Tapping two sources: Farmers’ conjunctive use of groundwater and surface water in Northwest China

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List of Abbreviations

CNY = Chinese Yuan (renminbi)

CWIM survey = Chinese Water Institutions and Management survey

GASS = Gansu Academy of Social Sciences

GAU = Gansu University of Agriculture

IDB = Irrigation District Bureau

WUA = Water Users’ Association

General Introduction

Chinese farmers and scientists don't use the same words when talking about water resources. Chinese farmers literally say "water from the well" （井水）when they speak of groundwater. Referring to surface water they say "water from the river" （河水）or when the river is far away they rather say "water from the canal" （渠水）. Scientists on the other hand will use the terms "underground water" （地下水） or "on the ground surface water" （地表水）. While farmers are mostly occupied with the question how the water is conveyed to their land – either through a well or through a canal, scientists focus on the question how the water is stored. Eventually the largest challenge is to speak the same language and formulate scientific insights into policies and practices which match farmers' realities.

1.1 Background

1.1.1 The groundwater governance challenge

Societies have long focused their efforts on building canals to convey surface water from lakes and rivers to irrigate their land. However, since new technologies became available to mechanically drill wells and pump up water, groundwater irrigation spread rapidly. Worldwide the use of groundwater for agriculture grew from 100 km^3/year in 1950 to about 1000 km^3/year in 2000 (Shah et al. 2007). The access to groundwater meant a revolution particularly for small scale farmers, who could suddenly decide flexibly when to use water from their well and were no longer dependent on the irrigation bureaucracy managing the canal system or irregular rainfall (Giordano and Villholth 2007). China is one of the most important countries where the boom in groundwater use has led to agricultural intensification and increased income for smallholders (Shah et al. 2007 ; Wang et al. 2006). The development took off particularly in northern China where rainfall is scarce and extensive alluvial plains are underlain by high-storage aquifers. Currently at least five million wells are in use for irrigation purposes mainly located in northern China (Wang et al. 2009a). It is estimated that China's total annual groundwater withdrawal reaches 100 km^3/year, which makes China the third largest groundwater extracting country after India and the United States (Shah et al. 2007 ; Wada et al. 2010).

In China, like in most other countries, well drilling developed without much regulation by the state (Wang et al. 2007). The essentially "open access" to groundwater allowed farmers to increase their water security and/or shift to high-value crops (Llamas and Martínez-Santos 2005 ; Shah et al. 2003). To a certain extent groundwater has also been used to enlarge the irrigated area, but in many cases pumping activities developed inside or at the fringes of existing canal command areas (Foster and

Steenbergen 2011). Although the increase in groundwater use meant a substantial improvement in farmers' livelihoods at first, soon problems of overexploitation appeared. Overexploitation is generally defined as the occurrence of groundwater withdrawal exceeding groundwater recharge (Lopez-Gunn et al. 2011). The overexploitation of groundwater resources is characterized by a continuous drop of groundwater tables. Falling groundwater levels have been reported in areas of intensive groundwater use in China like elsewhere, leading to multiple problems such as increased energy costs for farmers, reduced groundwater availability for natural ecosystems, groundwater salinity intrusion in coastal areas and land subsidence (Kendy et al. 2004 ; Konikow and Kendy 2005 ; Liu et al. 2001 ; Lohmar et al. 2003). These negative effects eventually render intensive groundwater use environmentally and socio-economically unsustainable.

How to curb intensive groundwater use has turned out to be a tedious question (Giordano 2009 ; Hoogesteger and Wester 2015). Particularly in a setting of small scale agriculture, cases in which the rate of intensive groundwater use could be "tamed" are scarce (Shah 2009 ; Shah et al. 2007). Ensuring sustainable groundwater use for agriculture is widely reckoned as primarily a *governance* challenge (Bouarfa and Kuper 2012 ; Giordano 2009 ; Hoogesteger and Wester 2015 ; Mukherji and Shah 2005). By defining the problem of unsustainable groundwater use as a governance problem Mukherji and Shah (2005) criticize the one-dimensional perspective often employed by hydrologists and policy makers. They understand groundwater governance as a "multi-level, multi-actor and multi-instrumental" (p.329) approach, contrary to the concept of *management* which emphasizes activities carried out by the government. Seeing the need for a governance approach does not imply that groundwater management by the state is irrelevant, but that it is only one of many aspects shaping the groundwater socio-ecology.[1] Besides that, it tries to break away from the conventional technological view on groundwater issues (Burke et al. 1999). Giordano (2009) suggests that facing the governance challenge means to broaden our view on resource systems. He argues that even though our knowledge on hydro-geological conditions may be incomplete, "it is an understanding of how to determine and implement appropriate [institutional] frameworks in which we appear to be most deficient" (p.168).

In many countries the implementation of direct groundwater regulation measures by the state (i.e. measures which act within the groundwater sector like groundwater quota or well permits) failed (Kemper 2007 ; Molle and Alvard 2015). Failure can be ascribed to various reasons. First, the implementation of direct regulations is constrained by difficulties in monitoring and controlling the

[1] The term groundwater socio-ecology is coined by Mukherji and Shah (2005). They use the term to refer to groundwater irrigation in its socio-economic and agro-ecologic context. In his book on groundwater governance in South Asia, Shah (2009) describes a typology of four major groundwater socio-ecologies worldwide. He classifies China amongst the "smallholder intensive farming systems" (p 55).

use of groundwater because it is an invisible resource used by a high number of individuals (Giordano 2009 ; Hoogesteger and Wester 2015 ; Moench 2004). Second, local authorities in charge of policy implementation often lack the political will to enforce groundwater use restrictions because of the short-term economic benefits from intensive groundwater irrigation (De Stefano and Lopez-Gunn 2012 ; Hoogesteger and Wester 2015 ; Molle and Alvard 2015 ; Mukherji and Shah 2005). Other reasons which may cause direct groundwater regulation to fail are: corruption in the distribution of permits and quota and fiddling with groundwater abstraction rates by users (Hoogesteger and Wester 2015).

Several arguments can be brought up to argue that the effective implementation of direct groundwater regulation by the state would be more feasible in China than in most other countries characterized by small scale agriculture. First, the Chinese state has powerful decentralized government structures reaching out to agricultural groundwater users (Aarnoudse et al. 2012 ; Shah 2005). Second, a hierarchical political system that evaluates and rewards decentralized authorities allows the national government to reinforce environmental targets (Nickum 2010). Third, China has undergone substantial economic growth over the last decades, providing the financial means to implement groundwater regulation measures (Villholth 2006). Indeed we see a push for direct groundwater regulation in China over the last few years (Shah 2014). Nevertheless, one of the few exceptional cases of effective groundwater regulation – found in Minqin County in Northwest China – came at high costs both for the government and the local farmers (Aarnoudse et al. 2012 ; Bondes and Li 2013). Many farmers simply feel forced out of agriculture (Aarnoudse 2010). It is therefore debatable whether it can be labelled as a "success story".[2] Overall China's groundwater use is still largely unregulated like elsewhere, while the country is increasingly suffering from problems related to groundwater overexploitation (Qu et al. 2011 ; Shen 2015).

In search of a solution to curb intensive groundwater use for agriculture, much research has been done to better understand the functioning of groundwater socio-ecologies. New insights have been used for the development of alternative management approaches which would render direct regulation unnecessary. This type of research and policy development has expanded mainly outside China. A lot of attention has been paid to the potential of self-regulation, whereby local groundwater management is primarily achieved through collective action by groundwater users (Figureau et al. 2015 ; Lopez-Gunn and Cortina 2006 ; Steenbergen 2006 ; Taher et al. 2012 ; Wester et al. 2009). In different countries, like Mexico, India and Spain, attempts have been made to anticipate upon

[2] During the course of the PhD research this question was repeatedly discussed at different forums, internationally and in China. It always resulted in heated debates. A Chinese scholar reflected upon the question with the following expression: "When the costs are too high, even if you succeeded, you failed at the same time." （代价过高，即使成功， 同时失败）

agreements between groundwater users. As pointed out by Bondes and Li (2013), in China groundwater users are unlikely to participate in the formulation of groundwater policies. At most, collective institutions of user groups are taken advantage of to facilitate the implementation of state regulations (Aarnoudse et al. 2012).

Other research and policy experiments focused on the use of *indirect* regulation measures which act outside the groundwater sector. This approach developed particularly in view of the energy sector in India (Mukherji et al. 2009 ; Shah and Verma 2008). However, opportunities to modify groundwater use through energy policies depend on the context of poor energy supply and high energy subsidies, which is not the case in China. The potential of agricultural and/or land use policies to indirectly influence groundwater abstraction has also been discussed in literature, but related policy measures are hardly found in practice (Moench 2007 ; Shah 2014). It has been reported that some local authorities in China experiment with a ban on specific high-water demanding crops, like cereals or paddy rice, to reduce agricultural water consumption (Kendy et al. 2003 ; Peisert and Sternfeld 2004); however, there is little further information available on this topic.

1.1.2 Research on China's groundwater socio-ecology

Empirical research on the functioning of China's groundwater socio-ecology is still considered scarce by international researchers working in the field of groundwater governance. The bulk of English language literature on the topic is based on two large scale surveys carried out by the Chinese Academy of Sciences in northern China in 2001, 2004 and 2005 (see for example Huang et al. 2013 ; Wang et al. 2014 ; Wang et al. 2006 ; Zhang et al. 2010 ; Zhang et al. 2008). As the data was collected ten years ago the resulting literature mainly focuses on the scope of groundwater use for agriculture and the drivers of this development. Other research is based on small scale surveys carried out scattered over North China (see for example Aarnoudse et al. 2012 ; Bluemling et al. 2010 ; Kendy et al. 2004 ; Wang et al. 2013 ; Zhen and Routray 2002). Overall little empirical research is done on the functioning of policy measures which intend to regulate intensive groundwater use, partly because such measures only started to be implemented over the last few years (one exception is Aarnoudse et al. 2012). Existing analyses on groundwater regulation in China are often based on scarce data or modulation of policy scenarios (see for example Shah 2005 ; Wang et al. 2009b ; Zhou et al. 2015). Wang et al. (2014) claim that in order to understand the impact of new policies in the Chinese context there is a need for more "studies that examine groundwater institutions and rules of water allocation" (p.281).

1.1.3 The hidden link between groundwater and surface water

Although globally much research on intensive groundwater use has developed beyond the scope of direct groundwater regulation over the last decade, few researchers and policy makers draw a link to surface water management. It is widely reckoned that the initial development of groundwater use often followed upon an event of surface water scarcity or as a response to degraded surface water delivery (Bouarfa and Kuper 2012 ; Hammani et al. 2009 ; Shah et al. 2003). However, little attention is paid to the relation between farmers' groundwater and surface water use after initial development. Several authors warn that the narrow focus on groundwater and the emergence of new, isolated groundwater institutions is a "blind spot" or a "lost opportunity" for water governance in developing countries (El Haouari and Steenbergen 2011 ; Evans et al. 2014 ; Foster and Steenbergen 2011).

This limitation is particularly evident when looking at research in the Chinese context. For example, the two abovementioned surveys carried out by the Chinese Academy of Sciences do in fact contain data on both surface water and groundwater management institutions. Despite the available data, the two aspects are analyzed and discussed in separate papers (see for example Huang et al. 2009 and Wang et al. 2010 for a discussion of surface water institutions). As noted by Kemper (2007) this way of presenting groundwater management gives the impression that groundwater use takes place in areas separate from canal irrigation systems, which is often not the case. A closer look at the data from the China Water Institutions and Management (CWIM) survey collected by the Chinese Academy of Sciences in 2001 and 2004,[3] reveals that in two third of the groundwater using villages in northern China groundwater is used in addition to surface water.

In fact, the simultaneous use of surface water and groundwater for irrigation either at field level or at irrigation system level is common worldwide. This phenomenon is widely referred to as *conjunctive water use* (World Bank 2005). This research understands conjunctive use in an agricultural setting not only to include situations in which groundwater and surface water are used at the same time and/or at the same location, but also situations in which surface water and groundwater use are alternated inter-annually or surface water and groundwater use developed at different locations within one canal irrigation system. Based on remote sensing data, Thenkabail et al. (2009) estimated that globally 90% of the groundwater irrigated areas also has access to surface water, even when overall the proportion of surface water irrigation in those areas is small. Official statistics on farmers' joint use of surface water and groundwater for irrigation in China is not available. However, different studies illustrate that this phenomenon is also widespread in northern China (Liu et al. 2008 ; Wang et al. 2010 ; Wang et al. 2013 ; Zhen and Routray 2002). Most of these studies do not explicitly

[3] For a description of the survey data see Huang et. al (2009).

discuss the conjunctive use situation, but mention the occurrence of both resources for irrigation as background information.

1.1.4 Broadening the groundwater governance debate

As mentioned above, many authors argue that the problem of intensive groundwater use is primarily a governance problem (Bouarfa and Kuper 2012 ; Giordano 2009 ; Hoogesteger and Wester 2015 ; Mukherji and Shah 2005). Mukherji and Shah (2005) claim that focusing on a single management measure (e.g. choosing between groundwater quota, self-regulation or energy rating) is unlikely to secure long-term benefits from groundwater resources for agriculture. They argue that “a tool kit for governance has to be substantially broad based to take into account contextual reality” (p.343). The aim of this research is to extend this “tool kit” by exploring the underexposed link between surface water and groundwater management under conjunctive use conditions. The focus is on management activities primarily defined by the government. However, it is also explored how formal policies function within the institutional setting at village level.

In literature a clear distinction is made between *spontaneous* conjunctive use and *coordinated* conjunctive use (Evans et al. 2014 ; Foster et al. 2010). Spontaneous conjunctive use is understood as the simultaneous use of surface water and groundwater which evolves by default driven by individual decisions at farm level. Blomquist et al. (2004) describe spontaneous conjunctive use as the result of “water users’ action even in the absence of deliberate management” (p.13). On the contrary, coordinated conjunctive use is understood as the purposely planned simultaneous use of surface water and groundwater, either at irrigation system or river basin level (World Bank 2005). The coordinated use and storage of surface water and groundwater is more widely known as “conjunctive water management” (Blomquist et al. 2004).[4] Both in the case of spontaneous and coordinated conjunctive use an effort is made to benefit from “the relative advantages of surface water and groundwater resources to offset each other’s shortcomings” (Blomquist et al. 2004 p.22), but the scale and time-frame at which benefits are obtained differ.

Foster and Steenbergen (2011) argue that spontaneous conjunctive use often exacerbates falling groundwater tables in certain parts of the irrigation system, while excessive surface water irrigation continues to cause water-logging problems in other parts. Therefore, they advocate a more coordinated use of surface water and groundwater within irrigation systems. In principle conjunctive water management can be understood as an integrated approach to surface water and groundwater management. Hence, it is basically part of the broader concept of integrated water resource

[4] In this thesis “conjunctive water management” and “coordinated conjunctive use” are used as synonyms.

management (Foster and Ait-Kadi 2012 ; Savenije and Zaag 2008).[5] The type of management activities and management outcomes associated with conjunctive water management differ depending on the hydro-geological and socio-economic conditions. In the context of irrigated agriculture on alluvial plains, where rivers and aquifers are physically interconnected, conjunctive water management can provide solutions for salinity control (e.g. avoid water logging by groundwater pumping or mix irrigation water sources to improve water quality) and long-term water security (e.g. groundwater recharge in wet years and increased pumping in dry years) (Foster and Steenbergen 2011 ; Sahuquillo and Lluria 2003).

1.1.5 Surface water and groundwater institutions

Whereas the concept of conjunctive water management is not new and technical possibilities have been discussed in literature (Foster et al. 2004 ; O'Mara 1985 ; Sahuquillo and Lluria 2003), examples of coordinated conjunctive use in a setting of small scale agriculture and intensive groundwater use are scarce. This is largely due to existing surface water and groundwater *institutions* which constrain the coordinated use of both resources (Evans et al. 2014 ; Foster and Steenbergen 2011). In this thesis institutions are understood as "arrangements between people which are reproduced and regularized across time and space" (Cleaver 2012 p.8).[6] *Water* institutions are understood as those arrangements which assign responsibilities, steer interactions and determine human practices with relation to water. Cleaver (2012) argues that even though institutions are able to steer water use behaviour over extended periods of time, they are "subject to constant processes of evolution and change" (p.8). There can be various drivers behind the emergence of new institutions; not only economic rationalities, but also "social concerns", "psychological preferences" and "culturally and historically shaped ideas about 'the right way of doing things'" (Cleaver 2012 p.15). Through her research Cleaver (2012) illustrates that new institutions often evolve based on pre-existing institutions, a process which she refers to as "institutional bricolage". Understanding institutions in this way means that possibilities to craft institutions are limited and depend largely on the blueprints

[5] Integrated water resources management is a popular concept worldwide. The Global Water Partnership (2000) defined the concept as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (p.22). The concept is criticized because it is unclear what actually needs to be integrated (Biswas 2004). Yet, the integration of surface water and groundwater is generally considered an essential part of the concept (Foster and Ait-Kadi 2012 ; Savenije and Zaag 2008).

[6] Different definitions of institutions exist. For example, McGinnis (2011) defines institutions as follows: "Institutions are human-constructed constraints or opportunities within which individual choices take place and which shape the consequences of their choices" (p.170). This definition emphasizes the role of people in "constructing" institutions. From an economic perspective, it is often assumed that institutions which assure the lowest transaction costs are selected from a set of feasible institutions (Shelanski and Klein 1995). Again, this emphasizes the role of rational human beings who are engaged in shaping institutions. The definition employed in this thesis primarily differs from other definitions in that it does not consider institutions to be merely a product of people's rational choice.

of pre-existing institutions. Therefore, the institutions existing under spontaneous conjunctive use should be considered as critical elements to explore the potential of coordinated conjunctive use.

Under spontaneous conjunctive use conditions the institutions steering surface water use generally have a different character from those steering groundwater use. Surface water irrigation is often depending on centralized management efforts (either at state or at local level), whereas groundwater irrigation in small scale agriculture is organised by a high number of autonomous users. In North China surface water is usually distributed through large scale irrigation systems which are managed by the state. Most of the time local water authorities allocate bulk quantities to villages, which are then responsible for the distribution amongst its households. This is traditionally in the hands of the village committee presided by the village leader. Hence, with regard to the access to surface water for irrigation, arrangements between farmers, the village committee and local water authorities are of critical importance. On the contrary, groundwater irrigation in China has for a long time hardly been controlled by water authorities. Although groundwater is officially owned by the state, farmers experienced a virtually “open access” situation. However, to access groundwater many Chinese farmers cooperate with their direct neighbours at sub-village level to drill wells and pump up groundwater (Aarnoudse et al. 2012 ; Bluemling et al. 2010 ; Wang et al. 2006 ; Wang et al. 2013). Under these circumstances the arrangements between farmers sharing ownership and usage of wells is likely to influence farmers’ access to groundwater for irrigation.

Over the last two decades China has undergone different institutional reforms in the water sector which to a smaller or larger extent changed the institutional environment of surface water and groundwater use for irrigation. These institutional reforms included, amongst others, the formation of river basin authorities, the foundation of WUAs and the implementation of groundwater regulations (Calow et al. 2009 ; Huang et al. 2009 ; Shen 2004 ; Shen 2015). The foundation of river basin organisations is a development which can be observed worldwide and followed the insight that water management boundaries need to overlay hydrological boundaries (Jaspers 2003). China’s revised Water Law of 2002 presents directives on the status of river basin management organisations (Shen 2004). However, the directives do not include a full clarification on the function of those organisations and the integration of surface water and groundwater management at river basin level (Shen 2004).

Another important institutional reform in the organisation of the irrigation sector in China has been the foundations of Water Users’ Associations (WUAs). WUAs are ideally self-organised and intend to allow water users to participate in water management (Svendsen and Meinzen-Dick 1997). Worldwide WUAs have been set up to solve problems in canal irrigation systems; however, WUAs which are responsible for groundwater management can also be found (Lopez-Gunn 2003). In China the first WUAs have been introduced through World Bank projects in canal irrigation systems; nowadays WUAs are common all over northern China (Huang et al. 2009). In many cases Chinese WUAs are found to be promoted by the government rather than self-organised by water users (Aarnoudse et al. 2012 ; Qiao et al. 2009). Moreover, members of the WUA board are often the same people who run the village committee. It has been argued that this constellation reduces the participation of farmers in WUA activities (Huang et al. 2010).

The third institutional reform which is particularly relevant for the question of conjunctive water management is the implementation of regulatory institutions with regard to groundwater. Until recently groundwater could be considered as an open access resource all over China. This has changed since the revision of the Water Law in 2002. The new law foresees the regulation of groundwater in areas of severe overdraft, even though it is not elaborated upon what such regulations should look like or how they should be implemented (Shen 2015). In response to the new water law various local water authorities scattered over North China have been found to implement groundwater regulation measures (Aarnoudse et al. 2012 ; Shah 2014).

1.2 Problem statement

1.2.1 The scientific problem

How to curb intensive groundwater use in a setting of small scale agriculture is widely reckoned as primarily a *governance* challenge. Attempts to cut back intensive groundwater use in small scale agriculture through direct regulation measures, like groundwater quota or well permits, failed frequently. Alternative approaches, like self-regulation and indirect regulation through the energy sector, have received considerable attention internationally. However, a third alternative management approach – the coordinated conjunctive use of surface water and groundwater – has received relatively little attention in the groundwater governance debate so far, despite the fact that spontaneous conjunctive use is a widespread phenomenon. Coordinated conjunctive use, whereby the relative advantages of surface water and groundwater resources are employed at irrigation system level (or higher), is expected to render groundwater use more sustainable. One of the main reasons why conjunctive water management is not widely practiced is the occurrence of separate institutions for surface water and groundwater use under spontaneous conjunctive use. To overcome such institutional barriers it is essential to build upon existing institutions.

1.2.2 Relevance for the Chinese context

China is one of the most important countries where intensive groundwater use by small scale farmers increasingly threatens the ecological and socio-economic sustainability of irrigated agriculture.

Compared to other countries effective groundwater regulation through the implementation of direct regulation measures seems to be more feasible in China because of the country's decentralised government structures and financial capacity. Nevertheless, such measures have so far shown limited results in China like elsewhere. International experiences with self-regulation and indirect regulation through the energy sector are not necessarily applicable to China, where the participation of water users in policy making is not widely established and energy provision is not heavily subsidized. Therefore, exploring the potential of conjunctive water managements is particularly relevant in the Chinese context. Even though groundwater use in canal irrigation districts appears to occur frequently, there is little knowledge available on how surface water and groundwater institutions are interlinked in China. Most related research focuses either on the one resource or on the other.

1.3 Research objectives and research questions

The main objective of this research is to explore the occurrence of *spontaneous* conjunctive use and the potential of *coordinated* conjunctive use in the context of intensive groundwater use for small scale agriculture in Northwest China. The idea behind the research is that dealing with intensive groundwater use should be approached as a holistic governance challenge and solutions should not focus on direct groundwater regulations alone. The research aims specifically at broadening the debate by considering the link between surface water and groundwater use and management and discussing the implementation of direct groundwater regulations in the Chinese context. This research can be placed in the broader domain of natural resources management.

The research is split up in the following three main research questions, which are dealt with in three separate papers:

1. How are surface water and groundwater institutions integrated at different management levels?
2. How is farmers' groundwater use behaviour in canal irrigation districts related to the surface water supply conditions?
3. How effective are direct groundwater regulation measures in curbing farmers' groundwater use in a conjunctive use setting?

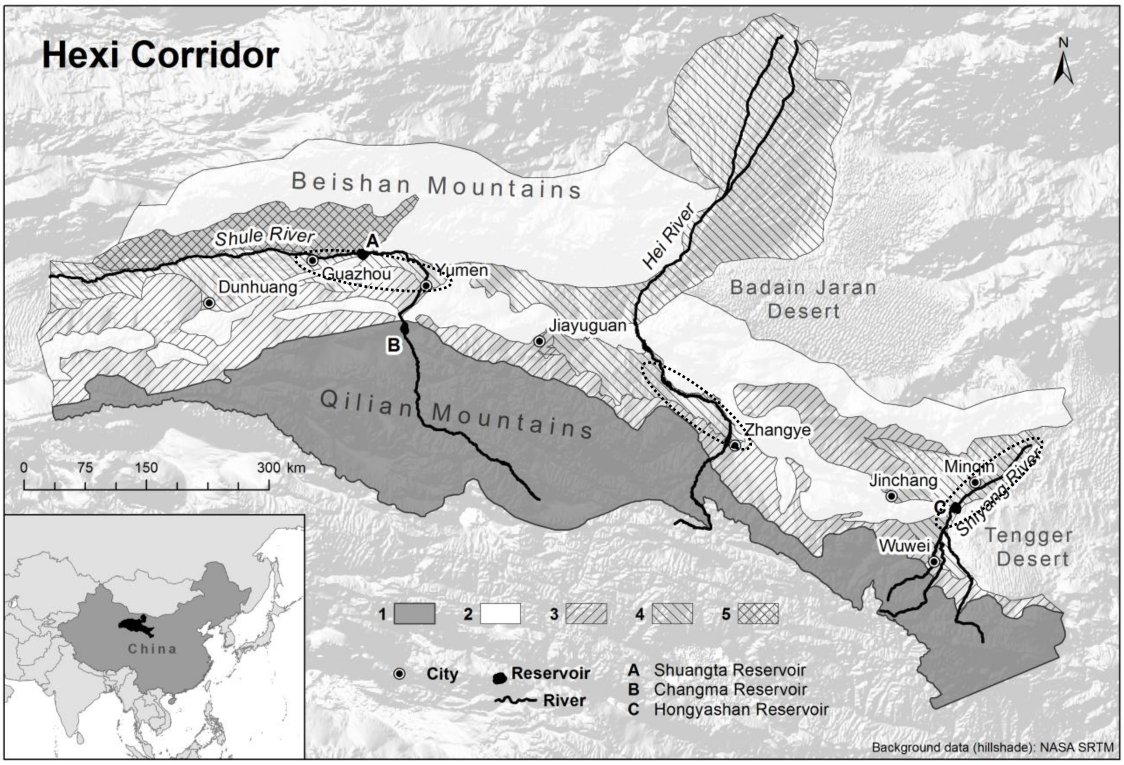
1.4 Research design

China was chosen as a case to answer these research questions because: 1) the country is increasingly suffering from intensive groundwater use; 2) the implementation of direct groundwater regulation measures in China is not well reported; 3) alternative approaches to curb intensive groundwater use like self-regulation and indirect regulation through the energy sector find little political response in China; and 4) little research is available on the linkages between surface water and groundwater institutions, even though conjunctive use is assumed to be widespread in the country. Because secondary data on agricultural groundwater use in China is scarce, it was considered crucial to collect primary data for the analysis from the outset of this research. Although the research has a strong explorative character which generally asks for a qualitative research approach, it was decided to apply a mixed methods approach and use both qualitative and quantitative research methods. This was done for a number of methodological and practical reasons. From the methodological point of view, the qualitative and quantitative research methods were expected to mutually support each other. On the one hand, descriptive statistics can be used to triangulate qualitative data; on the other hand, contextual knowledge obtained through qualitative research methods facilitates the interpretation of quantitative data analysis. From the practical point of view, the large scale household survey allowed for the purposeful selection of a variety of interesting cases for in-depth inventory. This was particularly helpful in face of the fact that field access to carry out in-depth interviews was limited, a situation which is characteristic for the Chinese context (Alpermann 2012).

