Norms in multilevel groundwater governance and sustainable development

Conti, K.I.

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Citation for published version (APA):
Chapter 1. Introduction

1.1 INTRODUCTION

“Water, water, everywhere nor any drop to drink”

– excerpt from *The Rime of the Ancient Mariner* by Samuel Taylor Coleridge

These words from the Rime of the Ancient Mariner were originally written to describe a man stranded on a ship, thirsty and surrounded by a tauntingly salty sea. But removed from their context, these words could be just as easily be applicable on dry land, for groundwater is almost everywhere, beneath our feet, and most often invisible to the eye.

This thesis analyzes how the current structure of normative groundwater governance laws and policies worldwide addresses today’s groundwater problems and can contribute to sustainable and inclusive development. Groundwater resources constitute 97% of the world’s liquid freshwater resources and are pervasive, underlying every country. Nevertheless, a startling paradox exists. On the one hand, there is a “groundwater crisis” (Famiglietti 2014) or a “silent revolution” (M. R. Llamas and Martínez-Santos 2005) where groundwater is being depleted in localized areas around the globe, jeopardizing livelihoods, ecosystems and economic development. For example, large and mega-cities are increasingly facing groundwater sustainability challenges (Howard 2015). On the other, there are many geographic areas where groundwater remains un- or under-utilized even though there are 783 million people who lack access to potable water (UN-Water 2013). There are also areas with potential for increased agricultural or industrial productivity if groundwater were used sustainably. In Africa, Latin America and Asia, increasing access to groundwater has been a major catalyst of economic growth and development (Wijnen et al. 2012). In light of the Sustainable Development Goals (UNGA 2015), addressing the challenges of over- and under-utilization of groundwater resources is of paramount importance for the global community.

This chapter articulates the groundwater resource problems (see 1.2), the state of the art of groundwater governance as well as the gaps in knowledge therein (see 1.3), the research questions as well as clarifies the focus and limits of the research (see 1.4), and outlines the structure of the thesis (see 1.5).

1.2 PROBLEMS FACING GROUNDWATER RESOURCES

This section presents the key challenges concerning groundwater resources, namely groundwater abstraction, quality degradation, and the increasingly global nature of the resource. While I present these challenges individually here, in reality they are complex and linked. The complexities and linkages are further discussed in Chapter 3.

1.2.1 Groundwater Abstraction and Depletion

Annually, humans abstract 200 times more groundwater than oil. Groundwater abstraction is not problematic per se; however, groundwater abstraction in excess of natural replenishment (or recharge) results in resource depletion. Depletion is a major challenge that can permanently shift the dynamics of groundwater resources and groundwater availability. There are two distinct situations in which depletion occurs. The first is when there are renewable groundwater resources available, yet abstraction occurs in excess of the volume of recharge. The second is where there is no recharge (on a human timescale) and thus any abstraction results in depletion.

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1 This section draws heavily on Conti and Gupta (2015).
Empirical data about groundwater abstraction and/or human uses is not available world-wide, necessitating that models estimate these values. Although models face several limitations\(^2\), they currently provide the closest approximations of the current state of groundwater abstraction and depletion due to human uses.

Since 1960, groundwater abstraction has increased by approximately 235\% (312 ± 37 to 734 ± 82 km per annum see Wada et al. 2010). Various models have estimated annual groundwater withdrawals ranging between 545 km\(^3\) per annum for agriculture (Siebert and Burke 2010) and 1100 km\(^3\) globally (Döll 2009). However, Döll et al. (2012) provide an estimate of 250 km\(^3\) net withdrawals, stating that a significant portion of surface and groundwater return flows recharges aquifers. These net withdrawals are related but not equivalent to depletion. Depletion is the medium- or long-term reduction in available groundwater. According to Wada et al. (2010), approximately 283 (±40) km\(^3\) of groundwater was depleted world-wide in 2000 – equivalent to nearly 40\% of the total volume abstracted that year. Approximately 31 km\(^3\) of depleted groundwater has been mined from non-recharging aquifers (Margat and van der Gun 2013).

There is a dearth of empirical data on transboundary groundwater resources, which again comes mostly from model-derived estimations. Nevertheless, there are several regional trends emerging from the analysis of surface water and groundwater consumption from 1979 to 2010 (Wada et al. 2013). In Europe, approximately 30\% of all water consumption is groundwater and this has between steady over time. In North and Central America groundwater is 60-70\% of all consumptive water use, representing a 40\% increase over the last 30 years. In West Asia, groundwater constitutes over 70\% of water withdrawals, having tripled in the last 30 years and now accounts for 96\% of groundwater mining, because of a lack of renewable groundwater resources.

Eight percent of known transboundary aquifers (TBAs) are experiencing reduced volumes of natural groundwater discharge and or groundwater depletion/mining due to human uses (Wada and Heinrich 2013). For example, irrigation schemes within TBAs crossing the US-Mexican and Indian-Pakistani borders have increased pressure on the underlying aquifers (see Map 1.1). In transboundary aquifers not yet experiencing depletion, population growth and increases in food demand exacerbate the pressure put on these resources. In many West Asian and North African TBAs, often the depletion depicted in Map 1.1 is due to lack of recharge. Thus, governance implications in arid groundwater-dependent countries are slightly different than in others (see 3.6). Map 1.1 also shows relatively low depletion in Southern Africa. However, this may or may not reflect the actual situation due to models’ limitations, as discussed above.

At the national level, groundwater data from in-situ monitoring or geophysical measurements are more readily available and frequently assessed, sometimes with national or sub-national scale models. Map 1.2 shows the areas experiencing groundwater depletion and highlights key cases: (1) where populations are highly dependent on groundwater for drinking water supply and/or food production; (2) where there is a dependency on non-recharging groundwater resources, and/or (3) where a country is experiencing rapid economic growth. It also indicates that most groundwater depletion is occurring in a few ‘hot spots’ shown by the red areas in Map 1.2.

