a
			1 = yes	Specified zones are subjected to tiered protection (e.g. no-drilling zones) or the competence to regulate is assigned.
30	Volumetric abstraction allocation/ restrictions	Does groundwater governance restrict (or provide for the restriction of) volumetric abstraction?	0 = not specified	n/a
			1 = yes	Volumetric abstraction is restricted in time, possibly for particular user groups (e.g. agricultural sector) or the competence to do so is assigned.
31	Pollution – prevention measures	Does groundwater governance include (or provide for the inclusion of) pollution prevention measures?	0 = not specified	n/a
			1 = yes	Regulations on the quality of wastewater effluent are in place or the regulatory competence is assigned.

32	Pollution – abatement measures	Does groundwater governance include (or provide for the inclusion of) pollution prevention measures?	0 = not specified	n/a
			1 = yes	Measures for pollution abatement are devised or the competence to do so is assigned.

Table 22 Coding scheme – Formality of groundwater governance

	Element	Coding question	Code	Criteria and examples
33	Formality	Does regional groundwater governance comprise of one or more international treaty that primarily concerns groundwater?	0 = informal	Groundwater governance comprises merely of plans, ministerial declarations, or informal arrangements between non-governmental entities.
			1 = formal	Groundwater governance comprises of at least one bilateral or multilateral treaty that is binding under international law upon ratification.
34	Validity	If *formal*, has at least one of the treaties entered into force?	0 = not valid or unknown	No treaty has entered into force due to an insufficient number of ratifying parties.
			1 = valid	At least one treaty has entered into force upon ratification.
35	Implementation	If *informal*, has groundwater governance been implemented	0 = not implemented or unknown	No groundwater governance documents have been implemented.
			1 = implemented	At least one groundwater governance document has been implemented.

Table 23 Coding scheme – Adjudication

	Adjudication	Coding question	Code	Criteria and examples
36	Dispute resolution mechanism	Does groundwater governance contain a dispute resolution mechanism?	0 = not specified	n/a
			1 = yes	References to good offices, mediation, conciliation, arbitration.

B-5 Monitoring and data-exchange

Table 24 Coding scheme – Mechanisms for monitoring and data-exchange

	Element	Coding question	Code	Criteria and examples
37	Harmonisation of meta-data	Does groundwater governance involve the regional integration and systematisation of knowledge-development?	0 = no	n/a
			1 = yes	Presence of joint mechanism for collecting data; Harmonisation of methodologies and procedures.
38	Numerical model	Does groundwater governance rely on hydrogeological modelling?	0 = no	n/a
			1 = yes	Presence of a (conceptual and/or numerical) hydrogeological model of the TBA, possibly including interactions with other water bodies.
39	Well inventory	Have exploitation and monitoring wells been inventorised?	0 = no	n/a
			1 = yes	Governance documents refer to a well inventory; there is a map of georeferenced wells.
40	Piezometric network	Do the countries claim that they have established a piezometric network?	0 = no	n/a
			1 = yes	Countries claim that they have established a network of observation points where groundwater level is periodically measured. This can be assumed if the governance documents contain piezometric maps.
41	Platform for data-exchange	Is there an online platform for data-exchange?	0 = no	n/a
			1 = yes	Governance documents refer to an online database or a protected online environment that can be consulted and/or updated by country representatives.
42	Types of information to be exchanged	Is the principle of data-exchange substantiated?	0 = no	n/a
			1 = yes	Types of information to be exchanged were identified such as electric conductivity or water level.

Table 25 Governance of eight TBAs coded for elements of institutionalisation

	Competences					
TBA No.	Information gathering	Advisory	Regulatory	Resource monitoring	Compliance monitoring	Conflict resolution
1[1]	0	1	0	0	0	0
2[2]	1	1	1	1	1	0
3[3]	0	0	0	0	0	1
4[4]	0	0	0	1	0	0
5[5]	1	1	1	0	0	1
6[6]	1	0	0	1	0	0
7[7]	1	0	1	0	0	0
8[8]	1	1	0	1	1	0

[1] **Abbotsford-Sumas**. ASA Task Force comprises a working group on legislation and policy advice.