1.4.1 The study area

As study area the alluvial plains of three major inland river basins in the Hexi Corridor located in Gansu Province was selected (see Figure 1.1). The most important selection criterion was that the alluvial plains are characterized by the conjunctive use of groundwater and surface water for irrigation by small scale farmers. Moreover, the three areas are rather homogeneous in terms of hydro-geological and climatic conditions, but followed different groundwater development and management trajectories. The combination of physical similarities and institutional differences provides the opportunity to identify how institutions influence farmers' conjunctive water use behaviour (Blomquist et al. 2004).

Figure 1.1 Map of the Hexi Corridor



1= high rock mountains, 2= low rock hills, 3= alluvial fans, 4= alluvial plains, 5=foothill plains, dotted circles mark survey area
Source: made by Ronald Kraemer, adapted from Zhou et al. (2007)

From a hydrologic point of view the Hexi Corridor can be considered as one unit with multiple streams flowing down the Qilian Mountains through the plains into the desert (Zhou et al. 2007). Amongst the multitude of streams, three major inland rivers can be distinguished: the Shiyang, Hei and Shule River. The research took place on the alluvial plains of these three inland river basins. The alluvial plains are flat with a mean slope below 5° and are underlain with both shallow and deep high-storage aquifers. The shallow aquifers are shaped by unconsolidated sediments and are directly connected to the river flow (Ji et al. 2006). Water from the mountains may change several times from the surface to sub-surface flows before reaching the river's tail-end. Naturally the alluvial plains are characterized by high groundwater levels and springs. As rainfall is scarce the shallow groundwater is also the main source of water for the natural vegetation, which are considered crucial for maintaining the hydrological cycle (Matin and Bourque 2015). Aquifer recharge takes place through river infiltration and seepage from unlined canals and flood irrigation (Ji et al 2006). The salinity levels of the groundwater increases upon intensive use (Wang et al. 2003). High salinity levels are quite common particularly in the lower reaches of the inland river basins (Wang et al. 2003). Because of the relatively abundant melt water from glaciers and snowfall in the Qilian Mountains, the plains of Hexi Corridor are regarded as the most productive agricultural region of Gansu Province.

So far, most socio-economic research on agricultural groundwater use in China has focused on the Northeast of China (see for example Bluemling et al. 2010 ; Huang et al. 2013 ; Kendy et al. 2004 ; Wang et al. 2006 ; Zhen and Routray 2002). The present study area is located in the Northwest of China, which differs from the rest of northern China in two ways. First, the area is considered to lie behind in terms of socio-economic development. The per capita rural income in Gansu Province ranks lowest amongst all Chinese provinces, while in hardly any of the north-eastern provinces the rural income reaches below the national average (National Bureau of Statistics of China 2014). Second, the climate in Northwest China is more arid and its agriculture thus more dependent on irrigation compared to most parts of Northeast China. On the plains of the Hexi Corridor annual rainfall lies between 50-200 mm and evaporation between 2000-3500 mm (Xiao et al. 2008). These are clearly dryer conditions than further East on the North China Plain where annual rainfall lies between 500-900 mm and evaporation between 900-1200 mm (Wang et al. 2008). It should be noted though, that the study area is culturally similar to the north-eastern provinces and the population on the plains belongs to China's major Han ethnicity, contrary to the rural population in provinces located further West.

1.4.2 Data collection

The data collection was carried out in cooperation with the Gansu Academy of Social Sciences (GASS) in 2013 and 2014. It incorporated a large scale survey with questionnaires for farm households, village leaders and well operators. The questionnaires contained both open and close questions. The household questionnaire covered the following topics: farmers' household characteristics; their cropping data for the year previous to the survey (including irrigation practices per crop); conjunctive use practices and related perceptions; formal and informal water management institutions and water use costs. The village leader questionnaire basically included the same topics as raised in the household questionnaire but then on village level. It also contained some additional questions on changes in land and water use over the last decade. The well operator questionnaire focused on agricultural groundwater use and management conditions. It contained detailed questions on the characteristics of all the wells managed by the well operator. Besides that a section was dedicated to the well operator's groundwater and (when applicable) surface water management activities. The questionnaires had been pre-tested before the actual survey took place. It was found that ordinary farmers have little knowledge about the technical conditions of the wells and have difficulties to recall past situations. Hence, it was decided that well-specific data would only be asked to the well operator and historic data would only be asked to village leaders who had the possibility to look it up in the village's accounts.

The following locations were identified as alluvial plains where conjunctive use for agriculture takes place and thus selected as study area: 1) the downstream sub-basin of the Shiyang River Basin part of Minqin County; 2) the middle reaches of the Hei River Basin part of Zhangye Prefecture including Ganzhou, Linze and Gaotai County; and 3) the upstream and downstream sub-basin of the Shule River Basin including Yumen and Guazhou County (see marked area on Figure 1.1). Despite different locations with respect to the upstream and downstream ends of the river, these areas all belong to the same hydro-geological formation of quaternary alluvial plains (Zhou et al. 2007). Therefore, the variation in upstream-downstream locations at most causes differences in the access to surface water and the level of groundwater salinity across the area covered by the survey. As a rule of thumb the surface water access and the groundwater quality is worse in downstream areas. However, as each of the three surveyed areas cover approximately a stretch of 80-100 km along the river, such differences also exist within the areas.

In order to have a representative household sample which captures the variation in water access and water quality, three to four townships were purposefully selected from relatively upstream to relatively downstream stretches along the respective river in each of the three areas. Afterwards, ten villages were randomly selected within the pre-selected townships. The approach approximates a stratified random sampling method. Per village one village leader, one well operator (if applicable) and approximately ten household questionnaires were selected. In total 30 village leader questionnaires, 27 well operator and 312 farm household questionnaires were filled out (see Table 1.1). The households were semi-randomly selected by the enumerators who could freely walk through the village and approach different homesteads. Before carrying out the survey it was not known whether farmers in the village were actually using groundwater or not.

Table 1.1 Number of questionnaires and in-depth interviews per river basin

	Questionnaires			In-depth interviews		
	Village leader	Well operator	Farm household	Village leader	Farmer	Staff water management
Shiyang River Basin	10	10	105	5	4	3
Hei River Basin	10	7	103	3	1	2
Shule River Basin	10	10	104	3	3	2
Total	30	27	312	11	8	7

The survey was carried out by staff from the GASS and students from the Gansu Agricultural University (GAU). Most of the enumerators had experience with conducting similar surveys. All enumerators took part in a one-day training before the survey took place. The survey took place in two time blocks. In the Shiyang River Basin the survey was carried out in August 2013. In the Hei and Shule River Basin the survey was conducted in May 2014. In the Shiyang River Basin seasonal data was collected for 2012, in the Hei and Shule river Basin seasonal data was collected for 2013. Due to time constraints of the enumerator team it was not possible to conduct the survey in one year.

Although the data may contain some variance caused by the time difference, this effect is assumed to be small as it concerns only one year. Moreover, potential inter-annual variability in surface water availability was captured by the collected data. The survey data was entered in Excel sheets by GAU students. After data cleaning the Excel sheets were transferred to STATA for statistical analysis. The methods for statistical analysis are described in more detail in the subsequent papers.

Besides the survey, semi-structured in-depth interviews were carried out by the PhD candidate in cooperation with staff from GASS. The interviews took place shortly after the household surveys were conducted. In the Shiyang River Basin the interviews were carried out in September 2013 and in the Hei and Shule River Basin the interviews were carried out in July 2014. Because the interviews were performed after the survey, the survey data could be used to prepare for the semi-structured interviews and purposefully select interview partners. Per study area three to four villages were selected with varying conjunctive use situations. Furthermore, villages with deviating water use institutions were prioritized. Normally two interviews were held per village, one with the village leader and one with a knowledgeable ordinary farmer (i.e. not member of village authorities or well operator). In addition, staff from different water management organizations was interviewed. In total 11 village leaders, 8 ordinary farmers and 7 staff members from different water management organisation were interviewed (see Table 1.1). Since general data was already collected during the survey, the interviews could focus on in-depth questions. For each interview a guideline was prepared accounting for the local situation as described by the survey data. Each interview lasted between one and two hours. The interviews were conducted in Chinese and documented in English based on notes made during the interview. Data from the interviews is provided in the subsequent papers to describe and analyse varying conjunctive use situations and related institutions in the study area. Insights from the interviews are also presented to facilitate the interpretation of quantitative data analysis.

1.5 Outlook on the three papers

This thesis is built up of three papers which are partly submitted to journals. Each paper deals with a separate research question. Nevertheless, the broader topic and the underlying database is the same. Hence, the papers complement each other and present the bigger picture all together.

The first paper explores how surface water and groundwater institutions are integrated at different management levels in the study area (see research question 1). The paper deals with the first main research question through a comparative case study analysis. For each of the three case study areas the organizations and institutions managing surface water and groundwater at different management levels are described separately. The descriptive analysis is mainly based on the data from the semi-structured in-depth interviews, but also supported by descriptive statistics from the survey. Finally, the paper compares the conjunctive use conditions in the three study cases and discusses at what end of the continuum between spontaneous and coordinated conjunctive use each case is located. The insights on the institutional setting provided here serve as important background information for the subsequent papers. The paper intends to contribute to the literature by showing to what extent conjunctive management can be considered a “blind spot” in China (El Haouari and Steenbergen 2011) and discussing what institutional conditions may facilitate or hinder the emergence of conjunctive management (Evans et al. 2014 ; Foster and Steenbergen 2011).

The second paper explores how farmers’ groundwater use behaviour is related to the surface water supply conditions (see research question 2). The paper deals with the second main research question primarily by analyzing the survey data. The analysis is confined to the areas under spontaneous conjunctive use. First, the paper introduces the reader to the occurrence of spontaneous conjunctive use at micro-level. Based on descriptive statistics it explains how surface water and groundwater are used in conjunction at field level and demarcates recent trends in groundwater use in canal irrigation systems. It also gives an overview on farmers’ own perception on conjunctive groundwater use. Afterwards, the determinants of farmers’ groundwater use quantity in canal command areas are further analyzed through a multivariate analysis of the cross-sectional household data. Finally, crop choice and cropping areas are statistically compared for groundwater users and non-groundwater users to estimate the impact of groundwater use on agricultural intensification. The paper intends to contribute to the literature by illustrating the scale of groundwater use in canal irrigation districts in Northwest China and better understand its drivers by quantifying the interdependency between surface water supply, groundwater use, crop choice and cropping area. So far, most socio-economic research on irrigation in China focuses *either* on surface water *or* groundwater (see for example Huang et al. 2009 ; Huang et al. 2013 ; Wang et al. 2005 ; Wang et al. 2010). At best the dependency between groundwater use and surface water supply is mentioned as background information, but not quantified (see for example Liu et al. 2008 ; Wang et al. 2009a ; Zhen and Routray 2002).

The third paper analyses how effective direct groundwater regulations measures are in curbing farmers’ groundwater use in a conjunctive use setting (see research question 3). The paper deals with the third main research question through a mixed methods approach. The paper compares two selected case studies within the study area which are characterized by limited surface water availability and intensive groundwater use, but differ with regard to the regulatory groundwater institutions. In the first case the authorities intend to regulate farmers’ groundwater use through the allocation of groundwater quotas, in the second case groundwater use is meant to be regulated through a tiered groundwater pricing system. First, the implementation of the groundwater policies and the authorities' underlying motivation to implement those policies is compared through a descriptive analysis. Then, farmers' groundwater use quantity as reported in the household questionnaire is statistically compared. The two cases show both the potential and the limitations of direct groundwater regulation measures in the Chinese context. The paper intends to contribute to the literature by discussing to what extent the expectation that direct groundwater regulation in China is more feasible than elsewhere is valid (Shah 2005 ; Villholth 2006). Moreover, it intends to demonstrate whether alternative groundwater management approaches (like conjunctive management) are needed in China. So far, China focuses mainly on direct groundwater regulation measures (Shah 2014 ; Shen 2015).

In the last section of this thesis the research results are summarized and placed in the scientific debate. Finally, it is discussed what the findings could mean for policy making and what impulses this thesis provides for further research.

Paper 1

From spontaneous to coordinated conjunctive water use: Institutional conditions and potential benefits in the context of irrigated agriculture in Northwest China

Abstract

In China, like elsewhere in the world, most groundwater use for agriculture developed largely unplanned within or at the margins of surface water irrigation districts. Coordination of conjunctive surface and groundwater use at irrigation system level is advocated as an approach to solve water issues in such a setting. So far, coordinated conjunctive use is not widely established in smallholder agricultural settings mainly due to institutional constraints. In this paper the surface water and groundwater management situation in three inland river basins in Northwest China is compared and contrasted. Recent river basin level reforms in the water sector provided the opportunity to establish a more coordinated conjunctive use approach. Yet, it is observed that the integration of surface and groundwater management is mainly a secondary outcome of the reform process and the emergence of new institutions. Through a comparative case study analysis it is explored how institutions can facilitate or hinder the emergence of coordinated conjunctive use and what benefits coordinated conjunctive use can bring in practice.

Keywords: conjunctive use, irrigation, institutions, groundwater regulation, arid regions, China

2.1 Introduction

China has known a tremendous increase in groundwater use over the last few decades. In the 1950s the country's groundwater use was nearly non-existent, while groundwater abstraction was estimated to reach around 100 km^3/year by 2000 (Wada et al. 2010). Most of the abstracted groundwater is used for agriculture in northern China. Worldwide groundwater use for agriculture often developed within or at the margins of surface water irrigation systems, so-called conjunctive water use (Foster and Steenbergen 2011). This research understands conjunctive use in an agricultural setting not only to include situations in which groundwater and surface water are used at the same time and/or at the same location, but also situations where surface water and groundwater use are alternated inter-annually or surface water and groundwater use developed at different locations within one canal irrigation system. Thenkabail et al. (2009) estimated that globally around 90% of the groundwater irrigated area also has access to surface water. Official statistics on farmers' joint use of surface water and groundwater in China are not available. However, many studies illustrate that this phenomena is also widespread in northern China (Liu et al. 2008 ; Wang et al. 2013 ; Zhen and Routray 2002). A survey conducted by the Chinese Academy of Sciences in 2004 shows that in important groundwater using provinces in northern China, such as Hebei and Henan, 40-60% of the irrigated villages use both groundwater and surface water (for a description of the dataset see Huang et al. 2009). Like elsewhere in the world, the conjunctive use of surface water and groundwater often emerged spontaneously. According to Foster and Steenbergen (2011) this exacerbates unbalanced situations whereby surface water over-use leads to water logging problems in one part of an irrigation system, while groundwater over-use leads to falling water tables in another part of the same irrigation system. They argue that there is a need to move from spontaneous to coordinated conjunctive use. This need is particularly pronounced in areas where surface water and groundwater are hydro-geologically connected like on most alluvial plains.

An important distinction between spontaneous and coordinated conjunctive use is that spontaneous conjunctive use (or conjunctive use by default) is primarily driven by "water users' action in the absence of deliberate management"(Blomquist et al. 2004 p.13), while coordinated (or planned) conjunctive use is primarily driven by deliberate management at irrigation system level or higher (Evans et al. 2014). The coordinated use and storage of surface water and groundwater is more widely known as "conjunctive water management" (Blomquist et al. 2004).[7] The main reason for farmers to use groundwater in canal command areas is to increase their water security (Bouarfa and Kuper 2012). Coordinated conjunctive use intends to sustain this advantage on the long-term, while

[7] "Coordinated conjunctive use" and "conjunctive water management" are used as synonyms in this paper.

countering the disadvantages of uneven surface water and groundwater development within an irrigation system. In the context of irrigated agriculture the two most important outcomes of coordinated conjunctive use are: 1) to maintain groundwater aquifers as storage buffer to allow for flexible resource use under uncertain surface water supply conditions (e.g. groundwater recharge in wet years and increased pumping in dry years); and 2) to implement conjunctive management measures which go beyond narrow surface water or groundwater solutions particularly with regard to salinity control (e.g. avoid water logging by groundwater pumping or mix irrigation water sources to improve water quality) (Foster and Steenbergen 2011 ; Sahuquillo and Lluria 2003). These potential benefits are critical in face of the fact that the pressure on fresh water resources is growing and surface water supply conditions are increasingly uncertain due to climate change (Döll 2002). In China this is particularly true for river basins currently supplied with glacial melt water (Piao et al. 2010) .

Coming from a spontaneous conjunctive use situation existing governance structures often form a major constraint to move towards more coordinated conjunctive use (Evans et al. 2014). In general surface water irrigation has hardly developed without centralized management efforts (either at national or local level), whereas groundwater irrigation has usually, at a later stage, emerged decentralized – characterized by a high number of autonomous users. To a large extent the centralized versus decentralized governance structures are cast in the specific irrigation infrastructure of surface water and groundwater irrigation (i.e. interconnected canal systems and isolated pumping installations) which further hampers integration efforts (Dietz et al. 2003). Therefore, conjunctive water management is not widely established, especially in the context of irrigated agriculture in less developed countries (Foster and Steenbergen 2011).

In literature two major constraints are identified which are both linked to the institutional setting in which spontaneous conjunctive use takes place. First, the separation of surface water and groundwater responsibilities over different water management organizations is found to create disincentives to manage the resources conjunctively (Blomquist et al. 2004 ; Bredehoeft 2011 ; Foster and Steenbergen 2011). This problem may exist at different managerial levels. Second, a lack of effectively implemented instruments and incentives for groundwater regulation is considered to hinder any form of groundwater planning required for conjunctive management (Evans et al. 2014 ; O'Mara 1985). Due to the high number of autonomous groundwater users it is often hard to effectively implement regulation measures (Giordano 2009 ; Kemper 2007). Moreover, local authorities usually lack the incentives to implement groundwater regulations due to the disparity between short-term costs and long-term benefits (De Stefano and Lopez-Gunn 2012 ; Hoogesteger and Wester 2015 ; Molle and Alvard 2015 ; Mukherji and Shah 2005). So far, these constraints have been identified mainly based on negative examples of "uncoordinated" conjunctive use. There is little evidence that overcoming these constraints will indeed facilitate the emergence of conjunctive management.

Over the last two decades China has implemented major water reforms touching both upon the organizational structure of irrigation water management and the implementation of groundwater regulation measures. The reforms have been undertaken to counter water scarcity issues in northern China and intend to shift the focus from supply side to demand side management. The main reforms are captured in the 2002 Water Law. Major reforms regarding the organisational structure include the creation of overarching agencies at river basin level and the turn-over of operation and maintenance responsibilities to newly established Water Users' Associations (WUAs) at village level (Calow et al. 2009 ; Huang et al. 2009 ; Shen 2004). Concerning groundwater management, there are no specifications valid for the whole country. However, the 2002 Water Law does prescribe the implementation of groundwater regulation measures in areas of severe overdraft (Shen 2015). At the same time the ambition to integrate surface water and groundwater management also proliferated in China, although its implementation has not been as pronounced as the aforementioned reforms. In 1998, the Chinese government made way for a more conjunctive management approach by transferring the responsibilities over groundwater regulation from the Ministry of Land and Resources to the Ministry of Water Resources. In theory, the recent institutional reforms in the water sector created a window of opportunity to shape new institutional arrangements which allow for the emergence of conjunctive water management. The question is whether this also happened in practice.

In this paper three cases of irrigation water management in Northwest China are presented. In all three study cases above mentioned reforms took place. Although the main building blocks of the undertaken reforms are similar, the reform process developed differently for each case. It is observed that the integration of groundwater and surface water management is mainly a secondary outcome of the reform process and the emergence of new institutions. As a result, the extent to which conjunctive water management is currently practised and the outcome in terms of flexible resource use and conjunctive management measures varies across the three case study areas. This provides us with an interesting empirical example to answer the following research questions: 1) how can institutions facilitate or hinder the coordination of conjunctive use at irrigation system or river basin level; and 2) what benefits can be generated through conjunctive management in practice?

In the next section the research methodology and analytical framework are introduced. Then, the three cases are described in more detail. After that, the insights from the three cases are compared and discussed. Finally, conclusions are drawn on the institutional conditions and benefits of conjunctive water management in Northwest China.

2.2 Methodology

2.2.1 Comparative case study

This paper employs a comparative case study analysis to answer the research questions. A case study means that "a particular instance or a few carefully selected cases are studied intensively" (Gilbert 2008 p.36). A case study analysis can provide in-depth understanding of processes and mechanisms, but is limited in its ability to generalise beyond the case at hand. This type of research method is usually chosen when an explorative question has to be answered (i.e. a question starting with *how* or *why*) and/or when only a few cases are available. The approach is considered suitable for this research because conjunctive water management is neither widely established nor thoroughly studied in a development setting. Moreover, conjunctive water management is primarily observed at irrigation system level or higher and can thus not be studied by focusing on village or household level only, which makes it hard to study a large number of cases.

For a *comparative* case study analysis the researcher purposefully selects multiple cases. These can either be cases showing a similar outcome with respect to the research topic but appearing in different contexts (see for example Scott and Shah 2004). Or, the researcher selects cases within a similar context which expose different outcomes with respect to the research topic (see for example Blomquist et al. 2004). The latter allows the researcher to understand why seemingly similar circumstances can lead to different results. For this research the second selection procedure was applied. Three cases have been selected which are relatively similar with regard to their hydro-geologic and climatic conditions, but followed different groundwater development and management trajectories. Through comparing these cases it is possible to isolate the impact of human induced factors on farmers' conjunctive water use behaviour.

To carry out a case study analysis different data collection methods can be used and combined (Kumar 2013). In this paper each case is described based on data from a large-scale household survey, in-depth semi-structured interviews and policy documents. The case description usually refers to different sources in order to triangulate the data. Primary data was collected in 2013 and 2014.[8] The household survey included 312 farm household questionnaires, 30 village leader questionnaires, and 27 well operator questionnaires evenly distributed over the three case study areas. The

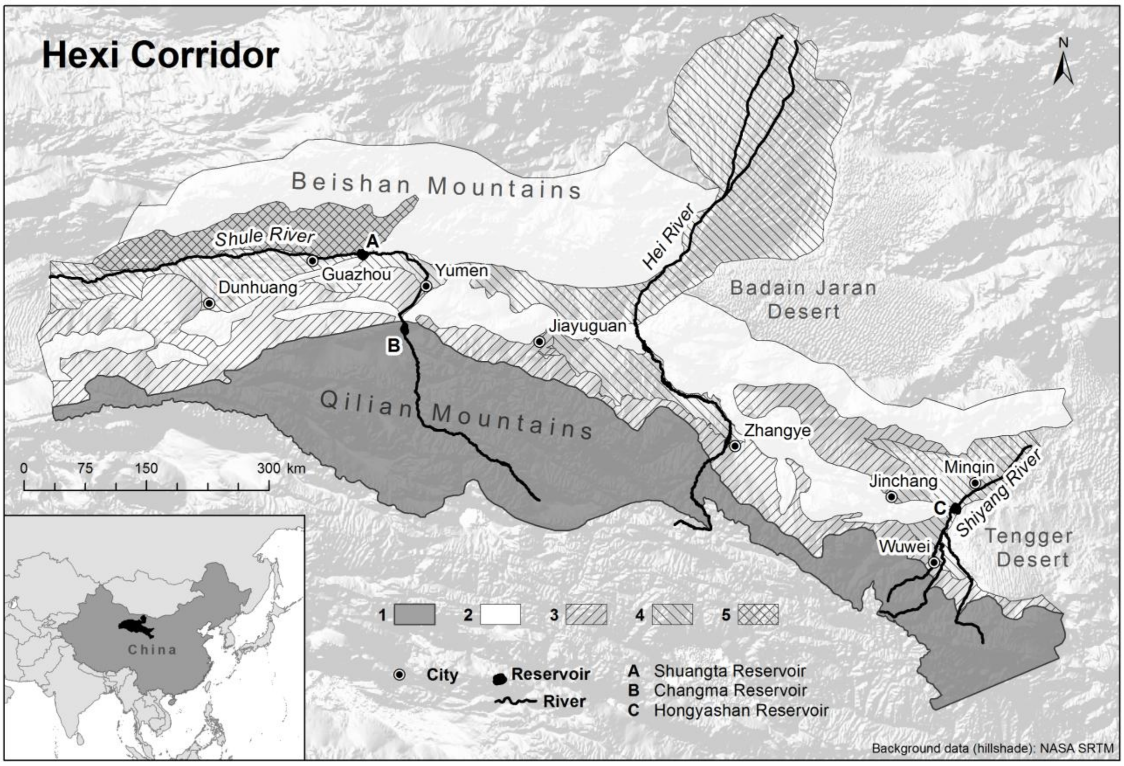
[8] More detailed information on the data collection procedure can be found in the introduction of this thesis.

questionnaires contained questions about farmers' surface water and groundwater use and the water management conditions. In addition 26 in-depth interviews were carried out with water managers, village leaders and farmers.

2.2.2 The study area

As study cases, the alluvial plains of three inland rivers, the Shiyang, Hei and Shule River, in Northwest China have been selected (see Figure 2.1).[9] The primary selection criterion was that these areas are characterised by conjunctive use of surface water and groundwater for irrigation by small scale farmers. In the Shiyang River Basin the study area is confined to Minqin County. In the Hei River Basin the study area includes Ganzhou, Linze and Gaotai County. In the Shule River Basin the study area covers both Yumen and Guazhou County. Each of the three case study areas covers approximately a stretch of 80-100 km along the respective river.

Figure 2.1 Map of the Hexi Corridor



1= high rock mountains, 2= low rock hills, 3= alluvial fans, 4= alluvial plains, 5= foothill plains
Source: made by Ronald Kraemer, adapted from Zhou et al. (2007)

All three case study areas are located in the Hexi Corridor, which forms a strip of flat land between the Qilian Mountains in the Southwest and sandy deserts in the Northeast. The natural "corridor"

[9] Irrigation water use on the alluvial plains is embedded in water management at river basin level. Although water management institutions at river basin level are also described per case, the alluvial plains are considered the main unit of analysis.

connected ancient China with the West. Despite low levels of rainfall (50-200 mm) and high evaporation rates (2000-3500 mm) (Xiao et al. 2008), the area is known for its high agricultural productivity due to abundant melt water from glaciers and snowfall flowing down the Qilian Mountains. Reaching the plains, the mountain streams form three major inland rivers, from East to West: the Shiyang, Hei and Shule River. The alluvial plains are flat with a mean slope below 5° (Matin and Bourque 2015) and are underlain with both shallow and deep high-storage aquifers. The shallow aquifers are shaped by unconsolidated sediments and are directly connected to the river flow (Ji et al. 2006). Water from the mountains may change several times from the surface to sub-surface flows before reaching the river's tail-end. Naturally (i.e. without human alteration) the alluvial plains are characterized by high groundwater levels and springs. The shallow groundwater is also the main source of water for the natural vegetation, which is considered crucial to maintaining the hydrological cycle (Matin and Bourque 2015). Shallow aquifer recharge takes place through river infiltration and seepage from unlined canals and flood irrigation (Ji et al. 2006). The salinity levels of the groundwater increases upon intensive use (Wang et al. 2003). High salinity levels are quite common, particularly in the lower reaches of the inland river basins (Wang et al. 2003).

Agriculture is the single most important economic sector on the plains of the three major inland river basins. The sector is characterized by small scale family farming. Average farm size clearly lies above national average and varies between slightly less than one hectare per household in the East to more than two hectare per household in the less densely populated West. Farmers produce a wide variety of crops; however, primarily cash crops, like cotton, melon and maize seeds, which are sold across China. On the plains both surface water and groundwater are used for irrigation, although the surface water–groundwater use ratio and the water use intensity differ per location. Surface water is supplied to the farm land through irrigation canals. The water is either captured in small to medium size reservoirs (in the Shiyang and Shule River Basin) or directly diverted from the river (in the Hei River Basin).