1.2.2 Groundwater Quality Degradation

Generally, groundwater is of high-quality and does not require intense treatment before use. For example, in Canada, approximately 30\% of groundwater only requires disinfection before being used for potable supply and another 17\% requires no treatment at all (Statistics Canada 2011). In Denmark, groundwater only receives mild oxygenation treatment before use (Hasler et al. 2005). In contrast, there are some locations -

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\(^2\) Models are based on different assumptions and use varying parameters. They also use proxy data and incomplete data sets (United Nations Environment Programme and Global Environmental Alert Service 2012).
Map 1.1 Groundwater Depletion and Population Density in Transboundary Aquifers

**Legend**

<table>
<thead>
<tr>
<th>Groundwater Depletion (mm per year)</th>
<th>Population Density* (population per sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>&lt;100</td>
</tr>
<tr>
<td>1 - 100</td>
<td>101 - 500</td>
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<tr>
<td>101 - 200</td>
<td>501 - 1,000</td>
</tr>
<tr>
<td>201 - 500</td>
<td>1,001 - 10,000</td>
</tr>
<tr>
<td>501 - 953</td>
<td>&gt;10,000</td>
</tr>
</tbody>
</table>

*Population projections for 2015  Source: Depletion Data - Wada et al. (2010); Population Data - (CIESIN et al. 2005)
where the geological and climatic conditions result in the presence of geogenic contamination (sometimes all referred to as ‘naturally-occurring’ contamination). Some of these compounds are hazardous to human health (i.e. arsenic, fluoride, and salts). They vary in concentration as a result of human activities e.g. over abstraction or natural influences such as the depth and chemical properties of the groundwater including acidity and temperature (Feenstra et al. 2007). Consequently, intensive treatment is required to remove the compounds prior to human consumption.

The occurrence of arsenic in groundwater is well-known and researched, as are the associated repercussions for health. Arsenic is carcinogenic and long-term exposure through food and/or drinking water can result in skin lesions, developmental defects, heart disease and neurotoxicity (World Health Organization 2012). Countries with high risk of geogenic arsenic pollution include Bangladesh, China and Thailand (Map 1.5). In high concentrations, fluoride ingestion can also result in negative health impacts. The most common of these is skeletal and dental fluorosis, which hardens bones, ligaments and cartilage and also discolors tooth enamel. Hot spots for fluoridated groundwater include the Horn of Africa, the Andes, and many archipelagos. Algeria, China, Eritrea, Ethiopia, Kenya, Mali, and Sudan all have a high probability of fluoride occurrence (Feenstra et al. 2007).

The effects of saline water on human health are not well known. However, irrigating crops with saline groundwater has detrimental effects on yields. Over-abstraction, irrigation, waste and wastewater disposal, coastal protection and land reclamation can lead to increases in groundwater salinity. Numerous coastal areas across the globe have saline groundwater as a result of salt water intrusion caused by sea-level rise associated with climate change and/or over-abstraction of the groundwater resource. There are also many deep saline aquifers that were formed when ocean water was trapped under sediments during geological processes.

Documentation of anthropogenic groundwater pollution began over 40 years ago in developed countries and about 25 years ago in less-developed countries. It shows that the amount of polluted groundwater and the number of pollutants therein is generally increasing although the potential health effects are poorly-understood. Anthropogenic contamination can enter groundwater via point sources, line sources, and diffuse pollution. The most easily observed and frequently scrutinized are point sources, such as industrial sites. However, line sources like roadways and pipelines as well as diffuse sources like agriculture have also significantly contributed to contamination. Some studies have also investigated specific types of contamination like emerging organic contaminants (EOCs) originating from human and veterinary medicines, food additives, industrial compounds, caffeine, nicotine, and synthetic hormones (Lapworth et al. 2012). However, there are no global assessments of anthropogenic groundwater pollution to date.

Although groundwater quality is influenced by processes occurring at multiple geographical levels, it is difficult to simulate groundwater quality globally. This is because the actual occurrence of groundwater pollution is often localized, wherein specific portions of aquifers are contaminated while others are not. Therefore, many efforts to map quality in regions rather than specific aquifers use risk rather than empirically measured quality. Additionally, groundwater quality mapping is typically limited to the top most groundwater formation and presents quality data in absolute terms. Thus, these global quality maps do not necessarily indicate how the current quality of the resource differs from the natural composition of the groundwater. This is likely because baseline water quality data are not available at the global level due to the absence of a global groundwater monitoring system. Developing such a global network faces significant challenges because many countries, both developed and developing, lack financial and/or technical capacity (Foster, Hirata, et al. 2013).

Known occurrences of regional level contamination are typically geogenic rather than anthropogenic in origin. Nevertheless, arid regions with shallow groundwater tables are vulnerable to contamination from concentrated wastewater discharges that are not diluted by surface waters. At the transboundary level, there are several aquifers with geogenic (natural) and/or anthropogenic groundwater quality problems (see Map 1.3 and Map 1.4). Examples of transboundary aquifers which suffer from anthropogenic pollution include the
Abbotsford-Sumas aquifer, which has been severely contaminated by nitrate pollution from agriculture (Norman and Melious 2004); the Dinaric Karst Transboundary Aquifer System, which faces quality issues related to discharge of untreated wastewater (Governments of Albania, Bosnia & Herzegovina, Croatia, and Montenegro 2011); and the Ramotswa Aquifer, which has been polluted as a result of various anthropogenic activities (British Geologic Survey and Wellfield Consulting Services 2011).

At the national level, mobilization of natural contaminants is also a pervasive issue that limits countries’ ability to take advantage of their groundwater supply. As information on Fluoride and Arsenic contamination is best-documented, the countries dealing with these natural contaminants are shown in Map 1.5 further below. Salinity contamination (and other natural contaminants) is also shown in Map 1.5. The map indicates that most countries have one or more types of natural groundwater contamination in some (but not necessarily all) of their groundwater resources. A mixture of coastal and inland countries also face salinity problems (e.g. Brazil and Botswana). Further, several countries (e.g. India and China) are at risk of all three types of contamination. However, they do not necessarily occur concurrently in the same geographic area.

There are also numerous countries with numerous reported instances of anthropogenic contamination (International Groundwater Resources Assessment Centre 2015). Map 1.6 shows the presence of anthropogenic pollution by country and Table 1.1 lists the countries facing the most severe anthropogenic contamination challenges in groundwater.