[2] **Genevese**. The Genevese committee may appoint technicians (art. 3§1 of the 2007 agreement) and give a 'technical opinion' on the construction of waterworks (art. 2§2 jo. article 5§2 2007 agreement). May propose yearly aquifer management programme, including measures to prevent/remedy pollution.May establish criteria on groundwater quality and well specifications (art. 2§1 and art. 16§1 2007 agreement). May demand water level records (art. 7§2 2015 agreement) as well as volumetric abstraction records be supplied periodically by well operators (art. 3§2 *jo*. article 6§2 of the 2007 agreement). Also in charge of the "[s]upervision of implementation of the terms of agreement" (art. 3§4 sub *a* of the 2015 agreement).

[3] **Guaraní**. Intergovernmental committee give recommendations on the resolution of any dispute regarding the interpretation of the 2010 agreement, subject to a mutual request from parties in the controversy (article 17).

[4] **Hueco-Bolsón**. The joint intermunicipal committee has competences in the sharing of data on pumping, sources of water, and water quality

[5] **Iullemeden.** Permanent scientific committee of the intergovernmental mechanism may give advice on any issue submitted it, "including the technical aspects of projects and programs, their likely impacts on the ITAS water resources, and their consistency with plans for the development of water resources" (article 10 of the 2014 MoU). Intergovernmental mechanisms may draft action plans to achieve their objectives (resp. art. 23 and 30 of the 2009 and 2014 MoUs). Competences in conflict resolution vested in the respective Council of Ministers based on advice by the scientific committee (resp. art. 30 and 31 of the 2009 and 2014 MoU).

[6] **North-western Sahara**. Mechanism has competence to develop a reference observation network and to process and analyse data (§IV 2002 MoU).

[7] **Nubian Sandstone**. Power to gather information is precisely defined for the committee as the "collection of all information, data, and results of studies made by relevant countries" and "[c]lassifying, analysing and correlating such information, data and study results" (art. 3 1992 agreement). May develop plans for the development of the aquifer and explore measures to "ration the consumption" (article 3 of the 1992 agreement). Power to monitor data and information supplied by the national offices and to provide yearly summaries of the biological status in the 2013 SAP.

[8] **Saq-Ram**. Competence to gather information defined as "[f]acilitate the collection and exchange of information, statements and studies" and to "appoint experts and advisors" (art. 3§2 and 4 2015 agreement). Committee may give non-binding advice on construction/modification of waterworks (art. 5 2015 agreement). Competence to observe both groundwater quality and quantity and volumetric abstraction (art. 3§4 sub *b* 2015 agreement).

Table 26 Governance of eight TBAs coded for elements of Knowledge and Scientific Learning

	Consensus on the problem			**Preliminary knowledge**		**Scientific learning**	
TBA No.	Nature of the problem	Pressures and drivers	Risk analysis	Delineation	Basic hydrogeo-logical features	Joint studies	Joint R&D pilot projects
1[9]	1	0	0	1	0	1	0
2[10]	0	0	0	1	0	1	0
3[11]	0	0	0	1	1	0	1
4[12]	1	0	0	1	1	1	1
5[13]	1	1	1	1	1	1	0
6[14]	0	0	0	1	0	1	0
7[15]	1	1	1	1	1	0	1
8[16]	0	0	0	0	0	0	0

[9] **Abbotsford-Sumas**. No map, but delineated in terms of size, shape, catchment area, and hydro(geo-)logical boundaries, according to the website of the ASA Task Force. Regular organisation of International Science forums and conducted studies on e.g. land use and nitrate trends

[10] **Genevese**. Map of spatial extent relative to administrative boundaries and position of monitoring and exploitation wells on the website of the Canton of Geneva. No evidence that the delineation has been contested by the French communities. Unclear whether there is a numerical model. Joint studies institutionalised through the joint technical committee.

[11] **Guaraní**. No problem statement, although preamble to the 2010 agreement did mention the "scientific understanding on the [...] aquifer system and the responsible management of its water resources". Hydrogeological cross-sections; consensus on location of recharge zones and –rates.

[12] **Hueco-Bolsón**. Hydrogeological cross-sections. Numerical model provided for, although existence is not confirmed. Institutionalisation of joint studies through principal engineers; pilot projects provided for in the MoU.

[13] **Iullemeden**. Pressures and drivers identified as socio-economic developments; economic integration. Transboundary risks visualised on map. Hydrogeological cross-sections; numerous informative maps. Numerical model (linked to database). Scientific committees institutionalised in the intergovernmental mechanism.