The canal irrigation system and surface water allocation is managed by the state through a hierarchy of water agencies at different administrative levels.[10] The overarching management organisation in each river basin is the River Basin Management Bureau. Below the river basin level are the *local water authorities*, these include water management organisations which follow administrative boundaries either at prefecture or at county level as well as the Irrigation District Bureaus (IDBs). The water management organisations at prefecture or county level roughly overlap the irrigation system boundaries, while the IDBs are divided according to the irrigation district boundaries with offices

[10] Below province level the Chinese administration is divided in four levels: prefecture (or city), county, township and village.

located in local towns. At village level, surface water operation and maintenance is managed by the water users themselves organised in a WUA board/ village committee.

Groundwater management has traditionally not been the responsibility of the irrigation bureaucracy. Although the state has been getting more involved in groundwater regulations recently, the responsible agencies differ per river basin which will be outlined in more detail later on in this paper. Groundwater pumping is mainly organised at sub-village level in farm groups of approximately 30-70 households.[11] Each farm group usually owns several wells. All members of the farm group share the ownership of those wells. Wells are rarely owned by individual households as reported elsewhere in China (Wang et al. 2006). In the study area all pumping installations are connected to the electricity network and farmers are charged around 0.4 CNY/kWh for their irrigation electricity use by the energy provider.[12]

2.3 Analytical framework

2.3.1 Institutions

Surface water and groundwater institutions which exist under spontaneous conjunctive use are considered the largest constraint for the emergence of conjunctive water management (Bredehoeft 2011 ; Evans et al. 2014 ; Foster and Steenbergen 2011). Hence, there is a need to look at the institutional setting to understand the critical difference between spontaneous and coordinated conjunctive use. In this paper institutions are understood as “arrangements between people which are reproduced and regularized across time and space” (Cleaver 2012 p.8). These arrangements encompass formal and informal agreements between people established as rules, norms and day-to-day habits (Cleaver 2012). *Water* institutions are understood as those arrangements which assign responsibilities, steer interactions and determine human practices with relation to water. Whereas other definitions of institutions often emphasize the role of people in “constructing” or “crafting” institutions (Bromley 2012 ; McGinnis 2011), the definition employed here emphasizes the messy process through which institutional change comes about. The evolution of new institutions is not only based on economic rationalities, but also on “social concerns”, “psychological preferences” and “culturally and historically shaped ideas about ‘the right way of doing things’” (Cleaver 2012 p.15).

[11] Villages are usually divided in smaller units. In China different names circulate referring to the sub-village units, such as natural village, community, (production) team and small group (*ziran cun, she, dui* and *xiao zu*). This paper will consistently refer to the sub-village units as farm groups.

[12] One CNY equalled 0.12 € in 2013.

A spontaneous conjunctive use setting is usually characterized by: 1) isolated surface water and groundwater institutions; and 2) the absence of institutions which effectively regulate groundwater use. Historically this is also the case for China. In North China surface water is often distributed through large scale irrigation systems which are managed by the state. The local water authorities usually allocate bulk quantities to villages, which are then responsible for the distribution amongst its households. This is traditionally in the hands of the village committee presided by the village leader. With regard to the access to surface water for irrigation, arrangements between farmers, the village committee and local water authorities are thus of critical importance. On the contrary, groundwater irrigation has for a long time hardly been controlled by water authorities in China. Although groundwater is officially owned by the state, farmers experienced a virtually “open access” situation. However, to access groundwater many Chinese farmers cooperate with their direct neighbours at sub-village level to drill wells and pump up groundwater (Aarnoudse et al. 2012 ; Bluemling et al. 2010 ; Wang et al. 2006 ; Wang et al. 2013). Under these circumstances the arrangements between farmers sharing ownership and usage of wells influences the access to groundwater for irrigation. Most of the time one person per farm group is responsible for the operation of the wells, the so-called “well-operator”. This can be the farm group leader, who is officially part of the village authorities or an independent person, who usually receives a little extra fee for the service.

Over the last two decades China has undergone different institutional reforms in the water sector which to a smaller or larger extent changed the above described institutional environment of surface water and groundwater use for irrigation. These institutional reforms included amongst others the formation of river basin authorities, the foundation of WUAs and the implementation of groundwater regulations (Calow et al. 2009 ; Huang et al. 2009 ; Shen 2004 ; Shen 2015). The foundation of river basin organisations is a development which can be observed worldwide and followed the insight that water management boundaries need to overlay hydrological boundaries (Jaspers 2003). China’s revised Water Law of 2002 presents directives on the status of river basin management organisations (Shen 2004). However, the directives do not include a full clarification on the function of those organisations and the integration of surface water and groundwater management at river basin level (Shen 2004). In the Hexi Corridor, river basin management authorities have been established for the three major inland river basins since the turn of the millennium. Yet, the mandate with regard to groundwater use is not the same for the three River Basin Management Bureaus. This is considered an important institutional aspect which is described and discussed in more detail in this paper.

Another important institutional reform in the organisation of the irrigation sector in China has been the foundations of WUAs. WUAs are ideally self-organised and intend to allow water users to participate in water management (Svendsen and Meinzen-Dick 1997). Worldwide WUAs have been set up to solve managerial problems in canal irrigation systems; however, WUAs which are responsible for groundwater management can also be found (Lopez-Gunn 2003). In China the first WUAs have been introduced through World Bank projects in canal irrigation systems; nowadays WUAs are common all over northern China (Huang et al. 2009). In many cases WUAs are found to be promoted by the government rather than self-organised by the water users (Aarnoudse et al. 2012 ; Qiao et al. 2009). In the Hexi Corridor WUAs have been introduced by the water authorities over the last two decades. In all three river basins the WUA boundaries are identical with village boundaries and the WUA board is made up of the same people as the village committee. It has been argued that this constellation reduces the participation of farmers in WUA activities (Huang et al. 2010). Indeed it has been observed that although all water users in the villages are officially WUA members, not all of them are aware of being a WUA member or see any use in being a WUA member (Aarnoudse 2010 ; Yu et al. 2014). In this context, WUAs can basically be understood as a new set of functions transferred to the village committee by the water authorities. In this paper the role of WUAs (in particularly WUA boards) is described to understand the integration of surface water and groundwater institutions at village level. It should, however, be kept in mind that what is called WUAs in this context defers from the original concept of participatory, self-organised user organisations.

The third institutional reform which is particular relevant for the question of conjunctive water management are regulations with regard to groundwater. Until recently groundwater could be considered as an open access resource all over China. This changed since the revision of the Water Law in 2002; the new law foresees the regulation of groundwater in areas of severe overdraft. Again, it is not prescribed what such regulations should look like or how they should be implemented (Shen 2015). In response to the new water law, groundwater management reforms have taken place in the Hexi Corridor over the last decade. However, regulatory institutions differ from basin to basin. In this paper particular attention is paid to those newly established formal institutions which intend to regulate farmers' groundwater use.

2.3.2 Perspectives on the role of public administration in the process of institutional change

The recent institutional reforms in the Chinese water sector were all backed up by the 2002 Water Law. Because China is known as a centralized, authoritarian state, we might expect such national policies to result in similar outcomes all over the country. However, as we will see, this is not necessarily the case. Differences in the implementation of national policies at local level can often be explained by: 1) unclear directives at national level; and/or 2) the ambiguous role of public administration in implementing national policies (Wegerich 2015). Because *institutionalised* policies rather than policies *on paper* are the focus of this research, this paper does not discuss the national policy directives in much detail. Instead, the paper concentrates on the role of local water authorities in shaping and implementing those policies.

From an economic perspective a rational choice approach is often applied to understand the behaviour of public administration. Rational choice theories are “a framework for understanding how actors operate with fixed preferences that they attempt to maximize under a set of constraints” (Barnett 2010 p.154). When applied to public sector organisations, the organisation is considered as an agency which acts based on rational decision making. Rational choice theories are often criticized because they reduce the motivation of an agency to a simplistic model which is based on individualised costs and benefits attached to a certain decision (i.e. costs and benefits for the society are not considered to be a true motivation of the public administration) (Hondeghem and Vandenabeele 2005 ; Popa 2015). Popa (2015) argues that to understand the choices made by agencies a broader model of motivations should be applied, which includes other incentives than individual utility maximisation alone. Moreover, it is argued that the institutional setting in which decisions are made is of critical importance and cannot be discarded as an external factor (Hay 2004 ; Popa 2015). Popa states that the institutional context “can end up altering radically the types and relative strength of motivational variables at play” (p.236).

In this paper water authorities are assumed to function as agencies which have a certain level of control over the decisions they take – in accordance with rational choice theories. However, the decisions are not considered to be based on personal utility maximisation alone, but on a broader set of incentives which are embedded in the institutional context. This perspective is in line with Cleavers’ (2012) definitions of institutions, which highlights that institutions are not merely constructed by human agencies, but evolve through a messy process of “bricolage”. In this process agencies “draw on existing social formulae to patch or piece together institutions in response to changing situations” (p.45). In literature local authorities are often considered to obstruct the implementation of groundwater regulations (De Stefano and Lopez-Gunn 2012 ; Hoogesteger and Wester 2015 ; Molle and Alvard 2015 ; Mukherji and Shah 2005). Therefore, this paper looks mainly at the motivation of *local* water authorities to implement groundwater regulations. The personal cost and benefit dimensions – classically part of rational choice theories – are considered, but also the institutional context which either creates positive or negative incentives are discussed.

2.4 A description of the three cases

In this section each case will be described in more detail. Each case description starts with a short introduction to the responsibilities of the river basin authority and the local water authorities. Then, the development of groundwater use and the current state of groundwater regulation is described. When applicable, conjunctive management measures are discussed next. Finally, village level water institutions are described as well as farmers' conjunctive use habits. At the end of each case description a short paragraph highlights the lessons that can be drawn from the case for this research. Table 2.1 summarises the most important topics described in the text.

Table 2.1 Summary of the three case studies

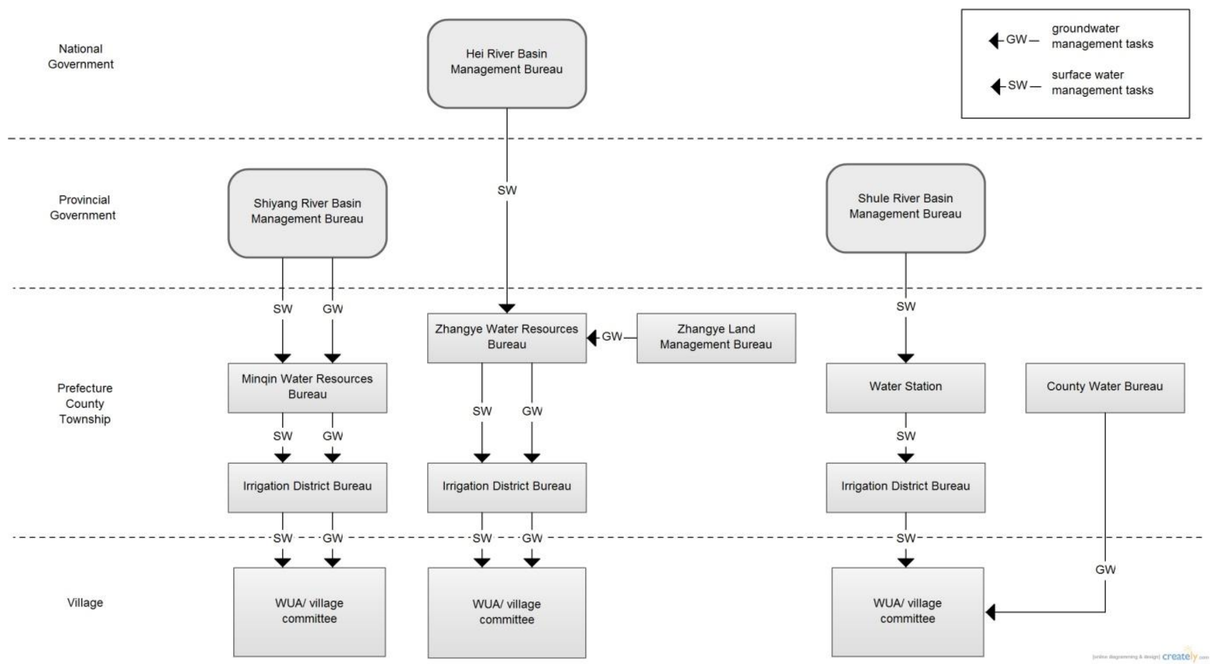
	Case study 1: alluvial plains of the Shiyang River Basin	Case study 2: alluvial plains of the Hei River Basin	Case study 3: alluvial plains of the Shule River Basin
Institutional conditions			
Management responsibilities of river basin and local authorities	River basin authority responsible for sw and gw At local level one agency responsible for sw and gw	River basin authority responsible for sw only At local level one agency responsible for sw and gw	River basin authority responsible for sw only At local level two agencies responsible for sw and gw
Gw regulation measures	*Effectively implemented instruments:*	*Ineffectively implemented instruments:*	*Ineffectively implemented instruments:*
	Well permits; Well closure; Gw quota	Well permits; Area based gw pricing; (Well drilling ban)	Well permits; Tiered gw pricing
	Positive incentive:	*Negative incentive:*	*Negative incentive:*
	Gw allocation targets set by river basin authority	Reduced sw allocation targets set by river basin authority	Sw and gw fees collected by two independent agencies
Sw and gw institutions at village level	WUAs responsible for sw and gw Well operator part of village authorities Sw and gw use collectively organised	WUAs responsible for sw only Well operator mostly independent Sw use collectively, gw use individually organised	WUAs responsible for sw (informally also for gw) Well operator mostly independent Sw use collectively, gw use mostly individually organised
Benefits of conjunctive water management			
Farmers' conjunctive use habits	Gw use is increased in sw scarce years and decreased in sw abundant years	Gw use is increased in sw scarce years and decreased in sw abundant years	In areas of intensive gw use, gw use is increased in sw scarce years and decreased in sw abundant years In areas of moderate gw use, gw use is independent from sw availability
Conjunctive water management measures	Sw reallocation to compensate for restricted gw use Sw reallocation to areas experiencing high soil-salinity Adjustment of sw schedule to benefit crops with low irrigation requirements (adapted to restricted gw use) Construction of small in-field basins to enable pressurized irrigation techniques with sw (instead of more saline gw)	-	Rotation of sw irrigation sequence between villages along the same canal to even out sw-gw use ratio

2.4.1 The plains of the Shiyang River Basin

Management responsibilities of river basin and local authorities

The Shiyang River Basin Management Bureau was established in 2002 and stands under the direct jurisdiction of the Gansu Province Water Management Bureau. The river basin authority is responsible for both surface water and groundwater management. Before its foundation, separate water management agencies at county level were eligible for the allocation and management of surface water. At that time, groundwater was effectively not managed by the water authorities. Currently the activities of the local water authorities are coordinated by the River Basin Management Bureau (see Figure 2.2). From 2007, the river basin authority carried out a far-reaching reform by implementing the Shiyang River Basin Management Plan; the plan affected both the allocation of surface water and groundwater. Since then a considerable share of the local water authorities' activities have been absorbed by groundwater management. The main goal of the new management plan was to prevent further desertification and salinization of Minqin County, located at the river's downstream reaches.

Figure 2.2 Organizational structure of water authorities and the division of surface water and groundwater management tasks



Source: own compilation

Groundwater development and regulation measures

Since the late 1990s, Minqin County suffered from severe water stress and high desertification rates. During the 1950s and 1960s many dams were built in the upstream reaches of the Shiyang River, which drastically reduced the river inflow to Minqin County. This led to a violent conflict between the people from Minqin and the people from Wuwei County, located directly upstream. The conflict ceased when farmers in Minqin started to pump shallow groundwater in the 1970s. However, reduced surface water inflow and intensive pumping over more than two decades caused a serious threat to the partly man-made oasis. As the disappearance of Minqin's oasis was considered to unite two large sandy deserts (the Tengger and the Badain Jaran) into one, the issue was propagated to be of national concern. In 2007, the central government intervened and supported the launch of the Shiyang River Basin Management Plan to "Save the Oasis". The plan foresaw, on the one hand, a decrease in groundwater pumping in Minqin; on the other hand, an increase in surface water inflow to Minqin. To enforce implementation career opportunities for water officials in the Shiyang River Basin are linked to reaching the groundwater allocation targets.

To reduce groundwater use in Minqin, the local water authorities closed a large number of wells from 2007 to 2010. Officially 3000 out of 7000 wells were closed, particularly wells which irrigated land at the edges of the desert. In addition, special water meters were installed on all remaining wells to enforce volumetric water pricing and a per capita groundwater quota. These so-called "smart card machines" are water meters linked to a digital administration system. Once the machines are connected to the pumping installation, the pump can only be turned on after swiping a smart card at a display on the machine. The abstracted water volume is measured by the built-in water meter. As soon as the pumped volume surpasses the water account on the card, the pump is turned off automatically. Only after the card is reloaded by the IDB the pump can be used again. In Minqin the volumetric groundwater price is 0.02 CNY/m^3 and mainly meant for cost recovery. Official water quotas are allocated per farm group based on a per capita norm of 1200 m^3/year[13]. The quota includes surface water, groundwater and rainfall (rainfall covers only a very small proportion though). Priority is given to surface water allocation, which means that actual groundwater quota can differ per year and per location depending on the surface water availability (and rainfall) during the season. Because farm groups now have to reload their smart card before each irrigation turn, the IDB can directly influence farmers' groundwater use decisions. 80% of the farmers stated that they currently use less groundwater per unit of land than ten years ago (i.e. before the machines were installed).[14] Furthermore, all well operators reported to have reduced groundwater pumping after the machines were installed.

[13] Similarly, a per capita norm was used to allocate *land* resources after de-collectivization of the Chinese countryside in the late 1970s. Initially land re-distribution took place every three years to adjust to changing household sizes. However, this practice was abolished since the late 1990s when national policy directives assured land use right for at least 30 years. In 2008 a new policy was introduced which assures land use rights for an undefined period of time.

[14] The answer is in line with crop changes reported by the village leaders over the same period of time. Currently farmers in Minqin grow crops with a lower water demand than ten years ago.

Conjunctive water management measures

To achieve increased river inflow to Minqin, the River Basin Management Bureau mainly undertook infrastructural measures. Minqin's surface water is diverted from the Hongyashan Reservoir, located at the narrow pass way between Wuwei and Minqin County. Canals from and to the reservoir were lined to save water. Moreover, a parallel canal was constructed in Wuwei to send a proportion of the river water directly to Minqin, without outlets for users upstream. The surface water supply to Minqin recently increased from 110 Mm^3/year (2000-2009) to 300 Mm^3/year (2010-2014) (Government of Minqin 2015). The increased surface water inflow only partly offsets farmers' reduced groundwater access. After all, Minqin's groundwater extraction has officially been reduced according to plan from 620 Mm^3/year in 2003 to 120 Mm^3/year in 2010 (Gansu Province Water Resources Bureau 2007 ; Meng 2013). In fact, the increased river inflow to Minqin is not only used for irrigation but also to regenerate the downstream located tail-end lakes. At the same time, local water authorities benefit from the improved surface water supply for salinity-control measures within Minqin. In the past, Minqin's Lake District, located at the river's tail-end, used to have the worst access to surface water. Farmers recalled receiving at most one irrigation turn, if any, in the early 2000s. The area suffers from high soil-salinity levels due to repeated irrigation with saline groundwater (up to 5 mg/l) (Ma et al. 2005). To relieve the salinity problem, the water authorities currently prioritize surface water supply to the downstream Lake District.[15] According to the survey data, farmers in the Lake District receive at present at least as many surface water irrigation turns as farmers in the more upstream districts of Minqin.

Besides the increase in surface water supply to Minqin, other changes in the water release schedule and irrigation infrastructure aim at improving the water use conditions for the farmers in Minqin despite groundwater use restrictions. One example is the early release of the first surface water irrigation turn, which is beneficial for the growth of new perennial crops propagated for its low irrigation demand, like date trees and gouqi berries. These crops need water earlier in the season than the annual crops previously grown by the farmers. Another example is the construction of small surface water basins in the Lake District to allow for pressurized irrigation techniques, like drip irrigation. Usually drip irrigation is supplied with groundwater, since the pumping automatically provides the required pressure. To save water the government has promoted the use of drip irrigation; however, farmers in the Lake District protested heavily because they consider the groundwater too saline to be "dripped" in high concentrations at the crop's root zone. Through the

[15] Surplus surface water irrigation either during or after the cropping season can be used to leach out salts from the upper soil (Corwin et al. 2007). This is a common practice in Northwest China.

construction of small surface water basins the authorities hope to persuade farmers to use the less saline surface water for drip irrigation (see Figure 2.3).

Figure 2.3 In-field surface water basin in the Lake District, Minqin

Source: own picture

Surface water and groundwater institutions at village level

In Minqin WUAs are officially responsible for both surface water and groundwater management tasks. All interviewed village leaders confirmed that both surface water and groundwater issues are discussed at WUA meetings. WUAs were formed in each village in 2007, at the same time as the new groundwater regulation measures came into effect. It has been argued that WUAs play an important role in the implementation of the new groundwater regulation measures (Aarnoudse et al. 2012). At the start of the irrigation season WUA board members are gathered at a general meeting organised by the IDB, here they are informed about the forecasted surface water availability and a tentative surface water schedule. Based on the number of inhabitants and a per capita water quota, villages are allocated a certain amount of irrigation water. The surface water-groundwater use ratio eventually depends on the surface water availability during the cropping season.

The operation and maintenance of the groundwater wells is mainly carried out by the farm group leader, who is also responsible for the farm group's surface water distribution. In his function as well operator, his main tasks are maintenance of the pumps and wells, collecting the groundwater fee, turning the pumps on and off and administering the groundwater account. Usually the smart-card has to be topped-up at the IDB office before each irrigation turn. In response to the limited access to groundwater, groundwater use decisions are most of the time made collectively. When to start irrigating is decided by a meeting of household heads. Such gatherings frequently take place to discuss various, also non-water related issues. To save water the groundwater irrigation turn is often suspended or postponed as long as possible. In the upstream villages, where farmers are used to grow crops with different water requirements, this sometimes leads to conflicts. In order to solve these problems, farmers now try to grow similar crops within one well command area and coordinate irrigation turns to avoid unnecessary losses (Aarnoudse et al. 2015).

Once the irrigation turn has started, each farmer is responsible for irrigating his/her own plot and noting down the reading on the electricity meter in a small booklet at the pump house at the end of his/her turn. The electricity consumption is considered equivalent to the water consumption and the records are used to calculate both electricity and water costs per household. The total groundwater volume on a farm group's account is restricted, which sometimes leads to difficulties to irrigate all plots of the well command area. In one village, the village leader explained that when one farmer is disadvantaged, he mediates between the farmers by demanding a compensation for the disadvantaged farmer. The compensation is preferably paid in nature (i.e. the disadvantaged farmer receives more water during the next irrigation turn), but can also be paid in monetary terms. One village leader even mentioned that in his village they continue to rotate the plots with good water access and bad water access annually, to allow equitable water access from year to year. This is, however, not a widespread practice. Most villages have eliminated land redistribution practices at least by 2008, when the central government announced to prolong land use right for an indefinite time.

Farmers' conjunctive use habits

In principle all farmers in Minqin use both surface water and groundwater for all crops. Surface water is usually applied during the early cropping season and groundwater during the late cropping season. Most farmers prefer to use surface water instead of groundwater, because of relatively high groundwater salinity levels. In the tail-end Lake District, where the groundwater salinity problem is most severe, farmers use groundwater only scarcely. Groundwater use is also particularly discouraged by the water authorities in this area. This is likely related to the long-term policy objective to develop the Lake District into a wetland area without much agricultural activity (Yang 2009).

Overall, conjunctive use is assessed positively by the farmers. 92% of the farmers indicated to adjust their groundwater use from year to year depending on the surface water availability. However, only 53% said to voluntarily reduce groundwater use in surface water abundant years, the rest does so on demand of the water authority. Moreover, 59% said to feel restricted in the amount of water they can use to compensate for the lack of surface water in water scarce years. The water authorities claim to loosen groundwater regulations when the annual river inflow is low and vice versa. At river basin level surface water and groundwater quota are allocated per year based on the forecasted surface water availability, whereby the use of surface water is prioritized. One of the local staff members explained that at irrigation district level this means inpractice that farmers are allowed to use more groundwater when they receive less surface water. “For example in 2013 *Township X* and *Township Y* both got three irrigation turns, but *Township Z* only got two irrigation turns, in that case *Township Z* can use more groundwater.” In principle the decision whether farmers are allowed to use groundwater is made by the IDB. It was even mentioned repeatedly that the IDB demands the next groundwater irrigation turn to be postponed or even suspended after rainfall. The occurrence of rainfall is limited though. It was, however, also found that to some extent villagers may be included in the decision making process. A village leader in one of the tail-end villages explained that in 2012 two farm groups from his village decided to wait for the announced third surface water turn and could avoid another groundwater turn, while the other farm groups considered the third surface water turn to arrive too late and used groundwater instead.

Lessons

In the past conjunctive use developed spontaneously on the plains of the Shiyang River Basin; however, over the last decade it was possible to overcome the institutional barriers and move towards a state of conjunctive water management. Currently surface water and groundwater institutions are integrated at all water management levels, from river basin to village level (see Figure 2.2). Moreover, groundwater use is effectively regulated through direct regulation measures, like the closure of wells and groundwater abstraction quota. One incentive driving local water authorities to implement those regulations is the increasing threat posed by desertification. However, a second important incentive is the sheer pressure from “above”, which has been made tangible through a reward system linking water officials’ career opportunities to groundwater abstraction targets. Several benefits related to conjunctive water management have been observed in the case study area, such as the flexible use of groundwater with respect to variable surface water availability and the implementation of different water management measures which bridge surface water and groundwater issues.

2.4.2 The plains of the Hei River Basin

Management responsibilities of river basin and local authorities

In 2000, the Hei River Basin Management Bureau was set up. Because the Hei River is located in two Chinese provinces, Gansu and Inner Mongolia, the River Basin Management Bureau is under direct jurisdiction of the national Ministry of Water Resources. The main seat of the Bureau is not as usual located within the river basin itself, but in Lanzhou, the capital of Gansu Province. The Hei River Basin Management Bureau is responsible for the allocation of surface water between the two provinces. Before establishing the new river basin authority, the Erjina Terminal Lake in Inner Mongolia was in danger of disappearing. The only task of the river basin authority is to secure the transfer of sufficient water from the upstream Hei River in Gansu Province to Inner Mongolia in order to preserve the terminal lake and its surrounding oasis. The River Basin Management Bureau is neither responsible for the distribution of surface water within the two provinces, nor for the management of groundwater. Instead local water authorities are in charge of groundwater management. The Zhangye Water Management Bureau is eligible for the allocation and management of surface water and groundwater in the middle reaches of the Hei River Basin (see Figure 2.2).

Groundwater development and regulation measures

Most villages in the middle reaches of the Hei River Basin started using groundwater over the last ten years. At the same time, many villages have increased their cropping area by irrigating previously uncultivated land. In fact, the area has known an important agricultural boost over the last ten years due to the introduction of high-value seed production. Farmers mainly produce maize seeds; to a limited extent vegetable seeds are also being produced. In ten years time, Zhangye has become the most important maize seed producer of China, covering 30-50% of China's maize seed production. This, as well as the tightened surface water situation due to increased allocation to the downstream area in Inner Mongolia, has likely driven the recent groundwater development.