<table>
<thead>
<tr>
<th>COUNTRIES WITH MANY REPORTED INCIDENCES OF GROUNDWATER POLLUTION</th>
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<tbody>
<tr>
<td>Brazil</td>
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<td>Ethiopia</td>
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<td>Haiti</td>
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<td>Kazakhstan</td>
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<td>Luxembourg</td>
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<td>Mexico</td>
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<td>Nicaragua</td>
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<td>Slovenia</td>
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<td>Syria</td>
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<tr>
<td>United States</td>
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<tr>
<td>Uzbekistan</td>
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</tbody>
</table>

Note: Reproduced with the permission of IGRAC.

### 1.2.3 ‘Glocalization’

‘Glocal’ refers to the connection between problems that are simultaneously global and local (Gupta et al. 2013). Thus, glocalization refers to the processes by which groundwater problems are becoming glocal. Climate change and trade are the primary contributors to glocalization.

Climate change is both global and local because it can cause global phenomena that compound the effects of local anthropogenic activities on groundwater resources and, at the same time, local groundwater use can enhance the global effects of climate change. The link between groundwater and climate change is explicitly acknowledged in the fifth Intergovernmental Panel on Climate Change (IPCC) report (Jiménez Cisneros et al. 2014). With respect to the global phenomenon having local effects, modeling scenarios have clearly linked ocean/atmospheric circulation with groundwater levels and recharge (Green et al. 2011; Kløve et al. 2014). Although groundwater is considered a natural buffer against climate variability, there are predicted fluctuations in recharge and flow, correlated with changes in precipitation as well as timing and volume of snow melt (Green et al. 2011; Kløve et al. 2014). Humans will experience shifts in groundwater availability with respect to time and volume potentially requiring changes to agricultural practices and necessitating...
Map 1.3 Presence of Geogenic Pollution in Transboundary Aquifers

Legend:
- Arsenic
- Salinity
- Fluoride
- Arsenic and Fluoride
- Arsenic and Salinity
- Fluoride and Salinity
- All Types of Pollution
- No Data

*This map uses solid colors to ensure the visibility of small transboundary aquifers.

Note: Arsenic and Fluoride are mapped according to risk of pollution based on the characteristics of the geologic formation. Salinity is actual observed occurrence in groundwater resources. For all of these pollutants, the map indicates where there is risk or occurrence within part of the transboundary aquifer or one of the layers of the aquifer system. It is not necessarily aquifer-wide. Source: IGRAC GGIS 2015
Map 1.4. Presence of anthropogenic pollution in transboundary aquifers.
Map 1.5 Presence of Geogenic Pollution in Countries

Legend:
- All Geogenic Pollutants
- Aseptic and Salty
- Salty
- Aseptic
- Salty and Fluoride
- Fluoride
- Aseptic and Fluoride

Note: Aseptic and Fluoride are merged according to their occurrence. The map indicates regions where at least one type of pollution is present. The occurrence within parts of the country is not necessarily country-wide.

Source: IERAC GEIS 2015
Map 16 Presence of Anthropogenic Pollution by Country
conservation or water storage. Projections for high and low emission scenarios show that climate change will result in a loss of fresh groundwater in all regions other than North Africa (Priyantha Ranjan et al. 2006).

In terms of local activities exacerbating the effects of climate change, groundwater pumping and its subsequent overland discharge has contributed to a 12.6 mm sea-level rise between 1900 and 2008 (Konikow 2011) with 0.57 mm (±0.9 mm) per annum contribution from groundwater discharge as of 2000 (Wada et al. 2012). Groundwater discharge is also expected to make significant contributions to sea-level rise in the next 45 years. Although groundwater extraction contributes to sea-level rise (see 3.5.2), the integrity of groundwater resources can also be threatened by it, due to increases in salt water intrusion, resulting in a positive feedback loop that negatively effects groundwater quality. However, other local activities such as managed aquifer recharge (MAR), carbon sequestration, and use of geothermal energy resources can reduce climate change effects. Under certain circumstance MAR would enhance groundwater recharge and potentially alleviate the need to pump groundwater from high depths or to transfer surface water over long distances, both of which are energy intensive activities. Deep saline aquifers are also being used in certain locations to reduce atmospheric concentration of Carbon Dioxide (CO$_2$). And where available, geothermal energy (e.g. energy derived from thermal groundwater) could be an alternative to carbon-based forms of energy.

Consumptive uses of groundwater play a critical role in economic activities around the globe, in particular energy and food production. These activities not only have the potential to affect the quality and quantity of available groundwater resources, but also give groundwater a central role within global, regional and national economic systems. Research on ‘virtual water’ (i.e. the concept that water is traded as part of agricultural and industrial products) has shown that water is increasingly becoming a global resource through processes of globalization (Dalin et al. 2012; Hoekstra and Hung 2002; Vörösmarty et al. 2015). Yet, to date, virtual water studies do not explicitly articulate the role of groundwater, although it is marginally included in the Lenzen et al. (2013) analysis of international trade of scarce water resources.

1.3 GAPS IN GROUNDWATER GOVERNANCE KNOWLEDGE: A SYSTEMATIC LITERATURE REVIEW

This section discusses the definitions of groundwater governance in existing literature. Then, I discuss the existing hydrogeology and groundwater governance literature. Based on this literature, I articulate four knowledge gaps: (1) hydrogeology literature is poorly integrated into groundwater governance literature; (2) groundwater governance literature does not take into account the multilevel perspective; (3) groundwater governance literature does not discuss the full range of groundwater governance principles nor does it discuss the principles in relation to the drivers of groundwater problems; (4) groundwater governance literature focuses on the political, environmental, social, economics and dimensions individually, but not through a sustainability approach (i.e. addressing the four dimensions simultaneously) or an inclusive approach (i.e. prioritizing the poor and focusing on the social, environmental and redistributive dimensions).