[14] **North-western Sahara**. No problem statement other than the objective for the establishment of a mechanism in the 2002 agreement, which is "to coordinate, promote and facilitate the rational management of the NWSAS water resources". Joint studies among the responsibilities of the mechanism.

[15] **Nubian Sandstone**. Depletion due to expansion of agriculture and population growth; pollution, salinisation and disturbed water balance due to agricultural and industrial development, related to the combination of increased population and national decisions related to food security priorities. Verbal account of risks, although rooted in a model. Map specifies the location of oases as well as cities and settlements. Joint research has been done yet not institutionalised. The SAP provides for pilot projects on water conservation, wastewater disposal, and climate change adaptation.

[16] **Saq-Ram**. Depletion appears to be implicitly recognised as a problem in the preamble, which states that "prudence in the management and utilization of the groundwaters, which have limited renewability" would be for the benefit of both parties. UN ESCWA report described aquifer configuration, stratigraphy, thickness, and relevant parameters, but no delineation or hydrological features in the governance documents themselves

Table 27 Governance of eight TBAs coded for elements of Principled Content

TBA	Principles of Environmental Law						Principles of Water law					Principles of Social justice		
No.	Exchange of information	Precautionary principle	Environmental conservation	No significant harm	Notification of planned measures	Notification of accidents	Reasonable and equitable use	Polluter pays	User pays	Integrated water resources management	Conjunctive use water resources	Access to water and sanitation	Rights of marginalised groups	Participation / transparency
1[17]	0	0	1a	0	1b	0	0	0	0	0	0	0	1b	1a
2[18]	1a	0	0	0	1a	1a	0	0	1a	0	0	0	0	0
3[19]	1a	0	1b	1b	1b	0	1b	0	0	0	0	0	1a	1a
4[20]	1a	0	0	0	0	0	0	0	0	0	0	0	0	0
5[21]	1a	1a	1b	1b	1b	0	1b	1b	1a	1b	1a	1b	0	1b
6[22]	1a	0	0	0	0	0	0	0	0	0	0	0	0	0
7[23]	1a	1b	1a	1a	1a	0	0	1b	0	1a	0	0	0	1b
8[24]	1a	0	0	0	1a	0	0	0	0	0	0	1a	0	0

* Both implicit (1a) and explicit (1b) are included.

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17 **Abbotsford-Sumas**. 1996 Memorandum of Agreement implicitly embodies the principle of information exchange since it promotes sharing relevant water quantity information.Principle of environmental conservation implicit in the mandate of the Task Force. No explicit notification of accidents, although Section III of the Memorandum of Agreement specifies that the parties "cooperatively respond to emergencies that could cause environmental harm and damages".

18 **Genevese**. Article 16 of both agreements provides for the exchange of water quality data. Principle of notification of accidents implicit in article 17 (warning system for accidental pollution). User-pays principle implicit in obligation of proportionate payment for operation of artificial recharge plant. Human right to WASH acknowledged, although the rationale of the agreement is to secure the capacity for providing people with drinking water.

19 **Guaraní**. 2010 agreement promotes "to adequately exchange technical information about studies, activities and works that contemplate the sustainable utilization of the Guarani Aquifer System water resources" and "sharing of (technical and scientific) knowledge and management practices as well as developing joint projects" (art. 8 and 12).

20 **Hueco-Bolsón**. Principle of information exchange implicitly embodied in the ambition to develop a team of binational experts to exchange data and develop joint datasets.

21 **Iullemeden**. MoUs provide that the riparians "shall regularly exchange easily accessible data and information [...] in particular those of geological, hydrogeological, hydrological, meteorogical and ecological nature and those related to the hydrochemistry of the aquifer or aquifer stystems and relevant for forecasts". Both MoUs assert that states shall delay the implementation of measures intended to avoid any situation likely to have a transboundary impact with the reason that scientific research has not shown the existence of a causality link between the measures and a possible transboundary impact (art. 16 and 23 respectively).

22 **North-western Sahara**.

23 **Nubian**. The SAP promoted to expand data exchange and monitoring to climate change, ecosystems and biodiversity. IWRM-principle implicit in joint irrigation and cattle projects and the construction of service centres along (animal) trade routes with fodder, water and vetinary services. SAP promotes taking measures if there are reasonable grounds for concern, even if there is no conclusive evidence of a causal relationship between activity and effect (precautionarity).