The Zhangye Water Management Bureau has the mandate to manage the groundwater; however, compared to the other two river basins, few activities have been developed in this regard. Groundwater management measures have been more symbolic than effective e.g. a groundwater price based on irrigated area or well permits which were basically provided without limitation. One reason may be that groundwater only recently became an important source of irrigation water for farmers in Zhangye. Usually groundwater management only develops after groundwater use has intensified (Kemper 2004). Another reason may be that the use of groundwater relieves pressure on the Bureau's obligation to send sufficient surface water to the terminal lake in Inner Mongolia. Farmers are less likely to complain about reduced surface water supply when they can use groundwater instead. Whereas the Zhangye Water Management Bureau does not seem to perceive the development of groundwater in the river basin as an acute problem, the rapid expansion of cultivated area is of concern to the local Land Management Bureau. The illegal cultivation of land at the fringes of the desert increases the risk of sand storms and desertification. Because the cultivation of previously barren land is associated with drilling new wells, the Zhangye Land Management

Bureau pleaded for a ban on well drilling (see Figure 2.2). In cooperation with the Zhangye Water Management Bureau, such a ban was put in effect in 2014.[16]

Surface water and groundwater institutions at village level

At village level, WUA boards are officially only held responsible for surface water management tasks. The concept of WUAs was launched in 2002 when Zhangye was presented as a nation-wide pilot project to promote water conservation under the slogan "Building a Water Saving Society" (see Figure 2.4). The project contained both institutional and infrastructural surface water management reforms. However, the infrastructural reforms (i.e. water saving through canal lining) are considered to have been more successful than the institutional reforms (i.e. water saving through trading water rights), particularly because groundwater use was not accounted for (Zhang et al. 2009). At the beginning of the irrigation season the IDBs organise a meeting with WUA board members to announce the forecasted water allocation for the coming year. To coordinate the irrigation schedule, staff from the IDBs is located in the villages during the irrigation season.

Figure 2.4 Slogan "Building a Water Saving Society" on a farmer's house

Source: own picture

The interviewed village leaders stated that groundwater management is not considered to be the responsibility of the WUAs. Per farm group one person is responsible for the wells, whose tasks are to collect the electricity fee and maintain the pumps and wells. Sometimes, particularly when there are only a few wells, the farm group leader carries out the well operator tasks (in three out of seven surveyed groundwater using villages). In all other cases these tasks are carried out by a separate person, who receives a small fee which is collected in addition to the electricity price. Farmers decide individually when and how much groundwater to pump and note down their electricity use per irrigation turn. A volumetric groundwater resource fee is not collected. Although officially farmers

[16] The policy was implemented after the survey was carried out and thus had no effect on the questionnaire results.

should be paying a groundwater price per area, village leaders are only limited aware of this and common farmers are not at all aware of this.

Farmers' conjunctive use habits

Not all farmers in the middle reaches of the Hei River Basin irrigate with groundwater. Only 40% of the surveyed farmers used groundwater supplementary to surface water irrigation. 77% of them prefer to use surface water over groundwater. Surface water is preferred for various reasons; above all because surface water is less saline and secures higher crop yields. In general the groundwater use intensity is higher in areas where the surface water supply is lower. Farmers consider the conjunctive use of surface water and groundwater beneficial, because it allows flexible access to water at any time. All conjunctive users confirmed to adjust their groundwater use to annual variability in surface water supply. 94% states to *voluntarily* reduce their groundwater use when more surface water is supplied. However, 40% of them consider the potential to compensate with groundwater to be limited; this perception is most widespread in the upstream villages where groundwater use is still less developed and the number of wells per unit of land is lower.

Lessons

The use of surface water and groundwater on the plains of the Hei River Basin is still in a state of spontaneous conjunctive use. At the same time, surface water and groundwater institutions are not integrated at most management levels (see Figure 2.2). The river basin authority is only responsible for surface water and also at village level surface water and groundwater use are organised separately. At the local level surface water and groundwater responsibilities are carried by the same organisation; however, groundwater management has largely been neglected so far. The local water authorities have been forced to reduced surface water allocation targets by the river basin authorities, this has probably motivated them be more lax on farmers' groundwater use in return. Even though conjunctive use is not coordinated at irrigation system or river basin level, farmers' confirm to adjust their groundwater use in accordance with variable surface water supply conditions. They do so mainly because surface water is preferred over groundwater due to differences in water quality.

2.4.3 The plains of the Shule River Basin

Management responsibilities of river basin and local authority

The Shule River Basin Management Bureau was founded in 2005. The Bureau is under direct jurisdiction of the Gansu Province Water Management Bureau. The newly established River Basin Management Bureau was assigned to allocate and manage the surface water at river basin level. This role had until that time been in the hands of the Prefecture Government of Jiuquan. Actual management activities were divided amongst smaller County Water Bureaus. The new river basin authority was created to initiate a water management reform and implement a more coherent water allocation and management plan at river basin level. The river basin authority took over all responsibilities regarding surface water management, which had until then been assigned to the County Water Bureaus. Supervision over the implementing agencies, like the Water Stations (at irrigation system level)[17] and the IDBs (at irrigation district level), was also transferred to the River Basin Management Bureau. The County Water Bureaus did, however, continue to exist and stayed in charge of groundwater management issues. This led to the current situation in which two separate state agencies are in charge of surface water and groundwater management (see Figure 2.2). Little cooperation takes place between the two agencies. In 2014, the river basin authority contested the separation of surface water and groundwater management. A plea was made at higher authorities to transfer the responsibility over groundwater management to the River Basin Management Bureau.

Groundwater development and regulation measures

Groundwater use developed in the Shule River Basin in the 1990s. At this time a large migration project brought rural inhabitants from central Gansu to the scarcely populated Shule River Basin (Zhang and Zhang 1996). The main concern of the government was poverty alleviation. Through this project people were offered to escape from the resource poor and remote mountainous areas. In new settlements groundwater wells were drilled by the government to enable agriculture on previously uncultivated land. In the pre-existing settlements groundwater drilling also took off around this time. The use of groundwater did not develop everywhere at the same pace within the Shule River Basin. In the upstream irrigation system (Yumen County), supplied by the Changma Reservoir, farmers' groundwater use decreased over time due to improved surface water supply conditions after construction of a new dam in 2006. In the downstream irrigation system (Guazhou County formerly Anxi County), supplied by the Shuangta reservoir, farmers' groundwater use intensified over the last decade due to worsened surface water supply conditions.

Initially, the government's interference in farmers' groundwater use was confined to the support of groundwater use development. However, since 2003 new regulations have been implemented to manage farmers' groundwater use. Under jurisdiction of the Prefecture Government of Jiuquan a groundwater resource price and well permits were introduced by the County Water Bureaus. The groundwater resource price was originally based on a flat rate per irrigated area and weakly implemented, but since 2007 volumetric water pricing with an increased block rate has been

[17] This type of water management organization was only found in the Shule River Basin.

enforced. This so-called “tiered pricing” is a regulatory institution which intends to stimulate users to safe water, while securing a limited amount of water at affordable levels for all users. To enable a volumetric groundwater pricing system, smart card machines were installed on all wells.

Village leaders and well operators reported that 0.01 CNY/m^3 is paid for the first 100,000 m^3 per well, and 0.02 CNY/m^3 is paid above this limit. The price is officially set at prefecture level and is claimed to be the same everywhere. It is unclear based on what standards the price and volume of the initial consumption block are defined. Since the well density is not everywhere the same it does not safeguard equal pricing for all water users. The implementation of the groundwater pricing system in the Shule River Basin seems to have been motivated mainly by administrative considerations, since the County Water Bureau’s income from surface water fees was omitted after the establishment of the River Basin Management Bureau. This may have created a negative incentive to strive for income from groundwater fees, rather than aim at a reduction in groundwater use. Whereas farmers confirm that the costs of groundwater use have increased since the introduction of the volumetric groundwater pricing system, their groundwater use has not been reduced. In fact, in Guazhou, where groundwater is used intensively, 80% of the farmers stated to use the same amount or more groundwater per unit of land compared to ten years ago (i.e. before the machines were installed). Moreover, hardly any of the well operators stated to have reduced groundwater pumping after installation of the smart card machines.

Surface water and groundwater institutions at village level

In the Shule River Basin the WUA board is officially only responsible for surface water irrigation. The WUAs were founded around 2005, when the new river basin management authority was established. In Yumen, meetings between the IDB and members from the WUA board take place every two-three weeks during the irrigation season (March-October). Surface water is practically available all the time throughout the irrigation season and the number of surface water irrigation turns is very high (9-12 per year). This is likely the reason why frequent meetings with the IDB are needed to coordinate surface water use between the villages. Village leaders in Yumen consider the WUA to be solely responsible for surface water management. In Guazhou, there are no regular meetings between the IDBs and the WUAs throughout the irrigation season. At the beginning of the year, WUA board members attend one fixed meeting at the IDB during which the surface water availability is forecasted and a tentative irrigation schedule is presented. Although WUAs have not been assigned to take up groundwater management tasks, the village leaders in Guazhou do consider WUAs to be responsible for official groundwater issues, such as applying for well permits at the County Water Bureau.

In both Yumen and Guazhou practical groundwater management is organised at farm group level. In some villages where there are only a few wells, the farm group leader is in charge of the well operator responsibilities (in three out of ten surveyed villages). Otherwise these tasks are carried out by an independent person, who receives a small remuneration which is collected on top of the electricity price. The main tasks of the well operator are to collect the electricity and groundwater resource fee and to repair and maintain the pumps and wells. In Guazhou, the well operator is also responsible for coordinating the irrigation turns. The timing is collectively decided by the household heads. As abstraction is not directly restricted and the cropping pattern is rather homogeneous this hardly leads to any conflicts. In Yumen, the use of groundwater is decided by households individually. The farmer simply informs the well operator and turns the pump on and off. In both cases the energy consumed or time spent to pump up groundwater is recorded by the households themselves. The farm group's groundwater and electricity bill is shared amongst the households based on a groundwater price per hour or per kWh. This means that the pricing threshold introduced with the tiered pricing system is not experienced by the farmers at household level.

Farmers' conjunctive use habits

In the Shule River Basin there are different practices of conjunctive water use. In Yumen, farmers use groundwater and surface water separately for specific crops. Groundwater is used for greenhouse crops and surface water is used for outdoor crops. In Guazhou, farmers use both surface water and groundwater for all crops. Surface water is applied during the early cropping season and groundwater during the late cropping season. Besides that, the groundwater use intensity differs strongly between Yumen and Guazhou. In Yumen only 20% of the surveyed households used groundwater in 2013, while in Guazhou all farmers used groundwater. Moreover, farmers' groundwater use per unit of land in Guazhou is much higher than in Yumen, primarily because the surface water supply is lower.

Farmers in Guazhou state to prefer the use of surface water, not because of price differences, but because groundwater is considered to be saline and surface water is associated with a higher crop yield. Farmers asses the conjunctive use situation positively because it makes agriculture less dependent on the insecure surface water supply. 85% states to *voluntarily* adjust their groundwater use to inter-annual variability in surface water supply. To some extent this adaptation to insecure surface water supply is institutionalized. In one village, the village leader explained that the sequence of the surface water irrigation schedule is rotated from year to year amongst three villages along the same canal. In water scarce years, the third village in the sequence will receive less surface water than the others and use more groundwater instead. The year after, this village will, however, be the first to receive surface water. In Yumen, most farmers prefer surface water because the water flow in the canals is larger which makes irrigation less time consuming. For farmers in Yumen the advantage of conjunctive use is related to the different flow characteristics of the two water sources. As mentioned by one village leader: “Groundwater is convenient to irrigate the greenhouse crops. Yet, surface water flows faster and is more convenient to flood the big fields.” Here, farmers usually do not use groundwater as a buffer to supplement variable surface water supply.

The different function of conjunctive water use in the two counties is also consolidated in the groundwater infrastructure and maintenance institutions. In Guazhou, where groundwater is used to supplement insecure surface water irrigation, wells are well-maintained and replaced when dysfunctional, this is considered a collective task. The application of a well permit to replace a broken well is even considered the responsibility of the WUA. In Guazhou, sufficient wells have been maintained to supply the whole cropping area with groundwater. In Yumen, the groundwater wells are also share-owned, but there is a decreased collective interest in maintaining the wells. Many of the old wells have been neglected and left abandoned over the last ten years. Use of the few remaining wells differs per household based on individual needs. The current number of maintained wells cannot supply the total cultivated area with groundwater. Farmers doubt whether they would be given well permits to replace the old, abandoned wells in case surface water would get scarcer again. Yet, they seem to care little, because the supply of surface water has been secure and abundant since the construction of the Changma Dam in 2006.

Lessons

Conjunctive use in the Shule River Basin is still largely spontaneous, despite the implementation of groundwater regulation measures. Surface water and groundwater management are carried out by completely seperate organisations, which are hardly cooperating. The River Basin Management Bureau is in charge of surface water, while groundwater management is the responsibility of water management organisations at county level. Recently the independent groundwater authority introduced a new groundwater pricing system. Although the new pricing system has raised the groundwater costs for farmers, it is not actually reducing their groundwater use. Revenue generation has likely been a more important incentive to implement the groundwater pricing system than curbing farmers’ groundwater use. One reason why local groundwater authorities are interested in generating revenue from groundwater fees may have been the loss of income from surface water fees, which has recently been reallocated to the newly established River Basin Management Bureau.

The extent of conjunctive use differs significantly between the upstream and downstream located counties. This also influences the institutions at village level and farmers’ conjunctive use habits. In the upstream reaches where groundwater use is rare, farmers do not perceive groundwater as a buffer to respond to variable surface water supply. Old groundwater infrastructure is neglected which cuts off the possibility to use groundwater in case of surface water scarcity in the future. In the downstream reaches, where all farmers use groundwater each season, groundwater is particularly appreciated by the farmers for its buffer function. It was even observed that the surface water irrigation sequence between villages was rotated inter-annually, so that on average the surface water-groundwater use ratio between the villages is the same.

2.5 Comparing and contrasting the three cases

In all three case studies presented in this paper conjunctive groundwater use initially developed spontaneously primarily based on decisions at farm level, like elsewhere in the world (World Bank 2005). Yet, at current the three cases are located at different positions on the "continuum" between spontaneous and coordinated conjunctive use as described by Evans et al. (2014). Conjunctive use in the Shiyang River Basin became more coordinated over the last few years, while in the Shule and Hei River Basin it still has a strong spontaneous character. Particularly in the Shule River Basin it can be observed that this has contributed to the increasingly uneven development of groundwater in the upstream and downstream located irrigation areas, which is considered typical for spontaneous conjunctive use situations (Foster and Steenbergen 2011). In the Shiyang River Basin a similar development took place in the 1970s, whereby agriculture in the downstream sub-basin relied more and more on the use of groundwater. But recently – only after soaring soil salinity and desertification rates – the trend starts to be reversed, mainly due to interventions by the water authorities. Those interventions were based on an integrated surface water and groundwater reallocation plan and went hand in hand with structural reforms in the water sector. The case illustrates that once a spontaneous conjunctive use situation has been established it asks for "major organisational change in water agencies" (Evans et al. 2014 p.32) to move towards a more coordinated conjunctive use situation.

2.5.1 Potential benefits of conjunctive management

As conjunctive use in the Shiyang River Basin has become more coordinated, new management strategies evolved at river basin and irrigation system level which "use relative advantages of surface water and groundwater resources to offset each other's shortcomings" (Blomquist et al. 2004 p.22). Examples of such conjunctive management solutions observed in the Shiyang River Basin are: 1) the reallocation of surface water to compensate for restricted groundwater use; 2) the reallocation of surface water to areas experiencing high soil salinity levels; 3) the adjustment of surface water irrigation schedule to promote crops with low irrigation requirements (adapted to reduced groundwater use); and 4) the construction of small in-field basins to enable pressurised irrigation techniques with surface water (instead of the more saline groundwater). This does not mean that a situation of perfect conjunctive management has been reached, but these are first signs of management solutions which are unlocked as soon as surface water and groundwater are managed conjunctively at irrigation system and river basin level. In the other two river basins it can be observed that surface water management strategies which are disconnected from groundwater management can be ineffective or have undesired effects on farmers' groundwater use intensity.

At farm level it was found that in all three study areas farmers profit from the shallow aquifer as a storage buffer and adjust their groundwater use to inter-annual variability in surface water supply.[18] The large majority of the groundwater using farmers (>80%) indicated to use more groundwater in years of surface water scarcity and less groundwater in years of surface water abundance. Under spontaneous conjunctive use conditions farmers' adjust their groundwater use voluntarily, primarily because they prefer the use of the surface water over the more saline groundwater. In one occasion, this mechanism was even found to be embedded in collective institutions which spread the burden of inter-annual surface water supply variability amongst neighbouring villages along one canal. Embedded in such collective institutions conjunctive use in those villages cannot be considered fully spontaneous anymore. Through collective action the surface water-groundwater use ratio between the villages is evened out. Under the more restricted groundwater use conditions in Minqin, farmers also adjust their groundwater use according to the surface water supply, but they do not always do so voluntarily. In the Shiyang River Basin only 53% of the farmers who indicated to reduce their groundwater use in surface water abundant years stated to do this voluntarily, opposed to 91% in the Shule and Hei River Basin. The case studies show that coordinated conjunctive use is not required to use the groundwater aquifer as a storage buffer. This mechanism can also be in place in a spontaneous conjunctive use situation given that surface water is preferred over groundwater use (e.g. because of superior water quality). However, when groundwater use is not restricted, recharge in years of abundant surface water supply may not be sufficient to maintain high groundwater levels. In that case, a conjunctive management approach is crucial to ensure enforcement of the buffer mechanism under restricted groundwater use conditions.

2.5.2 Institutional conditions for conjunctive water management

In literature it is assumed that conjunctive management in developing countries is hampered by the division of surface water and groundwater management over separate organisations (Evans et al. 2014 ; Foster and Steenbergen 2011) and a lack of "some form of regulation" (Evans et al. 2014 p.46)

[18] One exception forms the upstream irrigation system in the Shule River Basin where groundwater use is scarce and surface water supply has been abundant and reliable over the last ten years.

over farmers' groundwater. When comparing the three case studies these indeed appear to be major constraints for conjunctive management in the Shule and Hei River Basin – where conjunctive use is still largely spontaneous. But it was also found that these constraints have been overcome in the Shiyang River Basin providing the institutional conditions for a more coordinated conjunctive use situation. Hence, the study brings forward one positive and two negative examples showing what institutional conditions are required to facilitate conjunctive management.

Although one could imagine cooperation taking place between two separate agencies responsible for surface water and groundwater to achieve coordinated conjunctive use, reality shows that this is hard to achieve. In the Shule River Basin recent reforms caused a transfer of surface water management responsibilities from the agencies at county level (previously in charge of both surface water and groundwater) to a newly established river basin authority with its own decentralised organisations. This resulted in a state of rivalry between the agencies responsible for surface water and groundwater, which further complicates cooperation. In the Hei River Basin surface water and groundwater responsibilities are shared by the same organisation at local level, but at river basin level the superior authority is only concerned with surface water allocation. This bias at river basin level seems to motivate the water authority at local level to prioritize surface water management and hold a more reluctant attitude towards groundwater management. In both cases the spread of surface water and groundwater responsibilities hampers the emergence of conjunctive water management.

In the Shiyang River Basin, contrary to the situation in the other two river basins, surface water and groundwater fall under the joint responsibility of the same water management organisations at all management levels (see Figure 2.2). Even at village level, groundwater management (like surface water management) is in the hands of village authorities, while in the other river basins groundwater management at the village level is most of the time de-coupled from the village authorities. Based on this research it is only possible to hint at the reason why such completely divergent situations emerged. A likely explanation could be found in the different timing of the two types of reforms in the three river basins. In the Shiyang River Basin the organisational restructuring of the water management authorities coincided with groundwater management reforms which responded to alarming levels of overdraft. In the other two river basins, organisational reforms were mainly focused on surface water management and groundwater management reforms followed afterwards.

As expected, the groundwater regulations in Minqin also appeared to be paramount to move to a state of more planned conjunctive use. However, it was found that groundwater regulations do not necessarily lead to conjunctive management. For example, in the case of the Shule River Basin the groundwater pricing is: 1) not effective as a measure to regulate farmers' groundwater use; and 2) not adjusted to surface water allocation plans. It can even be argued that rigid groundwater regulations could cancel out benefits from conjunctive use conditions. For example, the banning of additional well drilling as is planned to be implemented in the Hei River Basin could further consolidate uneven groundwater development levels between upstream and downstream areas within the irrigation system. As such the flexible groundwater quota in Minqin – which vary depending on annual surface water availability levels – are a unique example of how groundwater regulations can be designed without losing the benefits of conjunctive use (i.e. increased water security).

The cases also underline the importance of the institutional context in altering the motivation of local water authorities to regulate groundwater (Hay 2004 ; Popa 2015). In the Hei River Basin local water authorities have for a long time not been interested in strictly regulating groundwater use because the superior river basin authority is only concerned with surface water allocation. This is contrary to the situation in the Shiyang River Basin, where particularly the pressure from higher authorities has motivated local authorities to regulate groundwater use. In the Shule River Basin the motivation of the local authorities to regulate groundwater use is again different. Here, the water authorities responsible for groundwater are primarily interested in groundwater fees as a management measure because they recently lost the responsibility over and also their income from surface water. In the other case study areas generating revenue through a groundwater fee is not an important incentive, because the concerned authorities do already collect the surface water fee.

2.6 Discussion and conclusions

The management of surface water and groundwater in the three major inland river basins in the Hexi Corridor followed different pathways over the last two decades. In the Shiyang River Basin recent water management reforms led to a more coordinated management of surface water and groundwater, while in the other two river basins this has not been the case. Based on a detailed description of the three cases, several conclusions can be drawn on why conjunctive management could emerge in the Shiyang River Basin and what have so far been the merits of conjunctive management observed in the river basin. It can be concluded that the emergence of conjunctive water management is facilitated by the shared responsibility over surface water and groundwater at all management levels. Moreover, groundwater regulation measures in Minqin were a precondition for the current state of conjunctive management. Nevertheless, groundwater regulations do not automatically facilitate the emergence of conjunctive water management. Incentives to regulate groundwater use need to align with surface water management strategies. With regard to the merits of conjunctive management it is observed that coordination at irrigation system level is not necessarily required to adjust agricultural groundwater use to inter-annual surface water supply variability. This mechanism can also be in place in a spontaneous conjunctive use setting given that surface water is preferred over groundwater (e.g. because of superior quality). It can be argued though, that conjunctive management is required to ensure enforcement of this mechanism under restricted groundwater use conditions. Besides that, several new water management measures going beyond a narrow focus on surface water or groundwater have been observed in the Shiyang River Basin. These include measures which are more widely considered as typical conjunctive management measures, such as the increased surface water allocation to tail-end districts for salinity control. But, less conventional management practices were also observed, such as the construction of small in-field surface water reservoirs to avoid drip irrigation with the more saline groundwater.

Although this paper might give the impression that the case of the Shiyang River Basin could serve as a model for conjunctive water management in small scale agriculture, this conclusion should be drawn with caution for two substantial reasons. The first reason is that the transformation from spontaneous conjunctive use to coordinated conjunctive use came about through a rigid top-down process. The Chinese central government itself made a considerable effort to push this change forward. This may be possible in a political system like in China, but is unlikely to function somewhere else. Under the current situation farmers completely lost their autonomy in using groundwater, while the power of the village authorities increased as they are now in charge of both surface water and groundwater allocation. Evans (2014) goes as far as to say that a top-down approach is inherent to coordinated conjunctive use. It is indeed questionable whether there could also be more bottom-up mechanisms to achieve conjunctive management in a setting of smallholder agriculture. Yet, the observed rotation of irrigation sequences amongst neighbouring villages could be seen as a positive example, even though on a small scale.

The second reason why the “Shiyang-model” does not necessarily function somewhere else is that the reduction of farmers’ groundwater use in Minqin has been considerable. Although not analysed in this paper, the groundwater restrictions are likely to have an important impact on farmers’ livelihood strategies and income from agriculture (Li et al. 2014). Even though there have been mechanisms of compensation (e.g. villages received a fixed sum per closed well, see Aarnoudse et al. 2012), the impact on farmers’ income makes the new policies unpopular. However, before the implementation of the new policies the situation was close to catastrophic, particularly at the rivers’ tail end the desert was encroaching on cultivated land. The severe situation might have increased the population’s acceptance towards the strict groundwater regulation measures. The question remains how water users can be convinced to cut back their groundwater abstraction and accept income losses when the consequences of intensive use are not yet visible. Moreover, it should be considered whether under all circumstances it is desirable to constrain farmers' groundwater use to such an extent. Lopez-Gunn et al. (2011) argue that "if farmers livelihood rely heavily on groundwater resources, a ruthless push toward wetland restoration may not be the most sensible solution to the problem" (p.103).

Paper 2

The impact of surface water allocation on farmers' groundwater use in Northwest China

Abstract

Intensive groundwater use poses a threat to local ecosystems and rural livelihoods in an increasing number of locations in northern China. Direct groundwater regulations, through well permits or pumping quotas, come at high costs both for the state and local farmers. Therefore, indirect regulations, which intend to steer farmers' groundwater use by taking measures outside the groundwater sector, are desirable. Although groundwater is often used in conjunction with surface water, surface water management is rarely considered as a tool to indirectly regulate farmers' groundwater use. To evaluate the potential role of surface water management with regard to groundwater regulation, the influence of surface water supply conditions on farmers' groundwater use behaviour is explored. The research is based on a farm household survey in two inland river basins in Northwest China where groundwater use is still largely unconstrained by government regulations. After presenting descriptive statistics on farmers' conjunctive use in the study area, a multivariate analysis is carried out to estimate the effect of surface water supply on farmers' groundwater use quantity. In addition, a statistical comparison is made between conjunctive groundwater users and single surface water users to analyse the impact of groundwater use on farmers' agricultural intensification. Finally, it is concluded whether surface water management could be used as a measure for indirect groundwater regulation based on the research results.

Key words: *conjunctive water use, groundwater depletion, household behaviour, arid regions, China*

3.1 Introduction

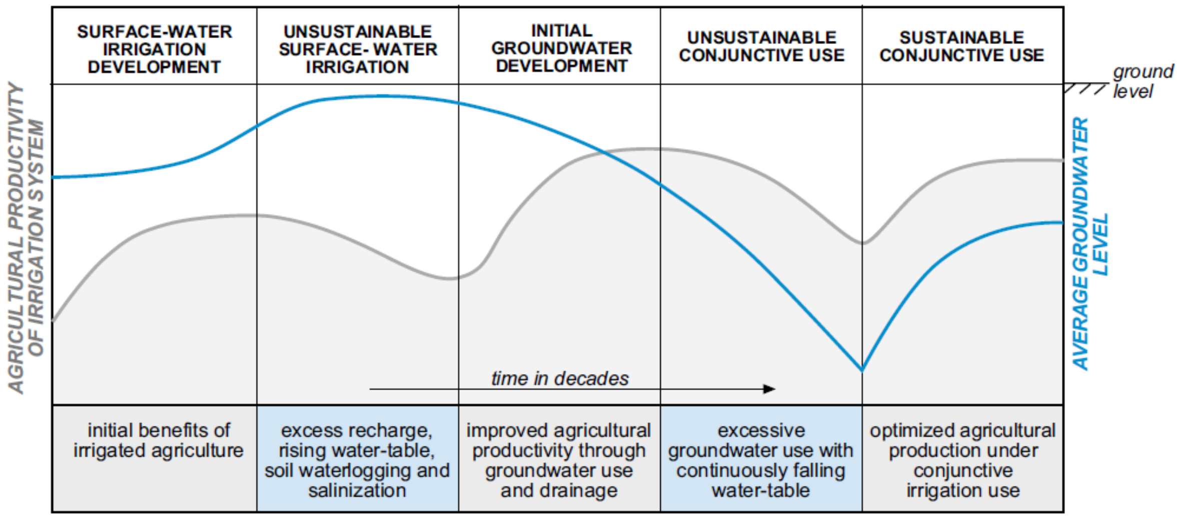
Groundwater use for agriculture is widespread in northern China. It is estimated that currently around five million wells are in use to pump up groundwater for irrigation purposes (Wang et al. 2009a). The intensity of groundwater use is not everywhere the same (Qu et al. 2011 ; Wang et al. 2007), but in an increasing number of locations overexploitation poses a threat to local ecosystems and rural livelihoods. Problems of steadily falling groundwater tables and salinity intrusion in coastal areas due to groundwater over-use have been reported (Kendy et al. 2004 ; Liu et al. 2001). The Chinese Water Law, revised in 2002, acknowledges the growing threat posed by groundwater depletion and authorizes local governments to strictly regulate groundwater use in case of overdraft (Calow et al. 2009 ; Shen 2015). However, *direct* regulation of groundwater use, for example through well permits or pumping quotas, has proven to be extremely difficult in smallholder agricultural settings (Kemper 2007). The autonomous character of groundwater use and the high number of individual users limit the effectiveness of such measures (Giordano 2009). Rare cases of effective groundwater regulation in China come at high costs for both the state and local farmers (Aarnoudse et al. 2012 ; Bondes and Li 2013). Therefore, *indirect* groundwater regulation is put forward as a preferable, more viable alternative (Giordano 2009).