1.3.1 Emerging Definitions of Groundwater Governance

Before defining groundwater governance, I explain how this research understands the term ‘governance.’ Governance definitions relate to one or more of three broad characteristics: the relationships/processes of governance (e.g. interactive or participatory governance); the elements/actors in governance (e.g. adaptive or corporate governance); or the location/subject of governance (e.g. climate or meta- governance). One key commonality in the definitions is the juxtaposition of government and governance. Whereas government is state-centered, hierarchical and reliant upon a top-down power structure, governance includes multiple pathways and actors functioning across hierarchical levels and space, thus having a ‘flattening’ effect on the structure (Bevir 2011; Chandhoke 2003). I use the governance concept because it puts law and policies derived from governments into their broader socio-economic context and it captures instances of coordination that occur with relatively little or no influence of the government. With this understanding, this section discusses emerging definitions of groundwater governance.
The concept of groundwater governance is still being defined and refined. Initially, ‘water governance’ was considered to include and be equally applicable to groundwater (Varady et al. 2012), also within expositions of the Integrated Water Resources Management (IWRM) discourse (Agarwal et al. 2000). However, by the early 2000’s, it became clear that neither the water governance nor IWRM discourses were taking groundwater-specific problems into account analytically or empirically. At this time, groundwater governance began to develop firmer conceptual boundaries. Four broad tenets for groundwater governance (i.e. transparency, participation, information, and the custom and rule of law) were posed, but no explicit definition was given (Saunier and Meganck 2012: 159). Notably, these tenants are very close to those discussed in the normative discourse on “good” water governance (Rogers and Hall 2013). Shortly thereafter, groundwater specific governance literature began to emerge, mostly focusing on difficulties with governing over-exploitation and pollution in specific contexts (Braune and Xu 2009; Foster and Ait-Kadi 2012; Giordano and Shah 2014; Wester et al. 2009; Wiek and Larson 2012).

Currently, social science, legal and hydrogeology literature offer related but different articulations of groundwater governance. In hydrogeology literature, groundwater governance is described as a societal phenomenon rather than as an analytical concept. One example states that groundwater governance is “focused on the exercise of appropriate authority and promotion of responsible collective action to ensure sustainable and efficient utilization of groundwater resources for the benefit of humankind and dependent ecosystems” (Foster, Garduño, Tuinhof, & Tovey, 2009:1). A later “working definition” from social scientists defines groundwater governance as “the process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels—one of which may be global” (Varady et al., 2013:7). Further development of this working definition says that groundwater governance is “the overarching framework of groundwater use laws, regulations, and customs, as well as the processes of engaging the public sector, the private sector, and civil society” that “shapes how groundwater resources are managed and how aquifers are used” (Megdal, Gerlak, Varady, & Huang, 2015:678). This most recent definition will be used in this research as it emphasizes governance as a framework, while still including the process and multi-stakeholder dimensions that are critical components to the governance concept. Yet the normative aspects (Saunier and Meganck 2007), the focus on benefits to humankind and ecosystems (Foster, Garduño, Tuinhof, & Tovey, 2009:1), as well as the multilevel aspects (Varady et al. 2013) included in previous definitions are also integral to this analysis.

Despite the progressive developments of the groundwater governance definition, the broader water governance and environmental governance literature engages with groundwater governance issues implicitly rather than explicitly. Generally, groundwater is implicitly viewed as an extension of surface water and it is assumed that governance frameworks for surface water can and should equally apply to it (see 3.6). The lack of consideration for groundwater is readily apparent, when examining the literature focused on frameworks for water governance.

1.3.2 State and Foci of Groundwater Governance

Groundwater governance is still in its infancy, both theoretically and empirically. The ungoverned overexploitation of groundwater resources, particularly with reference to Spain, has been called a ‘silent revolution’ (M. R. Llamas and Martinez-Santos 2005). Groundwater governance in South Asia is considered a “colossal anarchy” (Mukherji and Shah 2005: 336), but the South Asian situation has also been considered representative of the global state of groundwater governance (Giordano 2009). But even in “anarchy,” it is likely that some type of governance is at work (Nuijten 2004).

There are few laws and policies relevant to groundwater resources and only a small subset of those deal with groundwater holistically as opposed to targeting a specific problem (e.g. quality) or use (e.g. drinking water). At the global level, there are two water conventions in force, which include groundwater resources in their
scope and one groundwater-specific text that is drafted, but has yet to be adopted by UN member states (see 5.2). At the regional and transboundary levels, there are four regional agreements and 22 transboundary water resources (aquifers, lakes, rivers) with governance frameworks (see 6.2) that have a bearing on groundwater resources. Of the 193 UN member states, 140 have national-level laws applicable to groundwater resources (see 7.2). The total number of local groundwater governance frameworks has not been ascertained, although they are likely the most prolific. This is in sharp contrast to surface water governance where not only were the two aforementioned global agreements designed primarily to deal with the surface water, but there are also more than 3,600 transboundary legal agreements dealing with surface water-related issues (approximately 15% of which focused on non-navigational uses of rivers Oregon State University 2015) and nearly all countries with some form of surface water law. This shows that from an empirical perspective, groundwater is often overlooked in broader water governance frameworks and that there are few groundwater governance frameworks beyond the local level (Linton and Brooks 2011). Further, it implies that the development of norms and legal principles specific to groundwater are only in the beginning stages and may not yet be validated with research regarding the consequences of their implementation.

Literature assessing these groundwater governance frameworks has developed different foci at each geographic level: global, regional-transboundary, national and local. At the global level, literature has focused on legal analysis of the principles included in the 1992 UN Watercourses Convention and the International Law Commission’s Draft Articles on the Law of Transboundary Aquifers, particularly those relating to sovereignty and ‘equitable and reasonable use’ (i.e. allocation of (ground)water resources between states). As such, the key norms put forth in this literature are equity and cooperation. Further, this literature indicates that global-level agreements applicable to transboundary aquifers do not have a unified approach to limiting national sovereignty over groundwater resources (Conti and Gupta 2014; Dellapenna 2011; Eckstein and Hardberger 2008; Linton and Brooks 2011; McCaffrey 2009, 2011; Mechlem 2011; Yamada 2011). It also shows that equity (or the perception) of equity is an important factor in preventing transboundary water conflict, but is difficult to operationalize in terms of legal principles and their implementation (de Stefano et al. 2010; Lautze and Giordano 2006; McIntyre 2013). Nevertheless, there are numerous principles included in these two agreements and other agreements relevant to groundwater that have hardly received attention in the literature. A detailed discussion of governance principles for global groundwater governance is provided in Chapter 4.