24 **Saq-Ram**. Art 3§4 sub c of the 2015 agreement implicitly embodies the principle of information exchange.

Table 28 Governance of eight TBAs coded for elements of Legality

TBA No.	Rights and obligations					Legal status			Dispute resolution
	Well design	Protection zones	Volumetric abstraction allocation/ restriction	Pollution – prevention	Pollution – abatement	Formality	Validity	Implementation	Dispute resolution mechanism
1[25]	0	0	0	0	0	0	n/a	0	0
2[26]	1	0	1	1	1	1	1	n/a	1
3[27]	0	1	0	0	0	1	0	n/a	1
4[28]	0	0	0	0	0	0	n/a	0	0
5[29]	0	0	0	0	0	0	n/a	0	1
6[30]	0	0	0	0	0	0	n/a	1	0
7[31]	0	1	0	1	0	0	n/a	1	0
8[32]	1	1	1	1	0	1	0	n/a	0

[25] **Abbotsford-Sumas**. No rights and obligations; informal status of governance documents.
[26] **Genevese**. Article 7(1) provides for well design, i.e. their equipment with standard recording device. Article 8 restricts abstraction in the French communities to 5 million m^3 per year. Article 18 also provides for obligatory analysis of water injected into the aquifer at a laboratory, according to chemical standards issued by the commission in a Convention of 8 January 1985. Article 2(1) provides for the identification of measures to remedy possible causes of pollution. Article 20 specifies that any disputes shall be resolved in accordance with French law before being submitted to the Franco-Genevese Regional Committee and finally the Franco-Swiss Consulative Commission for Problems of Neighbourliness.
[27] **Guaraní**. Article 14 mandates cooperation in identifying (boundary) areas that require specific treatment, i.e. protection zones. Tiered procedure for the resolution of disputes (negotiation, consultation, and arbitration) outlined in articles 16-19.
[28] **Hueco-Bolsón**. No rights and obligations; informal status of governance documents.
[29] **Iullemeden**. Although specific provisions regarding protection zones are lacking, the Concertation Mechanisms have the power to identify risks and vulnerable zones and develop relevant action plans accordingly (article 5 sub l 2014 MoU). Restriction of volumetric abstraction not specified beyond "avoid excessive abstraction". Amicable settlement of disputes through mediation, conciliation, and adjudication by the International Court of Justice (articles 36-38).
[30] **North-western Sahara**. No rights and obligations. However, institution has been operationalised.
[31] **Nubian**. The SAP provides for the establishment of a pilot no-drilling zone between Chad and Sudan. Also provides for the development of waste disposal quality standards and guidelines as well as joint standards on chemical use in agriculture and for industrial and municipal waste disposal.
[32] **Saq-Ram**. Article 2(4) provides for the formulation of technical standards for abstraction wells by the committee. The agreement also prohibits horizontal drilling of wells. Article 2(5) prohibits the "injection" of pollutants into the aquifer.

Table 29 Governance of eight TBAs coded for Monitoring and Data-exchange

TBA	**Monitoring and data-exchange**					
No.	Harmonisation of meta-data (e.g. joint database)	Numerical hydrogeological model	Well inventory	Piezometric network	Web-based platform for data-exchange	Types of information to be exchanged
1[33]	0	1	0	0	0	1
2[34]	1	0	1	1	0	1
3[35]	1	1	1	1	0	0
4[36]	1	1	1	0	0	1
5[37]	1	1	1	1	0	0
6[38]	0	1	1	1	1	0
7[39]	1	1	1	0	1	1
8[40]	0	0	0	0	0	1

33 **Abbotsford-Sumas**. No indication of the presence of joint database, hydrogeological model, well inventory, or platform for data-exchange. Strikingly, the preamble of the 1996 Water Referral agreement provides for prior consultation on water quantity allocation permits.

34 **Genevese**. No indications that there is a joint hydrogeological model. Article 4 of the 1978 agreement provides for a joint waterworks inventory and there is a map indicating the location of monitoring and exploitation wells. Piezometric network appears to exist for each country segment. National registers that can be consulted upon request by either delegation (article 11), but there is no web-based platform for data-exchange. Lastly, the agreement specifically provided for the exchange of the results of obligatory water quality analyses of abstracted volumes (article 16).