Indirect regulations intend to steer farmers' groundwater use by taking measures outside the groundwater sector. Popular examples are to ration electricity supply for groundwater pumping (Mukherji 2007 ; Shah and Verma 2008) or to induce land use changes towards low water demanding activities (Moench 2007 ; Shah 2014). Yet, efforts to indirectly steer farmers' groundwater use are rarely linked to surface water management. Even though farmers' groundwater pumping is often taking place inside or in the vicinity of canal irrigation districts. The conjunctive use of surface water and groundwater for agricultural irrigation is considered to be a common phenomenon worldwide (Evans et al. 2014 ; Foster and Steenbergen 2011). Based on remote sensing data, Thenkabail et al. (2009) estimated that globally around 90% of the groundwater irrigated area also has access to surface water, even when overall the proportion of surface water irrigation in these areas is small. Compared to groundwater irrigation, surface water irrigation is less dependent on farmers' autonomous decision making. In northern China most canal irrigation systems are managed by governmental agencies who decide on the allocation of surface water.

Whereas surface water management is hardly considered as a tool to regulate groundwater use, it has been recognized that the development of agricultural groundwater use is often linked to changes in surface water supply. In many cases initial groundwater pumping is preceded by a period of unreliable, reduced surface water supply (Hammani et al. 2009 ; Liu et al. 2008 ; Shah et al. 2003).

Foster et al. (2010) sketch the typical development of groundwater use in canal irrigation districts as a phenomenon pushed by underperforming surface water supply, gradually leading to groundwater based agricultural intensification, which eventually results in neglected surface water supply systems and excessive groundwater use (so-called "unsustainable conjunctive use") (see Figure 3.1). The groundwater based agricultural intensification is mainly obtained through an expansion of the irrigated cropping area and a shift towards high-value, high water demanding crops (Allan 2007 ; Llamas and Martínez-Santos 2005 ; Shah et al. 2003).

Figure 3.1 Typical development path of conjunctive use on alluvial plains



Source: Foster et al. (2010)

It is hard to verify whether the path dependency described by Foster et al. (2010) also applies to China, because long-term national statistics on surface water versus groundwater irrigation are not available. Yet, a corresponding trend is shown by village level panel data from the China Water Institutions and Management (CWIM) survey carried out by the Chinese Academy of Sciences in North China (see Table 3.1). The sample includes 78 irrigated villages spread over Ningxia, Hebei and Henan Province. In Ningxia five out of the 32 surveyed villages and in Hebei seven out the 24 surveyed villages used both surface water and groundwater in the year 1995. From 1995 to 2004, six more villages started to use groundwater in addition to surface water per province. In Henan 18 out of the 22 surveyed villages were already using both surface water and groundwater in 1995. Over the next decade one village started to use groundwater in addition to surface water and five villages which previously used both surface water and groundwater became single groundwater using villages. This means that the data shows a trend moving away from single surface water use to conjunctive use in Ningxia and Hebei Province and a development from conjunctive use to single, intensified groundwater use in Henan Province.

Table 3.1 Number of surveyed villages using surface water, groundwater or both for irrigation

	1995			2004			Full sample
	Surface water	Groundwater	Conjunctive	Surface water	Groundwater	Conjunctive	
Ningxia Province	27	0	5	24	0	8	32
Hebei Province	7	10	7	4	10	10	24
Henan Province	2	2	18	1	7	14	22
Total	36	12	30	29	17	32	78

Source: CWIM survey, for a description of the data see Huang et al. (2009)

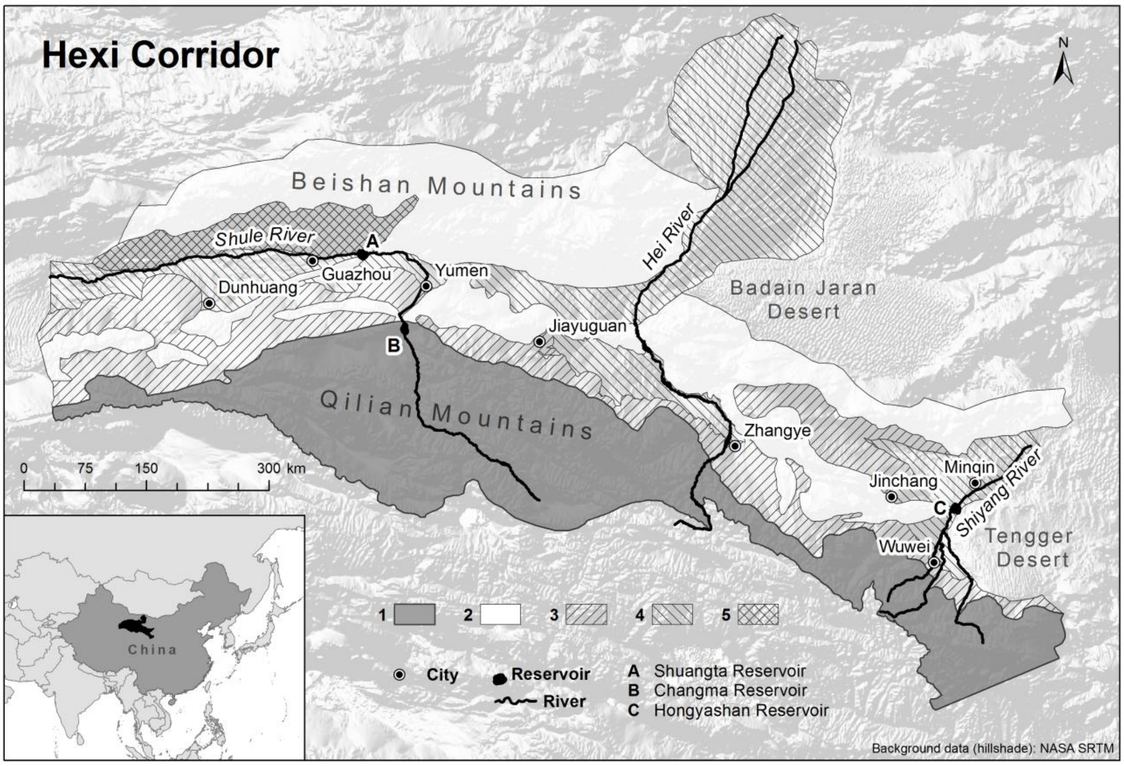
Despite the clear link between the development of groundwater resources and surface water supply, surface water and groundwater management are often approached separately (Foster and Steenbergen 2011). Evan et al. (2014) criticize the narrow definition of surface water management and the emergence of independent institutions to manage groundwater. It is argued that conjunctive water management – whereby the simultaneous use of surface water and groundwater is coordinated at irrigation system or river basin level (World Bank 2005) – is required for long-term water security and salinity control (Foster and Steenbergen 2011). In this paper it is explored whether improved surface water supply to areas of intensive groundwater use can function as an indirect measure to regulate groundwater use. If so, this would be another good reason to argue in favour of conjunctive water management.

To discern the potential role of conjunctive water management with regard to groundwater regulation, an analysis of the relation between surface water supply and farmers' groundwater use in Northwest China is carried out. The main questions this paper intends to answer are: *How does the surface water supply quantity influence farmers' groundwater use behaviour? And, is groundwater in canal irrigation systems only used to substitute a lack of surface water or also to intensify the agricultural production?* Based on empirical data from conjunctive use areas, four different aspects are looked at which could help to answer these questions. First, the relation between surface water supply and groundwater use trends over the last decade is explored. Second, a description is provided on the current situation of conjunctive use and farmers' motivation to use both water resources. Third, a multivariate analysis of cross sectional data is presented to estimate to what extent farmers' groundwater use quantity can be explained by the amount of surface water that is supplied to their village. Fourth, the relation between groundwater use versus agricultural intensification and total water use is explored by comparing characteristics of groundwater using household with single surface water using households. Finally, it is conclude whether surface water management could be used as a measure for indirect groundwater regulation based on the research results.

3.2 The study area

The study area includes the irrigated areas on the alluvial plains of the Hei and Shule River Basin in Gansu Province, Northwest China. Both river basins are located in the Hexi Corridor (see Figure 3.2), which forms a natural passage between the Tibetan Plateau and the Gobi Desert. The passage used to be the most important route to enter China on the ancient Silk Road. From East to West the Hexi Corridor stretches out over more than 800 km, while from North to South it barely reaches 200 km at narrow places. The area can be considered as one hydrologic unit with multiple streams flowing down the Qilian Mountains through the plains into the desert. The streams are fed mainly by melt water from annual snowfall and to some extent also from glaciers. Because of the relatively abundant water resources from the Qilian Mountains, the alluvial plains of the Hexi Corridor are regarded as the most productive agricultural region of Gansu Province. The alluvial plains are underlain with high-storage sedimentary aquifers, which means that both surface water and groundwater are readily available. At the same time the climate is arid with low annual rainfall between 50-200 mm and high evaporation between 2000-3500 mm (Xiao 2008). Due to the almost full reliance on irrigation for agriculture, the surface water-groundwater dependency in this area is more acute than in other parts of northern China. Amongst the multitude of streams in the Hexi Corridor three major inland rivers can be distinguished: the Shiyang, Hei and Shule River. This paper focuses on conjunctive use in the Hei and Shule River Basin, because here farmers' groundwater use is still largely unregulated in contrast to the situation in the Shiyang River Basin.

Figure 3.2 Map of the Hexi Corridor



1= high rock mountains, 2= low rock hills, 3= alluvial fans, 4= alluvial plains, 5= foothill plains
Source: made by Ronald Kraemer, adapted from Zhou et al. (2007)

Whereas the three main river basins in the Hexi Corridor show clear similarities in their hydro-geologic and climatic conditions, they underwent different socio-economic development pathways. The Shiyang River Basin on the East has always been best connected to the rest of China, while the Shule River Basin can be considered to be the most remote area, bordering Xinjiang Province in the West. Accordingly the population density drops and the per capita cropping area increases from East to West (see Table 3.2). Moreover, groundwater use is highest in the most densely populated Shiyang River Basin, even though the river inflow – which is the largest source of groundwater recharge – is smallest.

Table 3.2 Water use conditions of three main inland river basins in Hexi Corridor

	Shiyang River Basin	Hei River Basin	Shule River Basin
Population (million)	2.2	2.0	0.5
Cultivated land (ha)	300,000	330,000	180,000
Per capita cultivated land (ha/person)	0.14	0.17	0.36
River inflow (Mm^3)	1500	2100	2100
Surface water use (Mm^3)	1600	2500	1400
Groundwater use (Mm^3)	1100	400	500

Yearly data for 2007, except for river inflow which is a long year average
Source: Gansu Province Water Resources Bureau (2008)

Within the Hexi Corridor, the earliest development of mechanized groundwater pumping took off in Minqin County, the downstream sub-basin of the Shiyang River. In the 1960s the surface water supply to Minqin was reduced due to increased exploitation for irrigation upstream. While the people of Minqin literally fought for their surface water rights at first, they gave up on it once they started pumping shallow groundwater in the 1970s. By the 1990s intensive groundwater use in Minqin led to alarming desertification rates. To bring the desertification to a halt farmers' groundwater use in Minqin has been strictly controlled by the water authorities since 2007 (Aarnoudse et al. 2012). At the same time the surface water inflow to Minqin was increased to partly compensate for the groundwater use restrictions. During the first decade of the new millennium (2000-2009) the average inflow was 110 Mm^3/year, while over the last five years (2010-2014) it was 300 Mm^3/year (Government of Minqin 2015). Because the groundwater use restrictions and increased surface water supply occurred at the same time, it is hard to distinguish the isolated effect of these two measures. However, the case shows that water authorities have been capable of adjusting the surface water supply in response to the groundwater use situation. This experience raises the question whether at an earlier stage – when groundwater use was still unconstrained – improved surface water supply to Minqin could have avoided the boom in groundwater use. To answer this question, this paper focuses on the case of largely unconstrained groundwater use in the neighbouring Hei and Shule River Basin.[19]

In the Hei and Shule River Basin groundwater development took off much later than in the Shiyang River Basin. In the Shule River Basin the earliest wells were drilled in the 1990s and in the Hei River Basin even later. As groundwater management often develops only after groundwater use has intensified (Bouarfa and Kuper 2012 ; Kemper 2004), groundwater management in these two river basins is less advanced as in the Shiyang River Basin. Although well drilling permits are officially required, this has not limited groundwater development so far. In the Shule River Basin a tiered groundwater pricing system is implemented, but it does not seem to effectively regulate farmers' groundwater use.[20] Moreover, the surface water supply varies a lot within the study area both spatially and over time, which makes it a suitable case to explore the impact of different levels of surface water supply on farmers' groundwater use.

In the study area groundwater irrigation is differently organised than surface water irrigation. It is important to note that groundwater use is a decision made by the farmers, whereas surface water supply is a decision made by the irrigation bureaucracy hardly influenced by the farmers themselves. This division can be regarded to be inherent to the natural occurrence of the water resources which allows groundwater to be pumped directly on the farmer's land, while surface water is conveyed over long distances through irrigation canals (see Figure 3.3). Although ownership over wells is

[19] The third paper in this thesis dives further into the case of regulated groundwater use in Minqin County.

[20] More information on the groundwater management measures in the Hei and Shule River Basin are provided in the first and third paper of this thesis.

mostly shared by approximately 30-70 farm households within farm groups at sub-village level,[21] the decision to use water from the well to irrigate a plot is decided by the plot-owner (i.e. individual household). The actual practise can differ a bit from place to place. In areas where farmers are highly dependent on groundwater more coordination is required and farm groups may organise collective groundwater turns whereby all farmers receive their groundwater during that one round. In areas where groundwater use is more incidental, single households may decide when to use groundwater and turn the pump on and off to irrigate their own household's plot only. Nevertheless, groundwater irrigation decisions are always made by the farmers themselves and not dependent on higher level authorities.

On the contrary, whether to use surface water or not highly dependents on the supply of surface water. In the study area the supply of surface water is a decision made by the local water authorities based on the surface water availability.[22] As snowfall in the mountains differs from year to year some natural inter-annual variability in the river flow occurs. Although the amount of surface water *supplied* to the villages can be considered as an external factor not influenced by the villagers, the amount of surface water *used* is a decision made by the farmer on household level. During each irrigation turn farmers are personally responsible for irrigating their own plot. When they want, they can skip an irrigation turn. This means that farmers' surface water *use* can be equal to or lower than the surface water *supply*.

Figure 3.3 Surface water in the canal comes from far, while groundwater is pumped up directly in the field

Source: own picture

[21] Villages are usually divided in smaller units. In China different names circulate referring to the sub-village units, such as natural village, community, (production) team and small group (*ziran cun, she, dui* and *xiao zu*). This paper will consistently refer to the sub-village units as farm groups.

[22] The local water authorities include water management organisations at prefecture or county level as well as the subordinate Irrigation District Bureaus located in local towns.

3.3 Research approach and results

This section provides a closer look at primary data from potential conjunctive use villages in the Hei and Shule River Basin to better understand the relation between farmers' access to surface water and their use of groundwater. A survey was carried out in the study area in 2014.[23] The semi-random sample includes 15 villages and 157 households which are all located within the command area of a surface water irrigation system and have relatively good access to groundwater (i.e. not below 100 m).[24] The survey contained household questionnaires, village leader questionnaires and well operator questionnaires. Detailed questions about farmers' water use and agricultural practices in the previous cropping season were included. Moreover, questions were asked about irrigation management practices, physical water use conditions and changes in water use over time. In addition to the survey, 14 in-depth interviews were held with staff from different water management organizations, village leaders and farmers. In this paper the analysis is mainly based on data from the survey; however, from time to time data from the in-depth interviews is used to interpret the results. All statistical analyses in this paper are carried out using STATA. In the following sub-sections the data analysis and research results are described and discussed. First, the descriptive statistics are introduced. Then, further data analysis through a multivariate statistical model and a set of independent t-tests is presented.

3.3.1 Descriptive statistics

The historic development of groundwater use and surface water supply

The development of groundwater use is rather recent in the study area. Therefore, it is considered useful to look at recent water use trends to understand the link between groundwater use and surface water supply. The historic development is assessed based on information given by the village leaders, who in this case serve as key-informants. The village leaders were asked to compare today's surface water and groundwater use in the village with the situation ten years ago. When they indicated changes, the reason was asked for. Furthermore, they were asked to report the village's cropping area for 2003 and 2013. Based on the groundwater use trends, different regions within the study area can be grouped in three categories: 1) reduced surface water supply led to *initial* groundwater use; 2) increased surface water supply led to reduced groundwater use; and 3) reduced surface water supply led to *intensified* groundwater use (see Table 3.3).

[23] An elaborate description of the data collection procedure is given in the introduction of the thesis.

[24] Five villages were excluded from the original sample of 20 villages on the alluvial plains of the Hei and Shule River Basin. Three villages were excluded because the groundwater level was below 100 m and none of the farmers used groundwater; one village was excluded because it was located outside the command area of the surface water irrigation system; and one village was excluded because farmers had leased their land to an agri-business company and did no longer decide on farming practices.

Table 3.3 Surface water and groundwater use trends over the last ten years

	Location	Surface water	Groundwater	Cropping area
Initial groundwater use	Middle reaches Hei River Basin	↘	↗	↗
Reduced groundwater use	Upstream reaches Shule River Basin	↗	⇢ ↘	↗
Intensified groundwater use	Downstream reaches Shule River Basin	↘	↗	↗

Source: based on data reported by key-informants

Initial groundwater use

In the middle reaches of the Hei River Basin most village leaders (4/5) reported that farmers had started using groundwater over the last ten years and did not use groundwater before. As the main reason the village leaders pointed at the reduced surface water supply. In line with this most village leaders (4/5) reported a decrease in the amount of surface water supplied to their village. Since 2002 a new water allocation policy was introduced in the Hei River Basin which had to safeguard sufficient water for downstream located natural wetlands in Inner Mongolia (Liu et al. 2005). This has been the main the reason for reduced agricultural surface water supply in the middle reaches of the Hei River Basin. However, one village leader noted that due to the increased cropping area the surface water per unit of land decreased rather than the total water volume. All village leaders (5/5) reported a larger cropping area for 2013 than for 2003, signifying an increase of 5 to 50% per village (20% on average).

Like elsewhere in the Hexi Corridor, the increase in cropping area is obtained through the capture of previously uncultivated land at the edges of the oasis. The cultivation of barren land or so-called "wasteland" is made possible through the expansion of irrigation infrastructure. It is primarily driven by the drilling of wells, but can also be obtained through the extension of surface water canals and/or the use of pumps to lift surface water to elevated lands (see Figure 3.4). Of course, the location of the village, i.e. whether it has access to barren land or is surrounded by cultivated land of other villages, also determines land expansion practises.

Figure 3.4 A pump house and canal are built to lift water from the primary surface water canal to elevated land

Source: own picture

Reduced groundwater use

In the upstream irrigation district of the Shule River Basin supplied by the Changma Reservoir, most village leaders (4/6) reported a decrease or no change in farmers' groundwater use over the last ten years. Those who reported a decrease claimed that surface water is preferred because the quality is better and the productivity higher. Almost all village leaders (5/6) reported an increase in surface water supply over the last ten years. This can be attributed to the completion of the Changma Dam, which started operating in 2006. The new dam largely improved the surface water supply conditions for the upstream reaches of the Shule River Basin. The change in cropping area varied a lot per village – one village lost 35% of its crop land to urbanisation, while another village's cropping area increased by 85%. On average the cropping area increased by 15%. As groundwater use is not common, the increase in cropping area can mainly be attributed to the improved surface water supply conditions.

Intensified groundwater use

In the downstream irrigation district of the Shule River Basin, supplied by the Shuangta Reservoir, all village leaders (4/4) reported that farmers had intensified their use of groundwater over the last ten years. Both the decrease in surface water supply and the increase in cropping area were given as main reasons. The reduction in surface water supply is a result of the construction of the Changma Dam and the increased surface water use in the upstream reaches. The average increase of cropping area per village was 40%, which can mainly be attributed to the expansion of groundwater irrigation. Again the change in cropping area varied from no change at all in one village to a maximum of 70% increase.

The historic trends sketched by the village leaders indicate that changes in the surface water supply conditions have influenced farmers' groundwater use decisions over the last ten years. Increased surface water supply led to reduced groundwater use or at least avoided an increase in groundwater use, while decreased surface water supply induced initial groundwater use or led to intensified groundwater use. In any case farmers have tried to use additional irrigation water to expand the cropping area, even though on average those who intensified their groundwater use were able to realize the largest gains in crop land.

The current situation: farmers' conjunctive use behaviour and their motivation to use both resources

Since groundwater use is an autonomous decision made at household level, the study area shows a diversified conjunctive use picture. The full sample contained 15 villages; in two of those villages none of the surveyed households used groundwater in 2013 even though wells were available. In five villages all surveyed households used groundwater without a single exception. In the rest of the villages some of the surveyed farmers used groundwater while others did not. The total household sample contained 157 farm households of which 90 households actually used groundwater for irrigation in 2013 (from here on referred to as "groundwater users"), while 67 households did not use groundwater and fully relied on surface water instead (from here on referred to as "non-groundwater users") (see Table 3.4). Amongst the groundwater users, 86 households used groundwater in addition to surface water (from here on referred to as "conjunctive water users"), while only four households fully relied on groundwater and refrained from surface water use in 2013. A large number of the conjunctive users supplied their full cropping area with both surface water and groundwater at different points in time (n=65). Usually surface water is supplied during the early cropping season and groundwater during the late cropping season. Some farmers have additionally a few plots irrigated with surface water only or groundwater only (n=13). For example, because the groundwater quality is considered unsuitable for a particular crop or the surface water canal does not reach a distant plot. Even less farmers keep surface water and groundwater irrigation spatially completely separated (n=8). These farmers mainly rely on surface water and only use groundwater to irrigate specific crops, like greenhouse crops which need more frequent irrigation.

Table 3.4 Occurrence of different water use practices amongst the surveyed households (n=157)

	Single sw users	Single gw users	Conjunctive water users			
			All crops sw and gw	Most crops sw and gw, some sw or gw only	All crops either sw or gw	All
N	67	4	65	13	8	86

Source: own survey

Almost 95% of the groundwater using farmers in the survey stated to prefer the use of surface water over groundwater (see Table 3.5). Farmers prefer surface water foremost because they consider the water quality to be better and relate higher crop yields to the use of surface water (mentioned by 56% of the farmers who prefer surface water). Another important reason to prefer surface water is the strong flow which makes irrigation less time-consuming and more convenient for the farmer (mentioned by 22% of the farmers who prefer surface water). Although the use of surface water is generally preferred over groundwater, about 60% of the groundwater using farmers considered the conjunctive use of both surface water and groundwater to be advantageous. Primarily, because the use of groundwater in addition to surface water increases the farmer's flexibility to irrigate whenever is needed. 85% of the groundwater using farmers stated to adjust their groundwater use to inter-annual variations in surface water supply. In those areas where the surface water supply quantity is sufficient and secure, the two water sources are considered to complement each other with regard to different cropping techniques (i.e. surface water irrigation is considered to be more suitable for irrigating large fields, while groundwater is considered more suitable for frequent irrigation inside greenhouses).

Table 3.5 Groundwater users' responses to questions on conjunctive use (n=90)

Question	Answer	*n*
Do you prefer the use of surface water or groundwater?	Surface water	85
	Groundwater	4
	No preference	1
Do you associate the conjunctive use mainly with advantages or disadvantages?	Advantages	53
	Disadvantages	9
	Neither of them	18
	Don't know	7
	Missing	3
Do you adjust your groundwater use to inter-annual variations in surface water supply?	Yes	76
	No	14

Source: own survey

3.3.2 Multivariate analysis of farmers' groundwater use quantity in canal irrigation districts

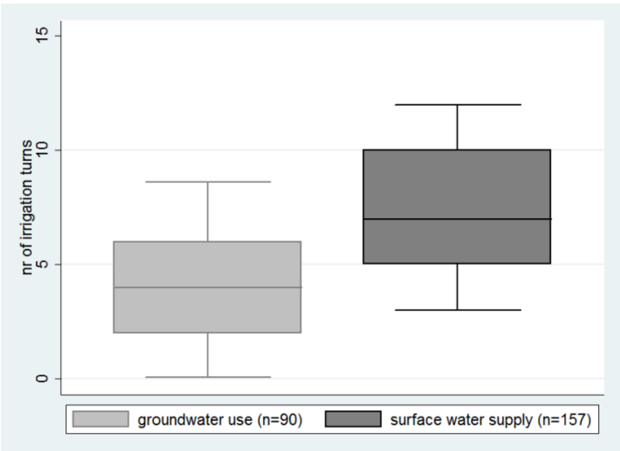
The last two sub-sections showed that the historic water use trends and the rationale behind farmers' conjunctive use practices affirm a strong link between farmers' groundwater use and access to surface water in the study area. In this sub-section the cross-sectional household data on farmers' groundwater use and surface water access is analysed to estimate to what extent farmers' groundwater use quantity can be explained by the supply of surface water.

Description of the groundwater use and surface water supply variables

To estimate farmers' water use they were asked to report the cropping area and the number of irrigation turns per crop. In the study area farmers usually grow multiple crops and apply a fixed number of irrigation turns per crop. As a measure of farmers' groundwater use the average number of groundwater irrigation turns per unit of land was calculated. For example, when a farmer has one crop on 2 ha of land irrigated with 3 irrigation turns (2*3=6) and another crop on 4 ha of land irrigated with 6 irrigation turns (4*6=24), the average number of irrigation turns is 5 (30/6=5). The average number of irrigation turns is assumed to correspond to the water volume applied per unit of land.[25] Whereas farmers' total water use volume can be approximated by multiplying the number of irrigation turns by the irrigated area, it was decided not to use such a combined variable because it blurs the isolated impact of groundwater use intensity versus cropping area. The main reason to use the average number of irrigation turns as the dependent variable for the analysis is that it is the most accurate indicator to assess farmers' individual water use per cropping season based on a household questionnaire. Farmers are usually not aware of the exact water volume they used or report standard norms propagated by the water bureaucracy. In the same context Fan et al. (2014) also considered the number of irrigation turns reported by farmers the best estimator of farmers' actual water use and made use of this data to calculate water use efficiencies for different crops in Minqin County.