At the regional-transboundary level, most groundwater governance frameworks are not holistic in scope, sometimes indicate equity and cooperation as the desired norms, and remain either un-ratified or are not legally binding upon the parties (Eckstein and Sindico 2014; Mechlem 2011). Legal literature centers around five transboundary aquifers with binding legal agreements. However, legal scholars tend to neglect the transboundary groundwater resources with informal or uncodified practices that may also constitute groundwater governance. Based on the growing literature on transboundary water interactions (Mirmachi and Allan 2007; Zeitoun et al. 2010; Zeitoun and Mirmachi 2008), a focus on interactions between relevant actors rather than a specific type of outcome (e.g. legal agreement) can broaden the spectrum of available examples of transboundary groundwater governance (Conti 2014).

At the national level, lawyers have proposed design frameworks for national (ground)water laws, which include specific principles necessary for groundwater governance (Caponera 2007; Tarlock 1985). They have also addressed different types of groundwater rights and allocation regimes and their impact on resource sustainability (Chandrakanth and Romm 1990; Emel 1987). Anthropologists have investigated customary water law (namely, non-codified water governance practices at the community level) and how these local frameworks interact with codified national frameworks (Boelens 2009), but investigations specific to groundwater are limited (e.g. Prakash and Ballabh 2005). Scholars in political economy and public policy have assessed how stakeholder-selected policy principles can impact resource governance in the context of common-pool resources management (Blomquist and Ostrom 1985; Ostrom 1990) and how non-groundwater policies (e.g. agricultural energy subsidies) can impact local groundwater management (Mukherji and Shah 2005).
Global water governance has been characterized as a “mobius-web” system that is multilevel and influenced by “formal and informal processes” (Pahl-Wostl et al. 2008). Consequently, broader water governance literature uses multilevel analysis (Gupta and Pahl-Wostl 2013; Moss and Newig 2010; Newig and Fritsch 2009); however, it includes groundwater cursorily rather than analytically so the differences between groundwater resources/problems and surface water resources/problems are not thoroughly considered. Groundwater governance literature has scarcely addressed the multilevel aspects and only selectively discusses the relationships between principles across geographic levels, although it has been done for ecosystems services and adaptive management within water governance (Knüppe and Pahl-Wostl 2013). Legal analysis has been performed on a subset of the available groundwater governance frameworks and only on a few principles. However, the level of coherence among the principles used within and across these existing frameworks has not been addressed. In a few specific case studies, the influence of frameworks at other levels is analytically integrated but inclusion of groundwater is limited (e.g. Finger et al. 2006; Norman and Bakker 2009).

### 1.3.3 Relationship between Hydrogeology and Groundwater Governance Research

Both hydrogeology and groundwater governance literature are developing rapidly. However, these developments are largely disconnected from each other. The maxim “You can’t manage what you don’t measure” is commonly linked with groundwater governance problems; the presupposition being that to govern a natural resource sustainably and inclusively it is imperative that the resource itself is adequately characterized in terms of its physical properties and dynamics. Hydrogeologists have analyzed the structure, function, and vulnerabilities of groundwater resources (e.g. Domenico and Schwartz 1998; Fitts 2002; Margat and van der Gun 2013), with a particular concern for preventing degradation of the resources themselves and related ecosystems. Various technical approaches for depletion prevention have been analyzed and utilized for the last 40 years (Kalf and Woolley 2005; Sophocleous 2000; Zhou 2009). The primary objective of these approaches is to ensure that long-term abstraction volumes do not exceed long-term replenishment and that abstractions do not change the physical properties of the geological formation storing the groundwater. There is also increasing knowledge about how groundwater resources and related ecosystems respond to pollution and depletion (see Chapter 3). Within the last decade, literature also indicates that hydrogeologists are moving towards using “groundwater sustainability” (Gleeson, VanderSteen, et al. 2010), as opposed to previous concepts such as “safe yield” (i.e. not pumping more than is recharged, see Zhou 2009), as the guiding principle for groundwater development.

These hydrogeological analyses are typically conducted at the resource scale; are designed to improve day-to-day groundwater management; and rely on proxies, rather than empirical data. It is also worth noting that much of the data presented here regarding groundwater problems are derived from models that are to a limited extent calibrated with empirical data. This highlights an issue underlying the groundwater resource problem, which is a lack of data at different scales and levels to fully and accurately assess the nature of the problem. This challenge will be a recurring point of reflection in this research. Despite a lack of empirical data, hydrogeologists have also proposed benchmarking sustainability strategies (Foster and Garduño 2012; Gleeson et al. 2012; Gleeson, VanderSteen, et al. 2010) and issue linkages (van der Gun et al. 2016) for enhancing groundwater governance. Common pool resources and political economy centered approaches to governance have also been recommended (Foster, Chilton, et al. 2013; Foster and Garduño 2012). Outside of academia, the World Bank GW-MATE Programme, the International Association of Hydrogeologists, the UNESCO International Hydrological Programme (UNESCO-IHP), and the International Groundwater Resources Assessment Centre (IGRAC) have made efforts to bring hydrogeologists’ knowledge into governance and policy making through various grey literature publications including ‘strategic overviews’, briefing notes, case studies, and position papers.

Similarly, groundwater governance literature has not given detailed attention to the hydrogeological characteristics of groundwater. To date, groundwater governance literature has focused on the legal and/or regulatory challenges at specific geographic levels or locations; specific principles for governance; or the
environmental, social, or economic aspects of groundwater governance (see 1.3). As mentioned above, the normative focus has thus far been on equity and cooperation in transboundary cooperation with lesser attention to holistic sustainability from a socio-ecological perspective. Groundwater governance literature has also discussed challenges with respect to defining and identifying typologies of groundwater resources that are useful for governance (Eckstein 2005; Jarvis 2014; Mechlem 2011). Further, a close read of groundwater governance literature often elucidates a cursory understanding of resource dynamics with inaccurate or imprecise use of groundwater terminology – the terms fossil aquifer, confined and unconfined aquifer being examples of this (see 1.3.3). This indicates a definitional issue in groundwater governance and the associated literature, where groundwater resources are defined in multiple ways that may not have direct links to hydrogeological definitions and knowledge. However, these definitions form the foundation of a given governance framework, determining which guiding principles, rights, and measures might be included.