35 **Guaraní**. Joint database has not been established, but monitoring procedures were purportedly harmonised. Numerical models were developed for four regions. Well inventory contains location and geographic coordinates of wells. Piezometric network seems to exist. Principle of data-exchange is not substantiated.

36 **Hueco-Bolsón**. Meta-data appear to be compatible, given the tabulated groundwater level recordings, pumping records, and TDS measurements. The municipalities of Ciudad Juarez and El Paso purportedly created a joint numerical model and shared information on well locations and –ownership. Unclear whether piezometric network exists. Interestingly, the MoU provides for sharing knowledge and best practices regarding the acquisition of grants and loans.

37 **Iullemeden**. The riparians purportedly created a database comprising data on climatology, hydrology, and water use. A mathematical model was linked to this database. Wells were inventorised and a piezometric networks exists. It is unclear whether a web-based platform for data-exchange exists, which would provide for periodic updating of the model.

38 **North-western Sahara**. Numerical models were created. Boreholes and so-called foggaras were inventorised and a piezometric network was completed. The governance documents provide for the development of a web-based reference observation network for groundwater monitoring.

39 **Nubian**. Governance documents provided for the harmonization of monitoring parameters (meta-data). A three-dimensional model was created for the Nubian. Governance documents provided for the inventorisation of wells and boreholes and for updating hydrogeological, meteorological and socio-economic data to a protected online environment. Lastly, these provided measurements of the groundwater table, abstraction, and electric conductivity as an indicator of salinity

40 **Saq-Ram**. No provisions on the harmonisation of meta-data appear to exist. Numerical models only exist separately for the country segments. Wells and boreholes were not inventorised, although the map in the appendix indicates where (some of) these are. Joint committee gathers information on quantity of water abstracted and its quality as well as the groundwater level.

Appendix D: Interview strategy: Hypotheses and questions

D-1: Abbotsford-Sumas

Hypotheses	Interview questions
• The problem is homogenous across the international border; • Interest groups are homogeneous across the border; • The agricultural lobby is strong.	• Is the governance of the Abbotsford-Sumas effective; if so why? If not, why not? • How to evaluate the political interest in protection of the ASA? • Is fair to state that there is lack of political/government involvement in groundwater quality? • To what extent is the problem homogeneous across the border? • To what extent do interest groups (e.g. agricultural sector, citizens) extend and mobilise themselves across the border? • What is the role of the agricultural sector in groundwater governance?

D-2: Genevese

Hypotheses	Interview questions
Geneva had a leading role in establishing artificial recharge for the benefit of all; Due to increased levels of mutual trust, second treaty entails a reduction of bureaucratic and technocratic elements.	• Is the governance of the Genevese effective; if so, why? If not, why not? • How has the conclusion of the 1978 and 2007 agreement affected levels of mutual trust?

D-3: Guaraní

Hypotheses	Interview questions
The apparent reluctance of Brazil to ratify points at hydrohegemonic relationships	• Would you consider governance of the Guaraní aquifer system to be effective; if so why? If not, why not? • What is the status of monitoring and data exchange? • What is the timeframe for implementation of the Strategic Action Programme? • To what extent have local transboundary committees remained active after the completion of SAP pilot projects? • How can the issue of groundwater protection be understood in the context of other regional interests? • Do you think Brazil is likely to ratify the agreement? • What could be the reason that Paraguay is not planning on ratifying the agreement?

D-4: Hueco-Bolson

Hypotheses	Interview questions
• The informal approach to groundwater governance seemed successful at first, but was later undone by a persistent drought • There are parallels with the Genevese aquifer; yet somehow El Paso has not been able to convince Ciudad Juárez of the benefits of joint aquifer recharge	• Would you consider governance of the Hueco Bolsón to be effective; if so why? If not, why not? • What is the status of monitoring and data exchange? • Has a joint JMAS-PSB model been established, as provided for by the 1999 Memorandum of Understanding? • Why did the U.S. federal authorities unilaterally

	decide to develop projects from 2005 onwards (i.e. USEPA project and U.S. – Mexico Transboundary Aquifer Assessment Programme)? • How did local authorities/utilities respond to the drought in the early 2000s and what was the effect on transboundary aquifer governance, if any? • Who were the primary beneficiaries of managed aquifer research and desalinisation initiatives in Texas (El Paso)? To what extent do Mexican actors benefit? • To what extent were Mexican actors involved in plans for artificial recharge from 1985 onwards?