The number of surface water turns supplied to the village as reported by the village leader is used as a measure of farmers' access to surface water. The same unit (i.e. the number of irrigation turns) is applied as for groundwater use, so that the quantitative relation between surface water supply and groundwater use can easily be interpreted. Again, it is assumed that the number of irrigation turns corresponds to the water volume supplied per unit of land. The number of surface water turns is generally decided per village and can thus be regarded the same for all villagers. Occasionally some parts of the village's land have inferior access to surface water canals and thus receives less surface water. Yet, such marginalised lands are usually equally divided amongst the villagers.

Figure 3.5 Distribution of farmers' groundwater use and surface water supply



Source: own survey

[25] In reality the water volume applied to a farmers' plot can differ per irrigation turn depending on the irrigation method, the soil type and also farmers' habits. The variation caused by the use of different irrigation methods is small in our study area. Basically all farmers use flood irrigation, drip irrigation covers only 1% of the total area covered by the survey. Also, the soil type is not expected to differ much between locations. Generally the soil ranges from fine sand to silt on the alluvial plains of the Hexi Corridor (Ji et al. 2006). However, to what extent farmers' habits differ from place to place remains an uncertainty in the estimation.

The dataset captures the high variance in surface water supply and groundwater use conditions existent in the study area (see Figure 3.5). Villages with a high number of surface water irrigation turns are generally found to be located in the upstream parts of the study area. On average, farmers are supplied with 7.2 surface water irrigation turns and groundwater users apply 4.1 groundwater irrigation turns (see Table 3.6). The average groundwater use is 2.4 turns when the household observations with 0 groundwater turns are included. The descriptive statistics on surface water supply and groundwater use show a clear negative relation (see Table 3.6). The proportion of farmers using groundwater is increasing when the surface water access is worsening. In fact, more than 80% of the farmers uses groundwater when the surface water is below seven irrigation turns, while only 25% of the farmers uses groundwater when the surface water supply is above seven irrigation turns. Moreover, the number of groundwater turns applied by groundwater users decreases with improved surface water supply. This indicates that groundwater use is largely used to supplement insufficient surface water supply (i.e. functions as a buffer), which confirms the findings presented in the previous two sub-sections. It also implies that when surface water supply is kept at a sufficient high level farmers are not interested in or aware of the benefits of using groundwater.

Table 3.6 Farmers' groundwater use for different levels of surface water supply

	n	Sw supply	% of gw users	Gw use excluding 0 turns		Gw use including 0 turns	
				Mean	Std. dev.	Mean	Std. dev.
	16	3	100	6.4	1.6	6.4	1.6
	44	5	93	4.9	1.8	4.6	2.3
	14	6	79	3.5	2.6	2.7	2.7
	23	7	43	2.0	1.3	0.89	1.3
	7	9	71	1.0	0.80	0.74	0.83
	30	10	10	0.20	0.10	0.021	0.070
	7	11	14	0.1	-	0.019	0.050
	16	12	19	1.4	1.8	0.26	0.88
Total	157	7.2	57	4.1	2.5	2.4	2.8

Groundwater use and surface water supply are given in number of irrigation turns
Source: own survey

Description of the model and control variables

A multivariate analysis was performed to estimate the effect of surface water supply on farmers' groundwater use decision while accounting for other factors influencing this decision.

The model is defined as follows:

[$groundwater\ use = \alpha + \beta\ surface\ water\ supply + control\ variables + \varepsilon$]

As control variables three groups are distinguished: 1) socio-economic household characteristics; 2) land and market access; and 3) groundwater use conditions. A brief description of the variables, their mean values and expected effect on farmers' groundwater use can be found in Table 3.7.

Table 3.7 Variable description and expected effect on farmers' groundwater use

Variable name	Variable description	Expected sign	Mean	Std. dev.
Groundwater use	A household's average number of irrigation turns per unit of land		2.4	2.8
Surface water supply	Number of irrigation turns supplied to the village as reported by the village leader	-	7.2	2.7
Age household head	Years	-	49	10
Position household head	Dummy variable, 1= farm group or village/WUA leader, 0= no leadership position	+/-	0.15	0.35
Education household head	Years of school attendance	+/-	8.0	3.4
Land availability	Total agricultural land of the village in hectare (including barren land) divided by the number of households as reported by the village leader	+	0.90	0.32
Market distance	Travelling time per car in hours from the village to the nearest urban centre based on google.maps	-	0.82	0.72
Groundwater depth	Average groundwater depth in meters as reported by the well operator	-	20	14
Perceived groundwater salinity	Percentage of villagers concerned about inferior groundwater quality	-	48	33
Well age	Average age of the wells in years as reported by the well operator	+	14	5.6
River	Dummy variable, 1=Hei River Basin, 0=Shule River Basin	+	0.34	0.47

Source: own survey

The socio-economic household characteristics include: age of the household head in years, the education of the household head in years of school attendance and a dummy indicating whether the household head holds a leadership position in the village. Because many farmers indicate that the use of groundwater is inconvenient and time consuming, it was expected that elder farmers are likely to use less groundwater. The effect of education and leadership position is ambiguous. It could be that higher educated farmers are more innovative and thus more likely to use groundwater, but they may also have more off-farm job opportunities which might prevent them from intensifying their agricultural production through groundwater use. Farmers who hold a leadership position in the village could have privileged access to groundwater, but they might also be too busy with administrative tasks to intensify their agricultural production through the use of groundwater.

Other socio-economic household characteristics, which include the cropping area, crop choice and off-farm income are likely to be simultaneously determined with the use of groundwater and thus endogenous.[26] Hence, these variables were omitted from the model. However, there are some external conditions which may influence farmers' economic decisions independent from their groundwater use. It is assumed that land access and market access are such external determinants of farmers' cropping area and crop choice. Moreover, the education level of the household head may influence the farmers' off-farm working opportunities and determine off-farm income independent from farmers' groundwater use.

[26] A correlation test shows that the omitted variables correlate with farmers' groundwater use as expected i.e. the crop choice and cropping area are positively correlated and off-farm income is negatively correlated with groundwater use. The correlation between groundwater use and the cropping area is 0.11; between groundwater use and the gross crop revenue is 0.20; and between groundwater use and off-farm income is -0.06.

As an indicator of land access the agricultural land available per household in the village is included.[27] The amount of agricultural land is not necessarily the same as the actual cropping area, which may differ from year to year based on the water availability. Some villages are bordering the edges of the oasis and may have barren land available for agriculture. Other villages are surrounded by cultivated land belonging to other villages and are disadvantaged with regard to land expansion. The availability of agricultural land measured in hectare per farm household captures this difference. The variable is based on the amount of agricultural land and number of households reported by the village leader and is expected to have a positive effect on farmers' groundwater use.

As an indicator of market access the distance to the local urban market is included.[28] Fresh fruits which are high-value crops favourably irrigated with groundwater are most profitable when the farm land is located close to an urban market. The travelling time by car as indicated on google.maps from the village to the next urban centre (being Guazhou, Yumen and Zhangye) is taken as a measure of market distance. It should be borne in mind though, that not all high-value, high water demanding crops are dependent on local urban markets. Other commercial crops produced in the study area are transported over large distances.

The following groundwater use characteristics are included: the groundwater depth, the perceived groundwater salinity, the age of the wells and a river basin dummy. The groundwater depth and river basin dummy are included to account for differences in the groundwater price. In both river basins farmers pay the same electricity price for pumping (0.4 CNY/kWh). However, variability in the costs per water volume is dependent on the groundwater depth. The groundwater depth is measured as the water depth in the wells reported by the well operators. Increasing groundwater depth is expected to raise the electricity costs and have a negative effect on farmers' groundwater use. Farmers in the Shule River Basin pay a volumetric water price on top of the electricity price. In the Hei River Basin such a volumetric pricing system is absent. A river basin dummy is included to capture the effect of different groundwater pricing policies in the two river basins (Hei =1, Shule=0). Since there is no volumetric water pricing in the Hei River Basin, the groundwater use is expected to be higher here (i.e. a positive dummy effect).

As an indicator for the groundwater salinity a variable based on farmers' own perception is used because data on exact groundwater salinity levels could not be collected. The perceived salinity level is considered to be higher in those villages where a higher number of farmers referred to the inferior groundwater quality (or its resulting impact on crop growth) as one of the main reasons to prefer

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[27] The correlation between land availability and farmers' cropping area is 0.31.

[28] The correlation between market access and farmers' gross crop revenue is 0.21.

surface water use.[29] Farmers were found to have different perceptions within one village; however, the actual groundwater salinity is assumed to be similar for the whole village. Therefore, a village level variable representing the percentage of farmers concerned about inferior groundwater quality is included in the model. It is expected that groundwater use will be lower when the salinity problem is more pronounced. The age of the wells is included to capture the different historic pathways in groundwater use. In some villages the farmers started drilling wells in the 1990s; others drilled their wells after 2000 only. It is expected that farmers have adapted their farming practices more to the flexible water access conditions and thus use more groundwater, when they have been using groundwater for longer (Foster et al. 2010).

In literature, variation in well ownership is mentioned as an important indicator of farmers' groundwater use in North China (Wang et al. 2006). However, such variation is very small in the dataset at hand. According to the definition handled by Wang et al. (2006) almost all wells in the study area are privately owned by a group of farmers, so-called share-holders. Collective ownership by the villages is reported for just 5% of the wells covered by the survey and usually concerns only one out of the multiple wells used by a farm household. Other constellations, like private well ownership by individual households only occurred in one village. During the in-depth interviews it was explained that water from those individually owned wells is shared amongst the farmers in the farm group in the same way and for the same price as water from the wells owned by a group of farmers. Therefore, access to groundwater from those wells is not considered essentially different from wells with shared ownership. In another village, the village leader claimed that previously individually owned wells were recently transferred to the farm groups, because farmers would not buy the groundwater for a higher price.

Another factor which might influence farmers' groundwater use is the availability of wells. However, farmers are also likely to drill more wells when they want to use more groundwater, which would mean that the number of wells is endogenous. Moreover, external factors which determine well drilling, like groundwater depth and geological material, are considered to be rather homogeneous over the study area. In fact, groundwater wells are available in all surveyed villages (also in the two villages where farmers did not use groundwater in 2013). Therefore, it is assume that well drilling is generally feasible and affordable for farmers in the whole study area. To test whether well drilling functions as a threshold which disadvantages non-groundwater users compared to groundwater users a two step Heckman model was performed.

[29] This indicator was chosen because the related questions in the questionnaire were answered by 99% of both groundwater users and non-groundwater users. Other questions on the perceived salinity level had a much lower response rate.

The modelling results

In the first step of the Heckman model the decision to use groundwater or not (i.e. groundwater use > 0 or groundwater use = 0) is modelled (n=157). In this step, the groundwater depth is included as a predictor for the well drilling threshold. In the second step, the dependent variable is the number of groundwater turns excluding those who applied zero turns (n=90). In this step the groundwater depth is excluded and a new variable called lambda is included. The lambda is estimated based on the first step and accounts for the sample bias caused by the threshold effect. Table 3.8 reports the modelling results. The Heckman model is rejected because the lambda is insignificant. This means that in the study area well drilling does not form an extra threshold for farmers to use groundwater and all observations can be included in one single regression.

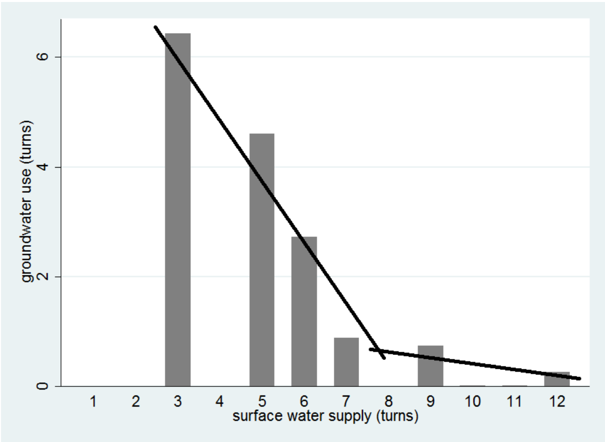
Table 3.8 The Heckman model results

	Step one: dependent variable gw use (yes/no)		Step two: dependent variable gw use (nr of irrigation turns)	
	Coefficient	Std. err.	Coefficient	Std. err.
Sw supply	-1.65	2.69	-1.09**	0.46
Household characteristics				
Age hh head	-0.0069	0.020	-0.021	0.20
Education hh head	-0.042	0.070	0.019	0.067
Position hh head	-0.24	1.1	-0.13	0.59
Land and market access				
Land availability	7.96	15.65	1.91*	1.17
Market distance	-5.98	9.72	-0.45	1.02
Groundwater use conditions				
Gw depth	-0.036	0.065		
Perceived gw salinity	0.056	0.12	-0.028*	0.015
Well age	0.76	1.46	0.17*	0.11
River dummy	7.11	13.23	0.30	1.89
Constant	7.45	15.81	9.97 **	4.85
Lambda			0.082	1.05
Observations	157		90	

*** (**, *) statistically significant with a probability of less than 1 (5, 10) percent
Source: own survey

Two linear regressions were performed; for the first regression it is assumed that the linear relation between groundwater use and surface water supply is the same for both high and low levels of surface water supply. For the second regression it is assumed that the linear relation between groundwater use and surface water supply is different for surface water supply above and below seven irrigation turns. This assumption appeared plausible based on a graphic visualisation of mean groundwater use and surface water supply (see Figure 3.6). The discontinuity in the linear relation is accounted for by adding a variable for the surface water supply above seven irrigation turns (surface water supply below or equal to 7 turns =0, surface water supply equal to 8 turns =1, surface water supply equal to 9 turns =2 etc.).

Figure 3.6 Visualization of relation between groundwater use and surface water supply



Source: own survey

The results show that the second regression with the discontinuous linear relation (R^2=0.75) performs slightly better than the first regression (R^2=0.73) (see Table 3.9). It implies that with low levels of surface water supply, farmers replace one surface water turn with about one and a half groundwater turns (-1.4). While above seven surface water supply turns, this effect decreases and farmers replace one surface water supply turn with only half a groundwater turn (-1.4+0.92= -0.48). The fact that below seven surface water turns farmers replace one surface water turn with one and a half groundwater turns indicates that additional groundwater is used for agricultural intensification, which will be discussed further in the next sub-section. Overall, the two regressions show that the effect of surface water supply on farmers' groundwater use is robust and significant. The high R^2 indicates that the model can explain most of the variance in farmers' groundwater use decisions. A test model excluding the control variables provides a similarly high R^2 of 0.65, which means that the surface water supply is the most powerful determinant of farmers' groundwater use.

Table 3.9 The linear regression model results

	Regression I: dependent variable gw use		Regression II: dependent variable gw use	
	Coefficient	Std. err.	Coefficient	Std. err.
Sw supply	-0.92***	0.14	-1.4***	0.11
Sw above 7 turns			0.92***	0.18
Household characteristics				
Age hh head	-0.015	0.012	-0.018*	0.010
Education hh head	0.011	0.37	0.010	0.037
Position hh head	-0.27	0.39	-0.33	0.39
Land and market access				
Land availability	1.36*	0.67	0.85**	0.31
Market distance	-0.83**	0.51	-1.9***	0.53
Groundwater use conditions				
Gw depth	-0.014	0.010	-0.0072	0.0064
Perceived gw salinity	-0.016*	0.010	-0.0014	0.0080
Well age	0.15***	0.042	0.089***	0.026
River dummy	0.43	0.72	1.9*	1.0
Constant	9.25***	2.00	12***	1.50
R^2	0.73		0.75	
Observations	157		157	

*** (**, *) statistically significant with a probability of less than 1 (5, 10) percent
Source: own survey

The significance of the control variables differs slightly between regression I and II; however, the direction of the impact is robust. The data shows that household level characteristics are hardly influencing farmers' groundwater use decisions. In fact 70% of the variance in groundwater use in the sample can be explained on village level, which implies that only 30% of the variance is likely to depend on household characteristics. Therefore, it is not surprising that household level variables hardly have any explanatory power in the model. Only in regression II, the age of the household head is slightly significant, but the impact is very small (i.e. an age difference of 100 years corresponds to one additional groundwater turn). Land availability and market distance are both significant in regression I and II, which indicates that these factors may influence farmers' decisions on groundwater use. As expected farmers rely more on groundwater when more land is available and the distance to the urban market is smaller. The physical groundwater characteristics, being groundwater depth and groundwater salinity, do not significantly influence farmers' decision to use groundwater. This is probably because the hydro-geological conditions do not vary much within the study area. Also the groundwater pricing difference between the Hei and Shule River Basin does not seem to influence farmers' groundwater use decision.[30] The dummy variable is just slightly significant in regression II. The age of the wells does, however, turn out to be a significant determinant, with stable significance in regression I and II. This affirms the idea that groundwater use in canal irrigation district follows a typical trajectory, whereby a lack of surface water may trigger initial groundwater use, but groundwater dependent agricultural intensification further boosts the use of groundwater (Foster et al. 2010).

3.3.3 A comparison of agricultural practices between groundwater users and non-groundwater users

Increased groundwater use often goes hand in hand with intensified agricultural production by switching crops and increasing the irrigated area (Allan 2007 ; Llamas and Martínez-Santos 2005 ; Shah et al. 2003). In China, the increased use of groundwater is seen as one of the main factors which improved Chinese farmers' income from agriculture over the last decades (Wang et al. 2006). Although the opportunity to switch to higher value crops and increase the cropping area are partly defined by land and market access conditions, cropping decision and groundwater use decisions are largely interdependent. This means that it is not possible to draw a causal interference between the use of groundwater and other decisions made at farm level. Nevertheless, it is interesting to analyse the correlation between farmers' groundwater use and indicators of agricultural productivity. It can

[30] This is in line with the argument that the groundwater pricing system is not effectively regulating farmers' groundwater use as presented in the third paper of this thesis.

tell us whether groundwater is solely used to substitute a lack of surface water or is also used to sustain intensified agricultural production.

In Table 3.10 the results of a set of independent t-tests are presented comparing the gross crop revenue per unit of land, cropping area and total water use (including surface water and groundwater) for groundwater and non-groundwater users (i.e. single surface water users) in the sample. Farmers who use groundwater grow crops with a significantly higher gross revenue and cultivate a significantly larger area. The gross crop revenue is around 20% higher and the crop area around 30% higher for groundwater users compared to non-groundwater users. It shows that farmers do not merely use groundwater to substitute a lack of surface water. In fact, the total number of irrigation turns increases by 30% once farmers use groundwater. When accounting for the increase in cropping area, farmers total water use is even 90% higher than non-groundwater users. This means that groundwater irrigation is not only used to buffer low surface water supply levels, but also to substantially increase total water use which allows for a higher agricultural income.

Table 3.10 Agricultural productivity and irrigation water use for groundwater users (n=90) and non-groundwater users (n=67)

	Groundwater users		Non-groundwater users		Significance
	Mean	Std. dev.	Mean	Std. dev	
Agricultural productivity					
Gross crop revenue (CNY/ha)	$43 \cdot 10^3$	$21 \cdot 10^3$	$34 \cdot 10^3$	$16 \cdot 10^3$	***
Cropping area (ha)	1.8	1.2	1.4	1.1	***
Total water use (gw + sw)					
Total nr of irrigation turns	6.9	2.0	5.1	1.6	***
Total nr of irrigation turns x cropping area (ha)	12.6	8.6	6.5	4.7	***
Surface water use					
Nr of sw supply turns	5.7	2.1	9.5	2.2	***
Nr of sw supply turns left unused	2.9	1.9	4.4	2.5	***
Proportion of sw supply turns left unused	0.50	0.27	0.43	0.25	*

*** (**, *) statistically significantly different with a probability of less than 1 (5, 10) percent
Source: own survey

So far, the data analysis shows that farmers' groundwater use is indeed responsive to the surface water supply. Yet, the other way around farmers' decision on how many surface water turns to use may also depend on their groundwater use. Foster et al. (2010) claim that intensive groundwater use eventually leads to a neglect of surface water infrastructure and a reduction in surface water use. Historically this is what happened in the case of Minqin soon after the early development of groundwater in the 1970s. A closer look at the relation between farmers' groundwater use and surface water *use* instead of *supply* may reveal whether this is currently also the case in the Hei and Shule River Basin. The surface water use is calculated as an average number of turns applied per unit of land based on the household questionnaire, just like the groundwater use. The data shows that basically all farmers use on average less surface water than supplied as reported by the village leaders. This is likely because surface water is not always supplied on the time that crops need it and surface water canals may not reach out to all land in the village. Non-groundwater users leave about 4.4 surface water turns unused, while groundwater users leave only 2.9 turns unused (see Table 3.10). Obviously, non-groundwater users can afford to skip more turns since their surface water supply is significantly higher than those who use groundwater. However, when accounting for this difference in surface water supply by looking at the *proportion* of surface water turns left unused, the data shows a different picture. The proportion of surface water turns left unused is slightly higher for groundwater users than for non-groundwater users, even though the statistical significance is low. This means that only to a limited extent farmers who use a lot of groundwater purposefully refrain from using the full surface water supply potential in the study area.

3.4 Conclusions

On the plains of the Hei and Shule River Basins, where both surface water and groundwater are relatively good accessible, there is a strong dependency between the amount of surface water supplied to the villages and farmers' groundwater use behaviour. Historic trends sketched by key informants show that in some areas increased groundwater use over the last ten years ran parallel to a decrease in surface water supply, while in other places reduced groundwater use followed upon improved surface water supply conditions. Moreover, farmers state themselves that they prefer the use of surface water and adjust their groundwater use in response to annual variability in surface water supply. With the help of cross-sectional data and a multivariate analysis it was possible to quantify the relation between surface water supply and groundwater use while controlling for other impact factors. It was found that in villages where a lower number of surface water irrigation turns is supplied (mainly in the downstream areas of the alluvial plains) farmers rely more on groundwater. Such village level characteristics are most important in explaining farmers' groundwater use behaviour; household level characteristics are less influential. This shows that even though individual households can make their own decisions, household behaviour is rather homogeneous within one village. The reason may be that the blue-prints from old farm collectives are still strongly pronounced in the rural society of the Hexi Corridor today.

Although literature claims that increased reliance on groundwater can lead to a reduced interest in surface water use and a neglect of surface water infrastructure (Foster et al. 2010), this does not seem to be the case in the study area. Only very few farmers completely refrained from using surface water in 2013. Moreover, when studying the relation between farmers' surface water use decisions (i.e. whether to make use of the full surface water potential) and groundwater use decisions, only a weak difference indicating a slightly reduced interest in surface water use by groundwater users was identified. This observation follows logically from the fact that almost all farmers in the study area prefer the use of surface water over groundwater. Actually, the data does provide evidence for the reverse development taking place (i.e. neglect of groundwater use in response to increased surface water supply). The history of the Changma irrigation district in the Shule River Basin (which profits from a newly constructed dam since 2006) shows that farmers reduce their groundwater use and leave wells unused when the surface water supply is improved substantially. This implies that at an early stage of groundwater development a steep increase in groundwater use may be avoided by securing high surface water supply levels. However, the data analysis indicates that farmers are only strongly discouraged to use groundwater when more than seven surface water irrigation turns are supplied (basically when the buffer function of groundwater becomes irrelevant).

Furthermore, it can be concluded that groundwater is not only used to substitute a lack of surface water, but also to intensify agricultural production. This is illustrated by the fact that under poor surface water access conditions farmers replace one missing surface water supply turn with one and a half groundwater turns. In line with this it was observed that farmers who currently use groundwater are used to farming practices which require a lot more water than practices of farmers who solely rely on surface water. The use of groundwater runs parallel with larger per household cropping areas and more water use per unit of land. The increased water use per unit of land is related to a shift to high-value crops, which generally require more water and/or more frequent irrigation. This change in farming practices makes it unlikely to achieve real water savings (accounting for both surface water and groundwater) by modifying the surface water supply at an advanced stage of groundwater development. Restrictions on land expansion and policies to propagate low water demanding, drought resistant crops may be necessary to curb intensive groundwater use. Nevertheless, a more balanced distribution of surface water between upstream and downstream reaches may have a soothing effect on farmers' intensive groundwater use and could also increase farmers' acceptance regarding possible groundwater use restriction policies. It should be mentioned though that improved surface water supply in downstream areas is likely to raise costs and lower delivery efficiencies; this must then be weighed against the benefits.

Paper 3

Groundwater quota versus tiered groundwater pricing: two cases of groundwater management in Northwest China[31]

Abstract

Difficulties in monitoring groundwater extraction have been one of the main reasons why groundwater regulations fail worldwide. Smart card machines to monitor farmers' groundwater use quantity have recently gained popularity in China. In Minqin and Guazhou County, both located in the arid Northwest of China, local water authorities have installed such smart card machines since 2007. However, the regulatory institutions behind the technology are different in the two counties. In Minqin, the machines primarily support the allocation of groundwater quota. In Guazhou, the machines are used to implement a tiered groundwater pricing system. We use data from a household survey and in-depth interviews to evaluate the effectiveness of the two regulatory institutions by looking at 1) the motivation of local water authorities to regulate agricultural groundwater use; 2) the implementation of the respective regulatory institutions; and 3) the impact on farmers' groundwater use quantity. Based on farmers' own perception we conclude that the groundwater quotas have been more effective in reducing agricultural groundwater use than the tiered pricing system. In line with this, we observe that farmers' groundwater use under the quota regime in Minqin is significantly and substantially less than under the tiered pricing regime in Guazhou, despite similar water use conditions. We argue that the difference in impact on farmers' groundwater use can primarily be ascribed to the societal context in which the groundwater regulations came about. The underlying motivation of local water authorities to regulate groundwater use has a big influence on the choice and actual implementation of the regulatory institutions.

Keywords: groundwater regulation; smart card machines; institutions; arid regions; China

[31] This paper has been submitted to the International Journal of Water Resources Development, co-authored by Wei Qu, Bettina Bluemling and Thomas Herzfeld.

4.1 Introduction

Around the globe groundwater use for irrigation has increased ten-fold over the last half a century. China is one of the countries which contributed most to this worldwide development. In China groundwater was hardly used until the 1950s, while groundwater extraction reached around 100 km^3/year by 2000 (Wada et al. 2010). Within the country most groundwater is used by the agricultural sector in the North, where around 5 million tube wells are in use for irrigation purposes (Wang et al. 2009a). The increased use of groundwater is seen as one of the main factors which improved Chinese farmers' income from agriculture over the last decades (Wang et al. 2006). However, these benefits are threatened by unsustainable groundwater use and steadily falling groundwater tables (Kendy et al. 2004 ; Liu et al. 2001 ; Zhen and Routray 2002). The problem is well-acknowledged in China and policies to bring groundwater overexploitation to a halt have been promoted on the national level. The national Water Law, revised in 2002, authorizes strict regulations on groundwater use in areas of severe groundwater overdraft (Shen 2015). However, like elsewhere in the world, it has proven very difficult to implement effective groundwater regulation measures (Calow et al. 2009 ; Shah 2007 ; Shen 2015 ; Wang et al. 2007). One of the main reasons is that groundwater is an invisible resource, pumped by a high number of autonomous users which makes it hard to monitor the volume of groundwater extracted by each user (Hoogesteger and Wester 2015). Another, more political reason is that local authorities usually lack the motivation to implement groundwater regulations due to the disparity between short-term costs and long-term benefits (De Stefano and Lopez-Gunn 2012).