Within the last 15 years, there have been several efforts to rigorously integrate hydrogeology, law and social sciences empirically. The 2004 ILA Berlin Rules and the 2008 ILC Draft Articles included hydrogeologists in their drafting processes. While some legal scholars have since debated these governance texts on their legal-technical merits (see 5.2), others have focused on their contents and used hydro(geo)logy to develop a nuanced understanding of the emerging law of transboundary aquifers (Aureli and Eckstein 2011; Eckstein and Eckstein 2005). Further, the Global Environment Facility’s (GEF) transdisciplinary Groundwater Governance Project (2011-2013) sought to consolidate groundwater knowledge from across the world and develop a ‘framework for action.’ Much of the project’s results are grey literature reports, but publications of some results in peer-reviewed journals is expected. Also, the (groundwater) economics and political economy fields are increasingly integrating hydrogeological data into their economic models (Faisal et al. 1997; Guilfoos et al. 2013; Katic and Grafton 2012).

At present, scholarship on groundwater resources science, namely hydrogeology, and scholarship on groundwater governance have only weak linkages. Of the hydrogeology-focused literature that discusses governance issues used in this literature review, only two papers refer to social sciences literature (Dumont 2013; Foster and Garduño 2012). And of the social sciences and legal literature that discusses groundwater resources, hydrogeology literature is only referenced nine times (Baldwin et al. 2012; Eckstein and Eckstein 2005; Feitelson 2005; Knüppel and Pahl-Wostl 2011; Mechlem 2011; Mukherji and Shah 2005; Sugg et al. 2015; Wester et al. 2009). Nevertheless, there is potential convergence from both fields around sustainability as a key objective/norm (see 1.3.5)

1.3.4 Depth of Research on the Drivers of Groundwater Problems

As of yet, there is no complete picture of whether groundwater governance appropriately addresses the causes of groundwater problems through its governance principles (see 3.2). This is because the literature has not comprehensively surveyed or analyzed the human causes of groundwater problems, how these problems may shift in the future, nor how the content of (ground)water laws addresses the root causes of groundwater problems.

To some extent, hydrogeology literature discusses the human causes of groundwater problems (such as agricultural or drinking water supply expansion) in specific case studies. Literature on cases from India, China, Indonesia and Mexico, among others, are summarized in a publication series from the World Bank GW-MATE Program and the International Association of Hydrogeologists. However, as a result of the limited elaboration of the driving mechanisms causing the problematic activity, technocratic end-of-pipe solutions are still the norm (e.g. Girman et al. 2007). In environmental literature, the use of the Drivers, Pressures, States, Impacts, Responses (DPSIR) model led to a focus on drivers (e.g. Levy et al. 2012; discussed further in Chapter 8). In governance literature, these driving mechanisms often remain a point of reflection rather than a central element of the analysis. Common pool resources (CPR) literature tends to investigate drivers in greater detail than others and has highlighted the importance of identifying behavioral drivers, especially economic considerations, in groundwater governance (Burness and Brill 2001; Lopez-
Gunn 2003; López-Gunn 2012; Ostrom 1990; Wester et al. 2009). Institutional analysis (Young et al. 2005) made these drivers a central issue. However, actual applications have yet to be implemented in the groundwater fields.

The literature also neglects how these may intensify or shift in the medium and long-term. Future challenges are related to uncertainties regarding the dynamics of the physical resources, demographic shifts, as well as economic and technological developments. From the physical perspective, challenges include increased water stress, degradation of groundwater-related ecosystems, and the potential effects of climate change (see 3.2). While many deeper groundwater resources are not significantly affected by climate change (Jiménez Cisneros et al. 2014), the rates of groundwater extraction and pollution are increasing rapidly (see 1.2). As greater pressures are put on surface water resources due to widespread changes in demographic shifts and global change, groundwater will become the resource of last resort. Population growth, urban migration, and displacement due to natural, economic, and political disasters will alter patterns and intensity of groundwater use. Economic and technical developments – including industrial uses, trade of groundwater-intensive products, improved groundwater technologies that allow deeper drilling, and more demand for geothermal energy will increase the potential for groundwater depletion and pollution.

Legal literature often discusses the content of ground(water) laws and the provisions therein from a legal positivist perspective focusing on their legal status (i.e. are they binding, customary, emerging, disputed? – see Eckstein and Sindicó 2014; Kliot et al. 2001; McIntyre 2006; Rieu-Clarke et al. 2012; Tanzi 2011); the intrinsic validity of principles (i.e. can equity truly be considered a principle? – see McIntyre 2012; Rieu-Clarke 2000), and the operationalization of principles (i.e. how would one achieve equitable and reasonable use? – see Tanzi 2010; Wouters et al. 2005). As such, historical legal accounts and jurisprudence play a key role in the analysis. However, further reaching aspects of the law, its function in governance, and its role in achieving broader policy goals is rarely discussed in the context of groundwater (see Spijkers 2016 r.e. the SDGs).

An additional limitation in legal literature is that it generally targets the symptoms of groundwater problems as opposed to the causes. For example, legal literature suggests adjusting groundwater rights to prevent depletion, as discussed above. However, if depletion is driven by social and economic inequities in allocation which are further solidified by rights regimes or economic incentives, the legal measure will not alleviate the problem (see India example, Box 3.3).

Few researchers have made the necessary links between these drivers and the institutions available to address them (see 3.2). While understanding the specific motivations of actors at specific locations is perhaps one determinant of the ‘success’ of a particular groundwater governance framework, taking a glocal approach to driver identification can also help understand whether the existing institutional frameworks are sufficient to address these drivers or if new frameworks should be considered (see 2.4). Consequently, Chapter 3 discusses drivers of groundwater problems; Chapter 4 discusses groundwater governance principles; and the links between them are considered by geographic level in Chapters 5-8.

1.3.5 Aspects of Sustainable and/or Inclusive Development in Groundwater Governance Research

Groundwater governance literature tends to focus on environmental, social and economic dimensions of sustainable development individually, notwithstanding overlapping research areas such as the valuation of ecosystem services for enhanced policy outcomes. As discussed above, there is a limited but growing literature presenting sustainable development as a key norm or objective for groundwater resources development and groundwater governance. The literature does not discuss groundwater governance through a sustainability approach, in which political, environmental, social, and economic aspects would be considered simultaneously. Situating groundwater governance within a sustainability approach has the potential to bring a unifying and cohesive element to its frameworks – especially taking into consideration what we know about
planetary boundaries (Rockström et al. 2009; Rockström and Karlberg 2010) and the need to operate within them in an ecologically safe and socio-economically just way (Raworth 2012, 2013).