D-5: Iullemeden

Hypotheses	Interview questions
• Despite large strides in consensual knowledge and understanding, efforts of institutional integration led to stagnation as soon as funding ran dry • Groundwater protection ranks low compared to other regional priorities, particularly poverty alleviation	• What is the status of the MoUs from 2009 and 2014 respectively in terms of implementation? • What is the status of the joint database? How does water use compare to number of datapoints per country segment? • How does groundwater protection rank compared to other priorities in the region? • What exactly was the duration of IAEA involvement?

D-6: North-western Sahara Aquifer

Hypotheses	Interview questions
• The three nations are very similar in terms of socio-economics; power asymmetry is low (Schmidt 2008) • Groundwater protection currently ranks low compared to other regional priorities (e.g. political stability and food security)	• Would you consider governance of the North Western Sahara Aquifer System to be effective; if so why? If not, why not? • What is the convening frequency of the Concertation Mechanism, that became operational in 2008? • Do the countries share data with each other, and if so how frequently? • How does groundwater protection rank compared to other regional priorities?

D-7 Nubian Sandstone Aquifer System

Hypotheses	Interview questions
• Accelerated unilateral development by Libya triggered Egypt to pursue bilateral cooperation in the early 1990s • The concept of hydrohegemony may explain the seemingly irrational endeavour to create a no-drilling zone between Chad and Sudan • Not only is there power asymmetry in terms of socio-economics in the region; the donor community has also prioritised Libya and Egypt ("the World Bank may need Egypt more than Egypt needs the World Bank") • The interests of 'voice-less' nomadic groups in Chad and Sudan are insufficiently taken into account; in this way, groundwater governance fosters existing inequality	• Would you consider the governance of the NSAS effective; if so why? If not, why not? • How do groundwater development and preservation rank compared to other national and regional priorities? • What is the level of (hydrogeological) uncertainty in the Shared Aquifer Diagnostics Analysis (SADA), given the spatial distribution of observation wells? • What was the rationale of the pilot no-drilling zone between Chad and Sudan, as provided for by the Strategic Action Plan (SAP)? • How was IAEA involved in the GEF/UNDP project? How active were Chad and Sudan in the GEF/UNDP project and negotiation of the final SAP?

	• How active is the Joint Authority for the study and development of the Nubian? • What is the status of monitoring and data exchange?

D-8 Saq-Ram aquifer system

Hypotheses	**Interview questions**
• Accelerated unilateral development by Jordan triggered Saudi Arabia to pursue a non-drilling zone in 2007 • Levels of mutual trust remain low, as evident by reluctance of data-sharing	• Would you consider the governance of the Saq-Ram aquifer system effective; if so why? If not, why not? • How does the 2015 agreement relate to the 2007 Memorandum of Understanding in terms of content and scope? • What is the status of the agreement; is it likely to be ratified/implemented any time soon? • How has the level of trust between the two countries shifted over time, particularly with the Disi GW Conveyance project? • What is the significance of the 2007 MoU and the 2015 agreements in terms of mutual trust?

Appendix E: Interview findings

Governance of the Guaraní

Name interviewee:	Luiz Amore
Profession; affiliation:	Hydrogeologist; Foreign Affairs Adviser in the National Water Agency of Brazil)
Interview modality:	Email correspondence (almost verbatim).

- Would consider the governance of the Guarani aquifer system to be effective: "According to the management instruments that took part of the SAP and approved by countries, if all information are shared and jointly evaluated by the Technical Support Commissions, with representatives from the 4 countries. In the higher political level, the Committee of countries representatives established by the Agreement have all conditions to coordinate all processes and I hope it can joint technical and diplomatic organisms from the countries. At national and state/provincial levels the National and State Commissions will depends on the coordination process in each country. The Local Support Commissions have the example of Ribeirao Preto (approving a zoning act in the Sao Paulo Water Resources Council). Other local commission could be implemented according to existing local problems. With the Agreement approval by the last countries (Brasil and Paraguay) all institutional arrangements will take place and we will have the opportunity to implement all that planed structure."
- On the status of monitoring and data exchange: "We have very effective data exchange between countries on rain and river levels. Brazil for example has bilateral cooperation agreements with all involved countries. After the Guarani Agreement approval the operation of groundwater management instruments will facilitate aquifer data exchange."
- On the timeframe for implementation of the Strategic Action Programme: "In fact the institutional framework will depend on the Guarani Agreement approval. The works depend on the countries. For example, the National Water Agency or Brazil (ANA) executed an important study on recharge areas of the outcrop areas in the country. Now Uruguay (UY) sent a letter to ANA asking for support on the implementation of similar study in the country. Paraguay is also interested."
- On the activity of local transboundary committees after the completion of pilot projects in the Strategic Action Programme: "The Ribeirao Preto local committee (Brazil) is very active. The Salto(UY)/Concordia(AR) and Santana (BR)/Rivera (UY) keep low interaction levels. In opposition the boundary development commission between Brazil