To improve the groundwater monitoring conditions the installation of water meters linked to a digital administration system has recently gained popularity in China (Aarnoudse et al. 2012 ; Liu et al. 2009). These so-called "smart card machines" are connected to the pumping installation. The pump is turned on by swiping a smart card at a display on the machine. The extracted water volume is measured by the built-in water meter. As soon as the pumped volume surpasses the water account on the card, the pump is turned off automatically. Subsequently, the card can be reloaded at a central administration point. The installation of one smart card machine costs approximately 2500 CNY.[32] This new technology allows close monitoring of farmers' groundwater pumping at an affordable prize in the Chinese context. However, to what extent the machines support an effective regulation of groundwater use depends on the institutions behind the machine's use i.e. the rules that define who has access to the card; under what conditions the card can be reloaded etc. These rules are set by the water authorities and thus coined by these authorities' motivation for regulating

[32] One CNY equalled 0.12 € in 2013.

groundwater pumping. Furthermore, these rules are realized in a societal context that, as we will see, also has a major influence on how effective the new technology is.

This paper presents two cases where such smart card machines are installed, but operated in combination with different regulatory institutions. In the case of Guazhou County the machines are used to implement tiered groundwater pricing. Tiered pricing means that "individuals pay a low rate for an initial consumption block and a higher rate as they increase use beyond that block" (Schoengold and Zilberman 2014 p.2). Officially the tiered water pricing is expected to stimulate users to safe water, while securing a limited amount of water at affordable levels for all users. In the case of Minqin County the machines are used to regulate farmers' groundwater use quantity through a groundwater quota system. In a quota system, total water use is controlled by allocating each user a maximum allowable quantity of water withdrawal. In Minqin, a volumetric groundwater pricing system has also been implemented after installation of the machines. However, here the groundwater fee is based on a fixed price per volume and from the outset meant for cost recovery. The two regulatory institutions implemented in Minqin and Guazhou are based on different resource allocation mechanisms. The allocation of groundwater quotas could be understood as a form of centralized planning, while groundwater pricing intends to set economic incentives and create a market mechanism. However, because the groundwater price is determined by the authorities to include a scarcity factor, both regulatory institutions highly depend on bureaucratic management.

In theory, both regulatory institutions could be effective measures to curb farmers' groundwater use. Based on a modelling exercise of farmers' long-term profit under different regulations, Madani and Dinar (2013) show that both quota and pricing are able to curtail farmers' groundwater use. They predict that groundwater quotas are more effective than groundwater pricing to render farmers' groundwater use sustainable on the long run when it is assumed that farmers prioritize short-term over long-term benefits. However, their model does not account for a tiered pricing system, which they expect to result in better outcomes. The effect of tiered pricing systems on efficient water use has been modelled by Schoengold and Zilberman (2014). They come to the conclusion that tiered pricing can be effective, but the volume and water price of the initial consumption block need to be set carefully, taking into consideration case specific conditions.

In practice, the pricing of agricultural water use shows mixed results and its effect highly depends on local production conditions (Bjornlund et al. 2007). Based on a review on practical cases of volumetric pricing for surface water irrigation, Molle (2009) concludes that all over the world water quotas are a more popular regulatory institution to deal with water scarcity than water pricing. The problem with water pricing is that due to bulk deliveries to a group of users volumetric prices are rarely passed on to the individual user. Moreover, water quotas can be adjusted more easily to seasonal variability in water availability compared to water prices. He also argues that when quotas are reduced this is usually done so evenly for all users, incorporating principles of equity. These arguments are based on the context of surface water irrigation, which means that they are not necessarily valid for groundwater irrigation.

In this paper, we discuss the effectiveness of water quota versus tiered water pricing in a setting of intensive groundwater use, based on two empirical case studies. Herewith, we do not foremost focus on the theoretical understanding of the two regulatory institutions, but on its use in societal contexts. The objective of our research extends beyond the question whether the regulatory institutions were effective in curbing farmers' groundwater use. We also explore how the effectiveness of the regulatory institutions is related to the way they are implemented and coined by the underlying motivation of local water authorities to control groundwater use.

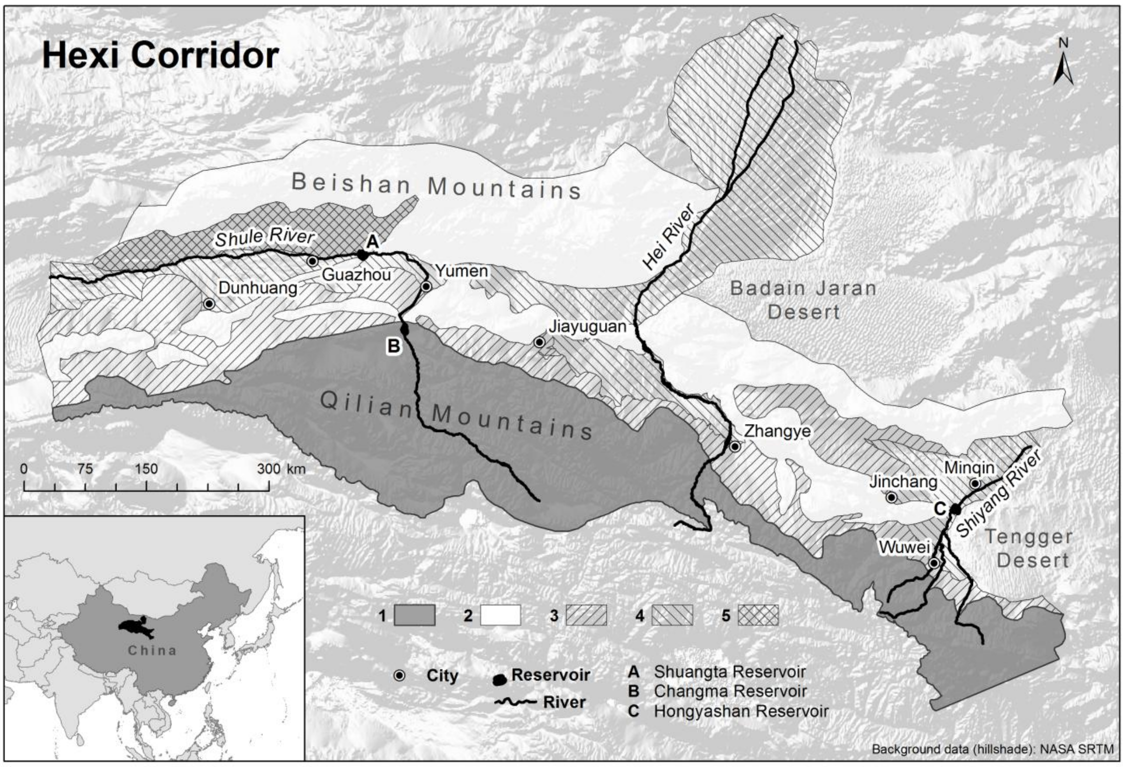
The paper is outlined as follows. First, we introduce our research approach by providing some background information on the study area, the data collection and data analysis. Then, we present the two case studies in separate sections. Finally, we compare our findings and draw conclusions.

4.2 Research approach

4.2.1 Case study area

The two case study areas, Minqin and Guazhou (formerly Anxi) County, are both located in the Hexi Corridor, Northwest China. The Hexi Corridor is a strip of flat land between the Qilian Mountains in the Southwest and sandy deserts in the Northeast. The natural corridor connected ancient China with the West. Despite its (semi-) arid climate, the plains have long been productive agricultural areas due to abundant melt water flowing down the Qilian Mountains. Reaching the plains, the mountain streams form three major inland rivers, from East to West: the Shiyang, the Hei and the Shule River (see Figure 4.1). The hydro-geology of the river basins is similar (Zhou et al. 2007). The plains are underlain with both shallow and deep high-storage aquifers. The shallow aquifers are shaped by unconsolidated sediments and are directly connected to the river flow (Ji et al. 2006).

Figure 4.1 Map of the Hexi Corridor



1= high rock mountains, 2= low rock hills, 3= alluvial fans, 4= alluvial plains, 5= foothill plains
Source: made by Ronald Kraemer, adapted from Zhou et al. (2007)

Minqin and Guazhou County are both located at the downstream reaches of the inland rivers: Minqin in the Shiyang River Basin and Guazhou in the Shule River Basin. In these areas groundwater is easily accessible, although salinity levels increase upon intensive use (Wang et al. 2003). Both counties contain vast areas of desert land, at least 90% of their total area. Annual rainfall in Minqin lies around 130 mm and evaporation at 2600 mm (Minqin County Government 2015). Guazhou is even more arid, with annual rainfall around 50 mm and evaporation of 3100 mm (Guazhou Land Resources Bureau 2015).

The population density in Minqin (16 inhabitants/km²) is clearly higher than in Guazhou (6 inhabitants/km²). Other macroeconomic conditions are fairly similar. Agriculture is the single most important economic sector in both counties. The sector is characterized by small scale family farming. Farmers produce a wide variety of crops; however, primarily cash crops, like cotton and melon, which are sold across China. As rainfall is low and evaporation is high, agriculture strongly relies on irrigation water. Due to the downstream location, farmers in Minqin and Guazhou have limited access to surface water and thus heavily depend on groundwater resources. At the same time shallow groundwater is the main water source for the natural vegetation in both areas, which means that falling groundwater tables easily lead to dying vegetation and increased desertification rates.

The two counties are very much alike in their hydro-geological and climatic conditions. Moreover, except for the population density, most macroeconomic characteristics are fairly similar. Therefore, the two counties suit well as comparable cases to study the impact of different water management institutions on farmers' groundwater use.

4.2.2 Data collection and analysis

This research is based on primary data collected in 2013 and 2014 in the study area. A survey on surface water and groundwater use and management was carried out by a team of experienced enumerators. A stratified random sample was selected to make sure different irrigation districts within the counties are represented. In Minqin, 105 farm households participated in the survey, spread across 10 villages in 5 different townships (representing 4% of the in total 249 rural villages in the county). In Guazhou, 44 farm households were interviewed, spread over 4 villages in 2 different townships (representing 5% of the in total 73 rural villages in the county). Respondents were asked to report their water use and cropping activities for the previous cropping season. In addition the survey included a village leader questionnaire and a well operator questionnaire in every village to collect information on the (ground-) water management institutions and physical groundwater use conditions at village level.[33] After a preliminary analysis of the survey data, a follow-up field visit was organized during which the lead author conducted in-depth interviews with water managers from irrigation district to river basin level, village leaders, well operators and farmers in the study area. In total 16 people were formally interviewed. The in-depth interviews were used to explain irregularities in the survey data and to better understand specific management institutions. Due to time constraints of the enumerator team, the survey was conducted over two years. In Minqin, the survey was carried out in 2013, collecting water use data for 2012. In Guazhou, the survey was carried out in 2014, collecting water use data for 2013. As the time lapse consists of only one year, we assume that changes in external factors which might influence farmers' decision making, like input and output prices, are fairly negligible.

In this paper the primary data is used to describe the groundwater use and management situation in the two case study areas. All information was cross-checked by consulting multiple sources (i.e. answers from the village leader, well operator and household questionnaires were triangulated and verified during subsequent in-depth interviews when irregularities occurred). In every case study we

[33] In both counties, the village leaders also function as leaders of the Water Users' Association (WUA). The WUA boundaries overlay the village boundaries.

describe in detail 1) the underlying motivation of local authorities' to regulate groundwater; 2) how the respective regulatory institutions have been implemented; and 3) the outcome in terms of farmers' groundwater use quantity. We evaluated the effectiveness of the respective regulatory institutions (i.e. whether they induced a reduction in groundwater use) in two ways. First, by asking farmers' own perception on the groundwater use quantity trend since the new regulation has been implemented. And second, by comparing farmers' groundwater use quantities and related decisions (such as surface water use, crop choice and cropping area) between the two cases. In absence of more accurate water use data,[34] we calculated each household's average number of surface water and groundwater irrigation turns per unit of land based on our survey data. For example, when a farmer has one crop on 2 ha of land irrigated with 3 irrigation turns (2*3=6) and another crop on 4 ha of land irrigated with 6 irrigation turns (4*6=24) the average number of irrigation turns is 5 (30/6=5). Fan et al. (2014) also used the reported number of irrigation water turns to calculate farmers' water use for different crops in Minqin. It is assumed that the number of irrigation turns roughly corresponds to the amount of water used per unit of land. Variation caused by the use of different irrigation methods can be considered small in our study area. Basically all farmers use flood irrigation, drip irrigation covers only 1% of the total irrigated area covered by the survey.

To examine the causal relation between the different management institutions and farmers' groundwater use, we discuss additional external factors which could possibly affect farmers' groundwater use in the study area. These include climatic, hydro-geological and macroeconomic conditions.

4.3 Results and discussion

4.3.1 Minqin County

Motivation for groundwater regulation

In the 1970s and 1980s, Minqin County experienced a big tube well boom. By the end of the 20th century, thousands of irrigation wells had been drilled in Minqin and annual groundwater extraction was estimated to be around 600 million m^3 (Gansu Province Water Resources Bureau 2007). This clearly exceeded groundwater recharge through surface water inflow, which reached around 100 million m^3 per year at the time (Zhang et al. 2011). In 2007, the Shiyang River Basin Management Plan was officially launched. This water policy reform was initiated to avoid further desertification and degradation of Minqin's environment (Wang et al. 2009b). The project was financed by the

[34] The measurement records from the smart card machines are not publicly available.

central government and officially kicked-off by a visit of the then Chinese Prime Minister Wen Jiabao in 2007. The main target of the water re-allocation plan was to reduce Minqin's total groundwater use by almost 80% from 2005 to 2010 and more than double the surface water release to Minqin from the Hongyashan Reservoir (Wonderen et al. 2008). The management plan is coordinated by the Shiyang River Basin Management Authority. Related surface water and groundwater management responsibilities are with the Water Resources Bureaus at prefecture and county level and implemented by the Irrigation District Bureaus (IDB) which usually have their offices in local towns.[35] At village level the board of the Water Users' Association (WUA) takes over surface water and groundwater management tasks. Since the introduction of the Shiyang River Basin Management Plan, career opportunities for water officials in Minqin are linked to reaching the groundwater allocation targets. Rewarding officials for reaching environmental targets is a known instrument of the Chinese national government to ensure policy implementation at local level (Nickum 2010).

To constrain farmers' groundwater use, the water authorities closed a large number of wells and restricted the pumping capacity of the remaining wells (Aarnoudse et al. 2012). According to official records, 3000 out of 7000 tube wells were closed from 2007 to 2009. At the same time smart card machines were installed on the remaining wells to enforce a per capita groundwater quota system. In 2010, the machines were not yet installed and/or functioning properly on all wells (Aarnoudse et al. 2012), but in 2013, the interviewed well operators reported that all wells were provided with smart card machines and earlier problems had been solved.

Implementation of the groundwater quota

The official per capita water use quota is 1,200 m^3/year. (In the downstream irrigation districts where evaporation rates are higher the official water quota is slightly higher.) The quota is calculated based on a norm of 2.5 mu of irrigated crop land per person.[36] Previous to the water reforms, the per capita irrigated land was estimated to be around 5 mu (Gansu Province Water Resources Bureau 2007). According to calculations by the local water authorities on crop irrigation requirements under conventional irrigation techniques and local climatic conditions the quota is expected to be sufficient for low water demanding, drought resistant crops, such as cotton (300 m^3/mu) and sunflower (445 m^3/mu) (Minqin Water Resources Bureau 2009). The per capita water quota is set to realize a significant reduction in farmers' groundwater use, while safeguarding basic

[35] Below province level the Chinese administration is divided in four levels: prefecture (or city), county, township and village. The Water Resources Bureaus follow the administrative boundaries of the prefectures and counties. The Irrigation District Bureaus follow the boundaries of the canal irrigation districts and often include more than one township.

[36] One mu equals 0.0666 ha.

livelihood conditions for farmers. The water quota includes surface water, groundwater and rainfall. Priority is given to surface water allocation, which means that the actual groundwater quota can differ per year and per location depending on the surface water availability and rainfall during the cropping season. Farmers pay a groundwater fee of 0.02 CNY/m³ to the IDB, based on their actual groundwater use. An electricity fee of 0.4 CNY/kWh for groundwater pumping is separately paid to the electricity provider.

In Minqin, groundwater use is organized at sub-village level in farm groups of approximately 40 households. In every farm group two to seven tube wells are in use.[37] Like elsewhere in China, the shared ownership and use of wells is associated with collective institutions inherited from the former production teams (Bluemling et al. 2010). Although the water quotas are officially calculated per person, the implementation is adapted to this reality. The groundwater quota is administered per farm group by the local IDB. The WUA reports the number of inhabitants per farm group to the IDB, based on which the water quota per farm group can be calculated. In order to control farmers' groundwater use during the cropping season, the groundwater is usually prepaid before an irrigation turn. In this way, a representative of the farm group needs to visit the IDB office to reload the card before each irrigation turn. This allows the IDB to adjust farmers' groundwater quota to the annual surface water and rainfall conditions. When a farm group has just received an extra surface water turn, they may have to skip the next groundwater turn. Fair distribution of the groundwater between the households is secured through collective institutions at farm group level (Aarnoudse et al. 2015).

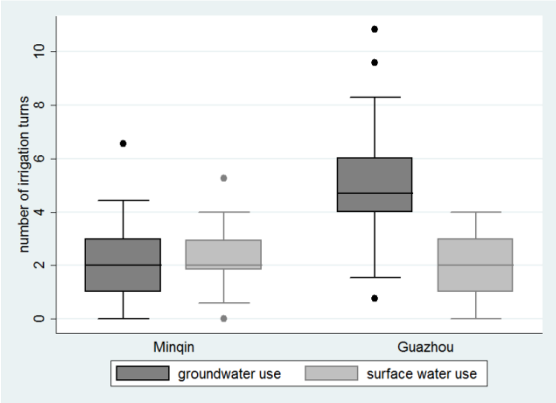
Farmers' groundwater use

Typically farmers in Minqin use both surface water and groundwater to irrigate their crops. Usually surface water is applied during the early cropping season and groundwater during the late cropping season. During the surveyed cropping season, farmers applied on average 2.2 groundwater turns and 2.2 surface water turns (see Figure 4.2). The mean cropping area per household is only 0.89 ha. The main crops are cotton, sunflower, maize and fennel (see Table 4.1). Whether the official per capita water quotas are complied with in reality is hard to evaluate based on our survey data. However, all interviewed village leaders and well operators claimed that the farmers reduced their groundwater use after the smart card machines have been installed. One village leader explained that they currently pump three times less groundwater than they used to. Moreover, 80% of the

[37] Villages are usually divided in smaller units. In China different names circulate referring to the sub-village units, such as natural village, community, (production) team and small group (*ziran cun, she, dui* and *xiao zu*). In this paper we will consistently refer to the sub-village units as farm groups.

farmers stated that they currently use less groundwater per unit of land than ten years ago (i.e. before the machines were installed) (see Figure 4.3).

Figure 4.2 Distribution of groundwater and surface water use per household in Minqin (n=105) and Guazhou (n=44)



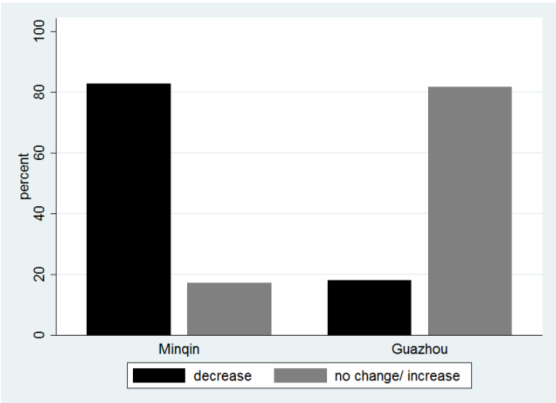
Source: own survey

Table 4.1 Water use characteristics for most important crops in Minqin and Guazhou

County	Crop	*n*	% of cropping area	Surface water use (nr turns)		Groundwater use (nr turns)	
				Mean	Std. dev.	Mean	Std. dev.
Minqin	Cotton	77	32	2.0	1.1	1.9	1.2
	Sunflower	63	22	2.3	1.1	2.0	1.2
	Maize	68	17	2.3	1.2	2.6	1.3
	Fennel	35	12	2.4	1.0	1.5	0.91
Guazhou	Cotton	34	60	2.1	1.2	3.9	1.7
	Melon	35	37	1.6	1.4	6.1	3.0

Source: own survey

Figure 4.3 Farmers' perception on groundwater use trends in Minqin (n=105) and Guazhou (n=44)



Answer to the question: How did your groundwater use quantity per unit of land change over the last ten years?
Source: own survey

4.3.2 Guazhou County

Motivation for groundwater regulation

Groundwater use for irrigation started to develop in Guazhou County in the 1990s. At this time a large migration project brought rural inhabitants from central Gansu Province to the scarcely populated Shule River Basin (Zhang and Zhang 1996). Through this project people were offered to escape from the resource poor and remote mountainous areas. In new settlements groundwater wells were drilled by the government to enable agriculture on previously uncultivated land. In the neighbouring, pre-existing settlements, groundwater drilling also took off around this time. At current there are around 2300 groundwater wells in use in the Shule River Basin. Annual groundwater extraction is estimated to be around 180 million m^3, which is at least double the amount of annual groundwater recharge (Shule River Basin Management Bureau 2013). Groundwater use within the basin is mainly taking place in Guazhou County.

In 2005, a large water management reform in the Shule River Basin split the responsibilities on surface water and groundwater management over two separate government agencies. Groundwater management stayed with the local government administration and it's Water Resources Bureaus at prefecture level and county level. Surface water management was transferred to a newly established River Basin Management Authority, which is under direct jurisdiction of the Provincial Government. Supervision over the Irrigation District Bureaus – previously in the hands of the Water Resources Bureaus – moved to the River Basin Management Authority. This shift in management responsibilities also meant that the surface water fees were now collected by the independent River Basin Management Authority.

It has been argued that irrigation water fees function as a new agricultural tax in China (Webber et al. 2008). In Guazhou, the surface water fee is currently 0.1 CNY/m^3, which amounts up to 10-20 million CNY per year for the whole county. Soon after the local Water Resource Bureaus lost its revenue from surface water fees to the newly established River Basin Management Authority, the smart card machines were installed and the tiered groundwater pricing system was introduced. Before that time (since the revision of the national Water Law in 2002) an area based groundwater price had existed on paper, but was not effectively implemented. Officially the tiered pricing system intends to create economic incentives for farmers to save water (Government of Guazhou 2015). However, the elimination of the income from surface water fees has likely increased the local government administration's interest in reinforcing the groundwater pricing system. Indeed, Yang et al. (2003) warn that groundwater pricing in China may create an incentive for local authorities to generate revenue.

Implementation of the tiered groundwater pricing system

Like in Minqin, households share ownership and use of groundwater wells per farm group. Farm groups consist approximately of 50 households, with four to seven wells per farm group. Although groundwater turns are often organised collectively – whereby the starting date is decided during a meeting of household heads – each farmer is responsible for irrigating his/her own plot. This means that how much water is used is primarily an autonomous decision made at household level. After installation of the smart card machines, the tiered groundwater pricing system was introduced in 2007. According to the interviewed well operators all wells are currently equipped with smart card machines. Block rates are calculated per year per well. Village leaders and well operators reported the price to be 0.01 CNY per m³ for the first 100.000 m³ per well and 0.02 CNY per m³ above 100.000 m³. It is unclear based on what standard the price and volume of the initial consumption block is defined. One interviewed village leader estimated that up to 200.000 m³ are pumped per well. However, reported command areas per well differ between 10 and 40 ha, which means that total water use per well is also likely to vary. Moreover, well density between farm groups varies from four to seven wells per 50 households. So, because of the uneven well density between farm groups a block rate per well does not safeguard equal initial consumption blocks per household. In farm groups with a high well density individual users can pump more water for a low price than in farm groups with a low well density.

The functioning of the tiered pricing system is further blurred through the way the groundwater fee is paid and collected at farm group level. Usually the farm group puts a deposit on their shared groundwater account once and continues to use the well throughout the season i.e. the card does not have to be reloaded after each irrigation turn. The deposit is automatically charged based on the farm group's water use. Once the account is empty, the pump is turned off. After a new payment is made to the local Water Resources Bureau and the card is reloaded, the pump can be turned on again. The farm group's collective bill is paid by charging the individual households a groundwater price per hour or per kWh. The pumping hours or electricity use per household is recorded manually by the irrigators during each irrigation turn. The price includes both the electricity fee and the groundwater resource fee. The electricity fee is 0.4 CNY/ kWh for agricultural use purposes and collected separately by the electricity provider. The combined prices farmers mentioned were around 12 CNY/hour and around 0.65 CNY/kWh. In fact, many farmers are actually not aware of the exact groundwater price per m³ and do not differentiate rates for different levels of consumption. This means that the tiered pricing is not actually functional at household level, even though decisions on groundwater use quantities are made at this level.

Farmers' groundwater use

Most farmers in Guazhou use both surface water and groundwater to irrigate their crops. Like in Minqin, surface water is applied during the early cropping season and groundwater during the late cropping season. During the surveyed cropping season, farmers applied on average 4.9 groundwater turns and 1.9 surface water turns (see Figure 4.2). The mean cropping area is 2.2 ha per household. The main crops are cotton and melon (see Table 4.1). In general farmers consider the groundwater price to be just fine or slightly expensive. However, they do not feel forced to reduce their groundwater use. Almost all village leaders and well operators think that the farmers did not change their groundwater use after the smart card machines have been installed. In fact, 80% of the farmers stated to use the same amount or more groundwater per unit of land compared to ten years ago (i.e. before the machines were installed) (see Figure 4.3).

4.3.3 Comparing the two cases

In both Minqin and Guazhou groundwater pumping for agriculture used to exceed groundwater recharge rates by far. Hence, China's national water law legitimates to constrain farmers' groundwater use by local authorities in both counties. Nevertheless, the underlying motivations of the local authorities to install smart card machines and implement groundwater regulation measures differ strongly. In Minqin, strict regulation of farmers' groundwater use was supported by the national government and a groundwater allocation plan was set at river basin level. Under these circumstances reaching the groundwater allocation targets is rewarded with future career opportunities, which strengthens the incentives of the local water officials to reach those targets. In Guazhou, the decision to reform the groundwater regulations was made at prefecture level, and was not backed up by a groundwater allocation plan. The fact that the implementation of the new groundwater pricing system coincided with the elimination of income from surface water fees for the local government, suggests that revenue generation was an important underlying motivation to establish the groundwater pricing system. One of the reasons why the national government has paid more attention to the case of Minqin is probably the severity of the problem. In Minqin the duration and intensity of groundwater overexploitation has been more pronounced than in Guazhou so far.

We observe that the underlying motivations of the local water authorities have had an impact on the choice for and implementation of the regulatory institutions. In Minqin, the quota are calculated based on a maximum irrigated area per capita representing half of the previously mean irrigated area per capita. The design of the quota system allows for the restrictions of pumping rates, while securing equal access across farm groups. Furthermore, collective institutions at farm group level facilitate a fair distribution between households (Aarnoudse et al. 2015). In Guazhou, the design of tiered pricing systems, with block rates set per well, fail to allow equal initial consumption blocks for all farmers, due to the uneven distribution of wells. The threshold within the tiered pricing system is further blurred by the habit to convert groundwater fees and electricity fees in a combined flat rate at farm group level. On top of that, the level of the groundwater fee does not seem to stimulate farmers to reduce their groundwater use. This supports the idea that the local Water Resources Bureau may be interested in keeping farmers' groundwater use at elevated levels to assure their own revenue from groundwater fees. As pointed out by Yang et al. (2003), raising prices to a level which will actually reduce farmers' groundwater use, would potentially also curtail their own revenue.