From the environmental perspective, the state of hydrogeological literature is theoretically advanced but suffers from a lack of empirical data and remains separated from hydrology and ecosystems literature, with a few exceptions in wetlands sciences. A few researchers have addressed the ecosystems services of groundwater from an environmental perspective (Bergkamp and Cross 2006; Boulton et al. 2008; Herman et al. 2001), the economic perspective of ecosystems services values (Katic and Grafton 2012; Qureshi et al. 2012; Rolfe 2010) and accounting for their implications for social sciences (Hayat and Gupta 2016). The literature shows that accounting for the ecosystems services of groundwater in decision-making has significant benefits for policy outcomes (Guilfoos et al. 2013; Katic and Grafton 2012). But, the value that groundwater provides when it is still in the ground (e.g. buffering against drought/climate variability and attenuating pollutants) is not often considered. One study of the Israeli-Palestinian transboundary aquifer’s capacity to buffer surface water scarcity estimated that it is up to 84% of the groundwater’s total economic value (Koundouri 2004; Tsur and Graham-Tomasi 1991). Further, ecosystem damages resulting from groundwater depletion have been shown to significantly reduce benefits to farming communities in the Western and Eastern La Mancha Aquifers of Spain (Esteban and Albiac 2011).

With respect to the social dimension, the human rights discourse has been the primary contributor to the literature regarding the social aspects of groundwater governance. To date there are various assessments of how the human right to water and sanitation and rights of women, children and indigenous peoples link to water governance more broadly and to other institutional frameworks (Bluemel 2004; Gleick 1998; Gupta et al. 2010; Lambooy 2011; McCaffrey 1992; Mirosa and Harris 2012; Obani and Gupta 2015; Ziganshina 2008). Yet very few of the assessments take groundwater into account or look at the specific challenges posed by and to groundwater (e.g. Gavoueli 2011). Evaluations of rural water supply come closest to analyzing these issues but tend to be technocratic in focus – looking at issues of well or hand pump failure (MacDonald and Calow 2009; Macdonald and Davies 2000) – but minimally considering the impacts that technology may have on the relevant societies, an exception being Gleitsmann and others (2007). To this end, it is important to recognize that there are still many areas where groundwater resources are vastly underutilized and accessed and could provide significant socio-economic support to communities with proper policy and financial support (Giordano 2009).

The existing research related to the economic aspects of the groundwater governance focuses on CPR studies. The CPR discourse uses a political economy perspective to understand the economic factors behind behaviors that create and resolve groundwater problems, such as water pricing that internalizes the costs of externalities (Madani and Dinar 2012, 2013), as well as relational factors such as levels of cooperation or public trusteeship of groundwater (Sand 2004). Typically, CPR research is focused at the resource scale, so most investigations have been conducted at the subnational level although there are some at transboundary and national levels. Pioneered by Elinor Ostrom (1990) the application of CPR to groundwater resources has increased (Blomquist 1992; Gardner et al. 1997; Provencher and Burt 1993); and has been used primarily in the western United States and Spain (Burness and Brill 2001; Guilfoos et al. 2013; Lopez-Gunn and Cortina 2006).

Despite the link between environmental protection and economic benefit, neo-liberal philosophies have often left environmental considerations by the wayside. Much of the concern of the international community has been formulated around economic globalization rather than environmental or social issues (Paterson et al. 2003) and key actors, such as the World Trade Organization (WTO) have lagged behind in developing environmental policies (Conca 2000). This indicates that inclusion of the economically marginalized in groundwater governance has not been prominent in the economic literature thus far, with the exception of indirect links present in literature on rural water supply and agriculture. So, while access to water is a primary concern of legal scholars, the role of groundwater in enhancing socio-economic and distributive equity is not well-developed in groundwater governance literature.
Given that these dimensions have mostly been approached separately, groundwater governance has not been analyzed from a sustainable and/or inclusive development perspective. Since there has not been an overall characterization of existing groundwater governance frameworks and the principles therein, it also becomes difficult to ascertain whether these frameworks have the potential to support sustainable and inclusive development. Sustainable and inclusive development are increasingly becoming a key norm in the global governance discourse as can be seen in their adoption in the Sustainable Development Goals (UNGA 2015, also see 2.3). As such, understanding groundwater governance in this context is essential for averting severe resource degradation, deepening social inequity and economic disparity, and the potential for human conflict.

1.3.6 Implications for Research Approach

This overview of groundwater resources problems as well as knowledge gaps in hydrogeology and groundwater governance literature lead to four key implications for my research approach. (1) Groundwater resources problems are multi-level and in dynamic relationship to each other. As such, the range of potential scenarios and effects on groundwater from human activities need to be considered in governance institutions at all geographic levels. (2) The links between hydrogeology and governance need to be strengthened in governance research and policies (see Chapters 5-9). (3) But first, the drivers of groundwater problems need to be better elaborated and understood in order to ensure that groundwater governance institutions are structured to cope with them in a context-specific way (see 3.2). (4) Pursuing sustainability and emphasizing inclusiveness as norms and objectives for groundwater governance may provide a clear overarching framework through which nascent groundwater governance institutions may be designed to avoid inconsistency and fragmentation (see 2.3).

1.4 Research Question

1.4.1 Questions and Subquestions

This research responds to the question:

What are the shortcomings of the current normative architecture for sustainable and inclusive groundwater governance and what are the key elements of a normative architecture at multiple geographic levels that are consistent with sustainable and inclusive development?

The following sub-questions are also addressed: (1) How are hydrogeology, ecosystems services and the drivers of groundwater problems taken into account in the architectural design? (2) How have groundwater governance frameworks evolved at multiple geographic levels, from global to local? (3) Which groundwater governance principles have been included in these governance frameworks at multiple geographic levels? (4) How does legal pluralism manifest within and across multiple geographic levels? (5) How do the current designs of the normative architecture contribute to sustainable and inclusive development at multiple geographic levels? These questions are briefly elaborated below. They also link to the knowledge gaps (see 1.3).

How are hydrogeology, ecosystems services, and the drivers of groundwater problems taken into account?