and Uruguay is very active and they are implementing a joint monitoring strategy in the Quarai and Lagoa Mirim watersheds."

- On the prioritisation of groundwater protection in the context of other regional (or national) interests: "Unfortunately low priority at national level means he same at regional level. With some exceptions..."
- Considers ratification of the 2010 agreement by Brazil to be likely: "It was approved by one of the involved Parliamentary Commission and it is going to be evaluated by two others and final approval."
- Does not have any specific information as to why Paraguay is apparently not planning on ratifying the agreement.

Governance of the Hueco Bolsón

Name interviewee:	Gabriel Eckstein
Profession; affiliation:	Geologist, legal professional; Legal scholar at Texas A&M University School of Law
Interview modality:	Skype (7 June 2016 19:00-19:30 CEST)

- In terms of groundwater depletion, effectiveness of groundwater governance on differs on either side of the border. Discrepancy in knowledge on the groundwater resources. On U.S. side, e.g. location salt-water lens is known and groundwater monitoring is prevalent. Although it appears that information and data are exchanged on a regular basis, there is still less knowledge on Mexican side (less capacity?).
- Uncertain as to activity on the Mexican side. Heard that there recently was a meeting on monitoring organised by the Mexican leg of the IBWC; the CILA.
- Groundwater governance cannot be isolated from governance of water more generally.
- Disputes related to drought in the early 2000s and more recently in 2011; Mexicans were perceived to be "hoarding" on the U.S. side because they held on to the provisions of the water sharing treaty based on which Mexico is entitled to an annual share of surface water. Exception clause applies in case of "extraordinary drought" but this term is controversial.
- Use of Mexico's annual share unknown. Possibly for irrigation purposes.
- Disparities incentives to invest in water conservation and alternate sources (wastewater recycling; desalinisation). Also disparities in groundwater reliance, some estimate that it approaches 100% in parts of Mexico.

- Mandate of the IBWC is controversial: only surface water, or groundwater as well? Water is an issue of the state in the U.S. but is regulated on the federal level in Mexico. Texas has become more conservative in terms of water rights in recent years, as evident by a 2012 Texas Supreme Court ruling (Edwards Aquifer Authority v. Day).
- Water rights also pose questions in terms of adaptation measures; e.g. MAR is at odds with the law of capture that applies in Texas.
- Effectiveness of IBWC also hindered by political issues; although headed by engineers, this institution is politically savvy. Lack of funding is an obstacle, especially for the Mexican side (despite efforts to generate seat funding).

Governance of the Saq-Ram and SDG indicator 6.5.2

Name interviewee:	Ralf Klingbeil
Profession; affiliation:	Hydrogeologist; Groundwater expert at BGR Germany, former advisor on Water at UN ESCWA
Interview modality:	Skype (15 June 2016 14:00-14:30 CEST)

- Aware that there is an agreement, but not informed on its implementation. Recommendable to speak to people of the respective ministries: Ministry of Irrigation and Water in Jordan, unknown ministry in Saudi Arabia due to recent restructuring.
- French Geological Survey and the French Development Corporation might have been involved in the negotiation of the agreement.
- Doubts on the adequacy of SDG indicator 6.5.2 in addressing the appropriate issue. Measurement problems in case countries engage differently in cooperation on surface water and groundwater respectively (e.g. Egypt's role in the Nile basin vs the Nubian Sandstone aquifer system). Indicator's approach, which takes percentage of a basin that is covered by an institutional arrangement as a starting point, does not seem suited to transboundary aquifers.

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