This question lays the foundation for linking knowledge from the hydrogeological and social sciences literature and identifying the drivers of groundwater problems. It allows for linking natural sciences understandings of groundwater resources to the problems of groundwater governance understandings. Through literature review this research identifies the drivers of groundwater problems and links them to the key hydrogeological dynamics of groundwater resources and the resulting effects on ecosystems services.

How have groundwater governance frameworks evolved at multiple geographic levels, from global to local?

This question addresses, to some extent, the problem of the geographically siloed groundwater governance literature by looking at governance both within and across the relevant levels. To address this question, I analyze the evolution of existing groundwater governance frameworks (meaning a set of laws, policies, and programs applicable to a single jurisdiction) at each geographic level. In doing so, this research shows the
progression in the purposes for which specific groundwater governance frameworks at each level were designed.

*Which groundwater governance principles have been included in these governance frameworks at multiple geographic levels?* This question uses findings from the previous question regarding the evolution of groundwater governance to identify and explore relationships between the governance principles and sustainable development. This question facilitates analysis of the dominant architectural characteristics of each of the governance frameworks. Using content analysis and descriptive statistics, I show which principles are included in specific frameworks and how they are related to the dimensions of sustainable development.

*How does legal pluralism manifest within and across geographic levels?* This question builds upon the previous questions regarding the evolution of individual governance frameworks and the principles they contain to analyze how these frameworks may vary in a given location and how this relates to sustainable development. By operationalizing the legal pluralism concept, the analysis reveals whether aspects of the governance framework are indifferent, conflicting, accommodating, or supporting each. Spatial visualizations with a Geographic Information System (GIS) support the identification and elaboration of the consequences of legal pluralism at the various geographic levels.

*How do the current designs of the normative architecture contribute to sustainable and inclusive development at multiple geographic levels?* This question links together each of the previous sub-questions by relating sustainable and inclusive development to the drivers of groundwater problems, the evolution of groundwater governance, principles included within a given framework, and pluralism between frameworks. The response to this question considers how these elements can be adjusted or further supported to become consistent with sustainable and inclusive development.

### 1.4.2 Focus and Limits

This research presents a ‘big picture’ analysis of the current state of groundwater governance world-wide. I consider a big picture analysis both advantageous and innovative because it enables the established or emerging groundwater governance patterns to be traced and analyzed across geographic levels. This is relevant because of (a) the glocalization of groundwater resources; (b) the need to identify critical gaps in the groundwater governance framework, given its nascent state; and (c) the multilevel perspective needed to achieve sustainable and inclusive development. I am also able to focus on uncovering the key messages that are hidden within available data while having the necessary flexibility to eventually determine the core elements of a groundwater governance framework. However, a big picture approach may obscure context-specific detail. Therefore, I use a case study to draw these out for a particular transboundary groundwater resource, which has some attributes that may be generalizable to other groundwater resource. Section 10.7 includes further reflections on generalizability.

I focus on the normative content of laws (and to a much lesser extent policies and practices) relevant to groundwater through a content analysis approach. Focusing on content allows me to analyze a broader range of governance frameworks than in a legal positivist approach because traditional legal analysis may have excluded certain documents based on their lack of binding status. I study both ‘formal’ texts, such as global conventions, international treaties, and domestic laws, as well as ‘informal’ texts such as non-binding international policies, Memoranda of Understanding, ministerial declarations, and reports of project results with ministerial-level approval as well as uncodified groundwater governance practices. Content analysis also allows me to trace patterns in the frameworks’ principles and analyze the degree of their coherence and comprehensiveness. Thus, I can examine the design of the overall normative framework (and its parts) through the lens of sustainable and inclusive development by focusing on sustainable development as the synergy of the political, environmental, social, and economic dimensions and inclusive development as an emphasis on the political environmental, and social aspects.
My research also faced data limitations, which affected both its theoretical and methodological approaches. Significantly more data regarding groundwater governance would be required to accurately characterize how power influences the uptake of norms and principles world-wide (see 2.4). Additional facets of governance such as accountability, adaptiveness, actor agency, participation, and politics will not be addressed in-depth for the same reason.

Data was primarily collected in English and national laws and policies in Arabic, English, French, and Spanish were also evaluated; in some instances it was necessary to use unofficial translations. At the global, regional and transboundary levels as well as for the Stampriet case study, all three types of documents have been analyzed. At the national level, only water laws and codes have been assessed. Policy documents were used if they were the only groundwater or environmental governance text available. Other policy documents and declarations at the national level were not considered to be of sufficient influence to be included in the existing normative framework.

Also, many groundwater governance documents do not directly address issues of groundwater ownership, rights, the relationship between groundwater and land tenure, globalization and trade or trade laws. Rather these issues are addressed in other types of policy documents or perhaps not at all. Thus, the analysis is limited by the extent to which the groundwater governance documents’ content deals with this issue. As such, the potential for land ownership, water rights, and trade to affect power dynamics, result in disparities in access, and/or exacerbate environmental impacts and could not be thoroughly analyzed. Nevertheless, considerations about groundwater ownership and trade of groundwater-intensive produce are points of reflection throughout the analysis, particularly in the case study.

1.5 **Structure of Thesis**

Building upon this chapter’s framing of the problems, knowledge gaps, questions and methods, Chapter 2 articulates the theoretical underpinnings of the analysis of the groundwater governance frameworks and the resulting conceptual framework. In Chapter 3, I explore how an in-depth understanding of groundwater science (i.e. hydrogeology) can provide valuable insights for groundwater governance. Chapter 4 focuses on groundwater governance principles by identifying, defining, and describing them on their own, in relation to each other, and in relation to the drivers of groundwater problems. The following three chapters analyze and map the current state of groundwater governance at each geographic level: global in Chapter 5, regional-transboundary in Chapter 6, and national in Chapter 7. I then use the case study of the Stampriet Transboundary Aquifer System in Chapter 8 to understand how the evolution, actors, and principles of groundwater governance interact in practice and what consequence this has for the resource. Chapter 9 analyzes legal pluralism with respect to sustainable development across these geographic levels. Finally, Chapter 10 synthesizes the analysis and conclusions of the research and provides recommendations regarding how the groundwater governance framework can be adapted to further support sustainable and inclusive development. Annex A shows the logical framework used to development the thesis’ structure.