The circumstances under which the groundwater regulation measures have come about are also reflected by the actual impact these measures have had on farmers' groundwater use. Based on the survey respondents' own perception farmers' groundwater use in Minqin seems to have decreased since the implementation of the quota, while the farmers' groundwater use in Guazhou seems to have increased despite the tiered groundwater pricing. Whereas these trends in groundwater use may not only depend on the regulation measures, but also on other factors, such as changes in surface water supply over the last ten years, it does assert that the quotas have been more effectively implemented than tiered pricing. Moreover, the perceptions on the impact of the respective institutions on farmers' groundwater use are supported by our own observations of farmers' groundwater use. Based on statistics derived from the household questionnaire farmers' groundwater use quantity per household in Guazhou is significantly and substantially larger than in Minqin (see Table 4.2). On the one hand, we observe that the irrigated area per household in Guazhou is more than twice as much as in Minqin, even though the household size is slightly smaller. This can be explained by the difference in population density as well as the recent closure of wells in Minqin, which forced farmers to abandon previously cultivated land (Aarnoudse et al. 2012). Yet, on the other hand, farmers in Guazhou apply about double the number of groundwater turns per unit of land compared to Minqin, while farmers' surface water use quantity is almost the same between the two counties. This can partly be explained by the difference in climatic conditions. Based on average evaporation and rainfall data, one would expect the irrigation requirements for equivalent crops to be around 20% higher in Guazhou.[38] However, our data shows that the total number of irrigation turns (including surface water and groundwater) used per unit of land in Guazhou is almost 60% higher than in Minqin (see Table 4.2).

[38] When crop characteristics are neglected and basic irrigation requirements are calculated according to the following formula [irrigation requirements = evaporation – rainfall], the ratio for Minqin : Guazhou would be 2470 : 3050.

Table 4.2 Characteristics of surveyed households in Minqin (n=105) and Guazhou (n=44)

	Minqin		Guazhou		Significance
	Mean	Std. dev.	Mean	Std. dev.	
Groundwater use (nr turns)	2.2	1.2	5.0	2.0	***
Surface water use (nr turns)	2.2	0.93	1.9	1.3	*
Total water use (nr turns)	4.4	1.0	6.9	2.0	***
Irrigated area (ha)	0.89	0.34	2.2	1.3	***
Nr of household members	4.6	1.1	4.1	1.3	**
Cotton yield (kg/ha)	$4.2 \cdot 10^3$	$1.0 \cdot 10^3$	$5.2 \cdot 10^3$	$1.4 \cdot 10^3$	***
Average crop revenue (CNY/ha)	$28 \cdot 10^3$	$22 \cdot 10^3$	$35 \cdot 10^3$	$13 \cdot 10^3$	**
Total crop revenue (CNY)	$27 \cdot 10^3$	$35 \cdot 10^3$	$81 \cdot 10^3$	$60 \cdot 10^3$	***

*** (**, *) statistically significantly different with a probability of less than 1 (5, 10) percent
Source: own survey

Moreover, when we compare the cropping pattern, we see that the high groundwater use intensity allows farmers in Guazhou to grow melon as a major crop. Melon is a particularly large groundwater gobbler due to its frequent irrigation needs until late in the season. In Minqin, melon used to be a popular crop in the 1990s and early 2000s, but has largely disappeared recently. Most surveyed village leaders estimated that melon still made up 40% of their cropping area ten years ago. However in 2012, less than 5% of the surveyed farmers in Minqin reported to grow some melon, basically for own consumption. Village leaders regard the groundwater restrictions to be the main reason for the experienced crop change. On the contrary, melon production is a growing business in Guazhou. All village leaders stated that melon production has boomed over the last ten years. Furthermore, the crop water use data suggests that farmers in Guazhou obtain higher cotton yields due to additional groundwater use. On average, farmers in Guazhou apply two extra irrigation turns and obtain a 20% higher yield (see Table 4.2). Overall, farmers in Guazhou gain a higher revenue from crop production than in Minqin, both per unit of land and in total (see Table 4.2). This indicates that the restricted access to groundwater is a limiting production factor for farmers in Minqin.

The question remains whether it is indeed the difference in institutional regulations which primarily restricts farmers' access to groundwater in Minqin compared to Guazhou. Hydro-geological access conditions may also play a role. Although the natural hydro-geological conditions (i.e. without human alteration) in both counties can be considered similar, groundwater depth and salinity rates may differ depending on the duration and intensity of overexploitation. Based on groundwater depths reported by well operators and village leaders, it can be assumed that in Minqin the groundwater level is between 20 to 40 meter, while in Guazhou the groundwater level is between 10 to 20 meter. This means that the energy consumption per m^3 of pumped groundwater is expected to be a little higher in Minqin. However, as pointed out by Hoogesteger and Wester (2015), once tube wells are in place the threshold at which farmers' access to groundwater becomes critically threatened is at much deeper groundwater levels (>100 m). With regard to the groundwater salinity, the exact salinity rates in the two counties could not be obtained through our survey. However, we did find that the groundwater salinity problem is perceived alike in both counties. In general groundwater is considered more saline than surface water, which is the main reason for farmers to prioritize surface water irrigation (when available). Moreover, in about one third of the villages in each county, well operators and village leaders assessed the groundwater salinity to be high (i.e. selecting 4 or 5 on a scale from 1-5). So, groundwater salinity is perceived as a problem in both counties, presumably with locally varying levels of severity. This means that groundwater salinity may be a reason for farmers to reduce their groundwater use, but if so this would appear in both counties. All in all, the most flagrant difference in farmers' access to groundwater between Minqin and Guazhou is determined by the institutional conditions, as illustrated in this paper.

4.4 Conclusions

Difficulties in monitoring farmers' groundwater use is considered to be one of the main reasons why groundwater regulations fail worldwide (Hoogesteger and Wester 2015). Both in Minqin and Guazhou County local water authorities have installed smart card machines for groundwater monitoring over the last decade. However, the regulatory institutions behind the new technology are different in the two counties. In Minqin, the smart card machines have primarily been used to implement a per capita groundwater quota. In Guazhou, the technology has been used to implement a tiered groundwater pricing system. Based on farmers' own perception we find that the groundwater regulations in Minqin have been more effective in curbing farmers' groundwater use over the last ten years than in Guazhou. This finding is supported by the observation that farmers' current groundwater use in Minqin is significantly and substantially less than in Guazhou, despite similar climatic and hydro-geological conditions.

We argue that the difference in impact on farmers' groundwater use cannot simply be ascribed to a theoretical understanding of the different types of regulatory institutions and the underlying allocation mechanisms. In fact the societal context in which the groundwater regulations came into existence had a major influence on the choice of regulatory institutions and the way they have been implemented. Although in both counties the official reason to install smart card machines was to regulate intensive groundwater use, the water authority's incentives to actually curb farmers' groundwater use has been more pronounced in Minqin than in Guazhou. The strong motivation to reach groundwater allocation targets has likely caused the authorities in Minqin to select quotas rather than pricing as a regulation measure. This is in line with observations on surface water irrigation management made by Molle (2009). He argues that to deal with issues of water scarcity authorities are more likely to fall back on water quotas than water pricing. In Guazhou, the need to actually reduce farmers' groundwater use was less pressing. The actual reason for the new groundwater pricing system seems to have been a loss of income from surface water fees. Yang et al. (2003) earlier warned that revenue generation by local authorities may pervert the functioning of groundwater fees as an appropriate instrument to regulate farmers' groundwater use in China. Our study illustrates that groundwater pricing is more sensitive to distortion by false incentives than groundwater quotas.

The different underlying motivation also becomes apparent through the way the regulatory institutions have been implemented. The way the per capita quota is calculated in Minqin clearly aims at an equal reduction in groundwater use for all users. During the implementation process the per capita quota is transferred into a "bulk" quota for farm groups with shared well ownership. However, we observe that the fair distribution of groundwater quota between households is supported by collective institutions at farm group level (Aarnoudse et al. 2015). On the contrary, the implementation of a block rate per well in Guazhou fails to structurally incorporate the aspects of reduced groundwater use and equal initial consumption blocks for all users due to the uneven distribution of wells. A situation which is even more precarious taking into account that a careful design is regarded critical to achieve efficient resource allocation through a tiered pricing system (Schoengold and Zilberman 2014). On top of that, the way groundwater fees are collected at household level in Guazhou blurs the effect of a pricing threshold, which is the theoretical idea behind tiered groundwater pricing. Molle (2009) pointed at the same risk for irrigation water pricing when surface water is allocated in bulk quantities to multiple users. Therefore, we conclude that in the context of shared well ownership, groundwater quotas are more likely to realize a reduction in groundwater use while safeguarding equal access to all.

Our study shows that although the smart card machines may provide a technological solution for the groundwater monitoring problem, it does not automatically lift all obstacles regarding effective groundwater regulations. Other important obstacles, such as a lack of support by local authorities may continue to hinder effective groundwater regulation (De Stefano and Lopez-Gunn 2012).

Conclusions

5.1 Summary of the main results

The spontaneous conjunctive use of surface water and groundwater in canal irrigation systems is a common phenomenon worldwide. Groundwater can be an important resource to increase farmers' water security in canal irrigation systems. However, intensive pumping – mostly occurring at tail-end locations – can render groundwater use socio-economically and environmentally unsustainable. A conjunctive management approach, whereby surface water and groundwater are coordinated at irrigation system level, is advocated to maintain water security while countering the uneven development of surface water and groundwater within irrigation systems. In order to achieve conjunctive management the integration of surface water and groundwater institutions is needed as well as some sort of control over farmers' groundwater use. The main objective of this research is to explore the occurrence of spontaneous conjunctive use and the potential of conjunctive water management in the context of intensive groundwater use for small scale agriculture in the arid Northwest of China. In three papers the following aspects are dealt with: 1) the integration of surface water and groundwater institutions at different management levels; 2) the relation between groundwater and surface water irrigation under spontaneous conjunctive use conditions; 3) the effectiveness of existing groundwater regulation measures in a conjunctive use setting. The research is based on primary data collected in three inland river basins in Gansu Province, Northwest China. The empirical data includes a survey amongst roughly 300 farm households and about 30 in-depth interviews with multiple stakeholders.

Existing institutions under spontaneous conjunctive use often hamper the emergence of conjunctive water management. Particularly problematic are the division of surface water and groundwater responsibilities over separate state agencies (Blomquist et al. 2004 ; Bredehoeft 2011 ; Foster and Steenbergen 2011) as well as a lack of effectively implemented regulatory institutions to control farmers' groundwater use (Evans et al. 2014 ; O'Mara 1985). In the study area different conjunctive use situations have been observed. The question is what institutional conditions lead to coordinated conjunctive use. The first paper of this thesis treats the alluvial plains of the three inland river basins as three separate cases and presents a comparative case study analysis to answer this question. In general the study shows that water management in the study area is subject to a strong hierarchical bureaucracy including river basin authorities, local water authorities (at prefecture and/or county level) and Water Users' Associations (WUAs) at village level. Only in the Shiyang River Basin, one out of the three cases, the management organizations at all three levels are responsible for both surface water and groundwater. The conjunctive use situation in this context differs from the other two cases. Here, groundwater regulations are effectively implemented by local water authorities, because pressure is made by higher level authorities. It was also found that several new water management measures bridge surface water and groundwater management solutions. In the second case, located in the Hei River Basin, responsibility over surface water and groundwater is shared by the same organization at local level but not at river basin and village level. At river basin level the management authority is only responsible for surface water. Because of restrictions on surface water allocation enforced by the river basin authority, the local water authorities are eager to close an eye on farmers' groundwater use. Finally, in the third case, in the Shule River Basin, surface water and groundwater responsibilities are divided over different organizations at each of the three management levels. Cooperation between the organizations hardly takes place. The divide also means that the local groundwater authorities lost their previous income from surface water fees. This has created an incentive to collect groundwater fees for revenue generation, rather than groundwater regulation. With one positive and two negative cases of conjunctive water management, the paper shows that in a hierarchical water bureaucracy like in China the shared responsibility over surface water and groundwater is required at *all* management levels in order to facilitate conjunctive management. It was also confirmed that effectively implemented regulatory institutions for groundwater management are a precondition for conjunctive management to emerge.

Various push and pull factors can drive groundwater use for irrigation. Unreliable, reduced surface water supply is widely reckoned as an important trigger for farmers to start using groundwater in canal irrigation systems (Bouarfa and Kuper 2012 ; Hammani et al. 2009 ; Shah et al. 2003). The question is whether this development could also be reversed. Would it be possible to curb intensive groundwater use in tail-end irrigation districts by increasing the surface water supply? To answer this question the second paper of this thesis looks into the relation between farmers' groundwater use, the surface water supply and factors of agricultural intensification under spontaneous conjunctive use conditions. Data from the household survey in the Hei and Shule River Basin (n=157) is analysed using descriptive statistics, a multivariate regression and a set of independent t-tests. In 2013, around 60% of the surveyed farmers used groundwater for irrigation, the other 40% solely relied on surface water irrigation. Most of the farmers used groundwater in conjunction to surface water. Only 5% of the groundwater users completely refrained from using surface water. 95% of the groundwater using farmers stated to prefer the use of surface water when available, primarily because of the higher water quality compared to groundwater. Through a multivariate analysis it is estimated what factors are most important in explaining farmers' groundwater use quantity. It was found that only 30% of the variance in the sample could be ascribed to household characteristics. Most heterogeneity occurred between the villages and could be explained by the number of surface water irrigation turns supplied to the village. Above seven surface water irrigation turns farmers hardly used any groundwater. Below this level, farmers on average replaced one surface water turn with more than one groundwater turn. This implies that farmers do not only use groundwater to substitute a lack of surface water, but also to intensify their production. It was found that the gross crop revenue per hectare of groundwater users is 20% higher and the cropping area is 30% higher compared to households which solely rely on surface water. Moreover, the total number of irrigation turns applied (including surface and groundwater) is 30% higher for groundwater users. This makes it questionable whether the trend towards intensive groundwater use can simply be reversed by increasing the surface water supply. Restrictions on land expansion and policies to propagate low water demanding crops may be necessary to avoid intensive groundwater use. A more balanced distribution of surface water between upstream and downstream reaches may, however, have a soothing effect on farmers' intensive groundwater use and could also increase farmers' acceptance regarding possible groundwater use restriction policies.

The effective implementation of direct groundwater regulation measures by the state (like groundwater quota and well permits) is expected to be more feasible in China than in other countries characterised by small scale agriculture. This expectation is based on the fact that China has decentralised government structures reaching out to groundwater users and the country's recent economic growth provides the financial means for groundwater management (Shah 2005 ; Villholth 2006). China's 2002 Water Law indeed foresees the regulation of groundwater use by local authorities in areas of severe overdraft. But, because national policy directives on groundwater regulations are hardly elaborated, diverging situations can be found at local level. The question is whether the expectation that direct groundwater regulations can be implemented more effectively in the Chinese context holds in reality. In the third paper of this thesis two cases of direct groundwater regulation to curb intensive groundwater use in the downstream reaches of the Shiyang and Shule River Basin are compared. A mixed methods approach is applied to analyse what regulatory institution has been most effective in regulating farmers' groundwater use and why. In both case study areas local water authorities installed smart card machines – water meters linked to a digital administration system – to monitor and regulate farmers' groundwater use. In Minqin County in the Shiyang River Basin per capita groundwater quota are allocated as a regulation measure. In Guazhou County in the Shule River Basin a tiered groundwater pricing system is implemented officially to reduce farmers' groundwater use. However, the underlying motivation of local water authorities to implement the regulation measures differs between the two cases. In Minqin the reduction in groundwater extraction is pushed by higher level water authorities, who reward local water officials when reaching pre-defined allocation targets. In Gauzhou the local groundwater authority seems to be particularly interested in generating revenue from groundwater, because their previous income from surface water fees has been reallocated to the newly established river basin authority. Also, the way the quota regime is implemented aims more clearly at a reduction in groundwater use and an equal distribution of groundwater amongst all farmers compared to the pricing system. Based on farmers' own perception it can be concluded that quotas have been more successful in curbing farmers' groundwater use than the tiered pricing system. In line with this, it is found that groundwater use reported by farmers in Minqin is significantly lower than in Guazhou, even though their surface water use and other hydro-geologic and climatic conditions are very similar. The two cases illustrate that also in the Chinese context different underlying motivations may drive local water authorities to engage in groundwater regulation. Even when decentralised government structures and financial means are available to technically control groundwater use, this does not necessarily lead to effective regulatory institutions.

This PhD research shows that conjunctive use is widespread on the alluvial plains of the Hexi Corridor in Northwest China. Groundwater is primarily used to substitute low surface water availability and its use is most intensive in the rivers' downstream reaches. However, farmers also profit from groundwater irrigation to intensify their agricultural production by growing high water demanding, high-value crops and expanding the cropping area. Whereas conjunctive use is prevalent in all three major river basins, the groundwater management picture is very diverse. Only in one out of the three river basins groundwater is strictly regulated and groundwater management is integrated with surface water management. In the other two river basins groundwater is either hardly regulated or regulations are not effectively implemented. Moreover, separate state agencies are found to be responsible for surface water and groundwater management. All in all, spontaneous conjunctive use is more common than coordinated conjunctive use. To what extent the institutional setting allows for a conjunctive management approach is found to vary from place to place. The institutional context (e.g. who is responsible for groundwater management and what regulatory institutions are in place) is strikingly different from river basin to river basin within the study area.

5.2 Main contributions to the literature

5.2.1 The occurrence of conjunctive water use

Although conjunctive use has regularly been observed in northern China (Liu et al. 2008 ; Wang et al. 2010 ; Wang et al. 2013 ; Zhen and Routray 2002), it is difficult to estimate to what extent conjunctive use takes place because official data on groundwater use for irrigation is not available. This research shows that the use of groundwater in canal irrigation districts is widespread in the Hexi Corridor in Northwest China. The development started in the 1970s, but continues to expand today. Foster et al. (2010) sketches the typical development of groundwater use in canal irrigation districts as a phenomenon pushed by underperforming surface water supply, gradually leading to groundwater based agricultural growth, which eventually results in neglected surface water supply systems and excessive groundwater use. The development of conjunctive use on the alluvial plains in the Hexi Corridor shows similarities with this so-called typical development. The initial development of groundwater use is related to a decrease in surface water supply, as is found to be the case in many other countries (Hammani et al. 2009 ; Kuper et al. 2012 ; Shah et al. 2003). Moreover, it was calculated that at current farmers do not only use groundwater to substitute a lack of surface water, but also to intensify their agricultural production. The production is intensified by shifting to high-value, high water demanding crops and increasing the irrigated cropping area. This phenomenon can also be observed in other areas characterised by groundwater use worldwide (Allan 2007 ; Llamas and Martínez-Santos 2005 ; Shah et al. 2003). Nevertheless, instances of neglected surface water supply systems due to full reliance on groundwater were not found under today’s circumstances. Only a very small number of farmers seemed to purposefully refrain from surface water use. Almost all farmers prefer the use of surface water when available, mainly because it is not as saline as groundwater but also because the flow rate is stronger which makes irrigating less time consuming. It could be argued though, that in the 1980s and 1990s the surface water supply to the downstream sub-basin in the Shiyang River Basin was neglected, in accordance with the typical development described by Foster et al.(2010).

The relation between surface water supply and groundwater use over time could only roughly be sketched based on the research results. However, a more detailed quantitative analysis based on cross-sectional data is provided to estimate the relation between surface and groundwater irrigation under current spontaneous conjunctive use conditions. Such a quantitative analysis has not yet been carried out in the Chinese context, most research just hints at the relation between unreliable surface water supply and the development of groundwater use in the past (Liu et al. 2008 ; Wang et al. 2009a ; Zhen and Routray 2002). Foster et al. (2010) state that the main problem with spontaneous conjunctive use is the uneven spatial development of surface water and groundwater within canal irrigation systems. This was also found to be the case in the study area, where surface water and groundwater use levels varied largely between upstream and downstream villages. In general farmers’ groundwater use was found to have a strong negative relation with the amount of surface water supplied. However, this relation is basically cancelled out above a certain surface water supply level. In fact, farmers barely use groundwater above this level. Moreover, it was shown that in areas where farmers fully rely on surface water the total water use and the level of agricultural intensification is substantially lower than in areas of conjunctive groundwater use. This indicates that when surface water is relatively abundant, farmers are not interested in or aware of the additional benefits of using groundwater for agricultural intensification. A similar situation was found in large scale irrigation systems in arid regions in North Africa (Kuper et al. 2012).

5.2.2 The groundwater governance challenge

Groundwater management by the government often only develops after groundwater use has intensified (Bouarfa and Kuper 2012 ; Kemper 2004). In line with this it is observed that in the study area groundwater management by local authorities is most pronounced where groundwater development took off and intensified earliest. Currently different groundwater policy measures are implemented in the three river basins of the Hexi Corridor. However, most measures are based on a rather narrow understanding of groundwater *management* rather than a more holistic groundwater *governance* approach. The groundwater measures applied in the study area rely on *direct* regulation by the government, such as groundwater quota, groundwater pricing and a ban on drilling wells. This follows the observation of Shah (2014) that direct groundwater regulations are advancing in China. Attempts to curb farmers' groundwater use based on participatory approaches or indirect regulation through the energy sector as can be found in other countries have not been observed in the study area (Figureau et al. 2015 ; Lopez-Gunn and Cortina 2006 ; Mukherji et al. 2009 ; Shah and Verma 2008 ; Steenbergen 2006 ; Taher et al. 2012 ; Wester et al. 2009).

Yet, in the Shiyang River Basin it was found that direct groundwater regulation measures were combined with increased surface water inflow from upstream to partly compensate for groundwater restrictions and relieve soil-salinity in the tail-end district. These practises could be understood as a new approach which widens the traditional groundwater management concept. Mukherji and Shah (2005) consider the application of multiple management measures as one way to achieve a more holistic governance approach. Nevertheless, the integration of surface water and groundwater management solutions in the Shiyang River Basin does not fully embrace the "multi-actor, multi-level, multi-instrument" (p.329) governance process as advocated by Mukherji and Shah (2005) and others (Bouarfa and Kuper 2012 ; Giordano 2009 ; Hoogesteger and Wester 2015).

5.2.3 Insights on conjunctive water management

The new management approach in the Shiyang River Basin can be captured under the label of conjunctive water management, which is defined as the planned simultaneous use of surface water and groundwater within one irrigation system or river basin (World Bank 2005). So far, conjunctive water management is considered to be a "blind spot" or a "lost opportunity" in developing countries (El Haouari and Steenbergen 2011 ; Foster and Steenbergen 2011). As such, the case of conjunctive water management in the Shiyang River Basin represents a rather unique example. In literature conjunctive management is expected to solve problems related to the uneven development of groundwater and surface water within irrigation systems or river basins (Evans et al. 2014 ; Foster and Steenbergen 2011 ; World Bank 2005). In the Shiyang River Basin such benefits could indeed be achieved and historic developments of reduced surface water supply and intensified groundwater use in the downstream sub-basin have been reversed over the last decade. It should be noted though that the conjunctive management regime came into existence through a very top-down approach. In fact, the Chinese central government itself played an important role in recent water sector reforms. Evans et al. (2014) anticipates that conjunctive management is generally achieved through a top-down approach. Nevertheless, it is questionable whether the management approach in the Shiyang River Basin is applicable to other political systems. Shen (2015) even questions whether the case can be replicated in China due to the high costs involved.

Besides that, the case of the Shiyang River Basin stands in stark contrast with the other two cases described in this thesis. Evans et al. (2014) warn that the creation of new groundwater institutions isolated from surface water institutions potentially hinders the emergence of conjunctive management. This is exactly what has been observed in the Shule River Basin, where separate public sector organizations are responsible for surface water and groundwater management. Also in the Hei River Basin it was found that a narrow focus on surface water allocation at river basin management level resulted in the recent intensification of groundwater use. This means that typical problems of spontaneous conjunctive use continue to exist in two out of the three cases presented in this thesis. Therefore, conjunctive management cannot be considered standard in China and opportunities to advance conjunctive management still exist like in other countries characterized by smallholder agriculture (Foster and Steenbergen 2011).

It is often argued that conjunctive water management is largely constrained by the institutional setting in which spontaneous conjunctive use develops. Two specific aspects that are considered problematic are: 1) the spread of surface water and groundwater management responsibilities over different state agencies (Blomquist et al. 2004 ; Bredehoeft 2011 ; Foster and Steenbergen 2011 ; World Bank 2005); and 2) a lack of effectively implemented regulatory institutions for groundwater management (Evans et al. 2014 ; O'Mara 1985). On the one hand, this research shows that the same constraints hinder conjunctive management in China; on the other hand, it shows that it is possible to overcome these constraints in the Chinese political setting. So far, the argument that isolated agencies responsible for surface water and groundwater are a major constraint for conjunctive management is mainly based on negative examples (Foster and Steenbergen 2011). This research provides evidence for this argument through one positive example in contrast with two negative examples.

5.2.4 Direct groundwater regulations

In small scale agricultural settings the implementation of direct groundwater regulation measures by the state (i.e. measures which act within the groundwater sector like groundwater quota or well permits) has proven to be extremely difficult (Kemper 2007 ; Molle and Alvard 2015). It is expected that effective implementation of such measures is more likely in China than elsewhere (Shah 2005 ; Villholth 2006). This thesis shows that the government in China is indeed putting more and more emphasis on groundwater regulation through direct measures. In all three river basins it was observed that new regulatory institutions were put in place over the last decade. Nevertheless, the expectation that groundwater measures can be implemented effectively in the Chinese context holds only partly. It can be confirmed that the state can reach out rather easily to the groundwater users due to decentralized government structures and shared well ownership (Aarnoudse et al. 2012 ; Shah 2005). Also, the financial means to install smart-card machines on groundwater wells are available and facilitate close monitoring of farmers' groundwater use (Villholth 2006). However, the motivation of local authorities to regulate groundwater differs strongly depending on the local institutional context. In this research local authorities were only found to be truly motivated to reduce agricultural groundwater use when higher water authorities set groundwater allocation targets. In the other two cases the local water authorities were "left alone" with the task to regulate groundwater use. Here, it was observed that the motivation of local authorities to restrict farmers' groundwater use is rather low, like elsewhere in the world (De Stefano and Lopez-Gunn 2012 ; Hoogesteger and Wester 2015 ; Molle and Alvard 2015 ; Mukherji and Shah 2005). This exemplifies that the institutional setting in which decisions are made by public sector organizations can alter their motivational patterns (Popa 2015).

The research results strengthen the argument that the problem of intensive groundwater use should not be based on direct regulations alone; alternative measures such as conjunctive water management should also be considered. In fact, the cases presented in this thesis illustrate that "conjunctive management makes groundwater management possible and vice versa" (Blomquist et al. 2004 p.121). On the one hand, the integration of surface water and groundwater responsibilities at all management levels supports the effective implementation of groundwater regulation measures; on the other hand, additional surface water supply to areas of intensive groundwater use is not expected to reduce excessive water use when not combined with other policies. These could be policies to restrict land expansion and promote low water demanding crops, or policies for direct groundwater regulation.

5.3 Lessons for policy making

Lessons for other countries based on the Chinese case at hand can only be drawn with caution. What is possible in China is not necessarily possible or even desirable in other contexts (Shah 2005). This research shows that to truly curb intensive groundwater use in a small scale agricultural setting decentralized government structures and affordable technologies to monitor groundwater use are not sufficient. There needs to be a strong political will to actually cut down groundwater use. In China, the national government may be able to push this forward in certain cases, but in less autocratic political systems the willingness to reduce groundwater use needs to come from the local communities themselves. Also, it should be questioned whether the kind of conjunctive water management in irrigation systems as described by Foster and Steenbergen (2011) and Evans et al. (2014) can be realized under a less top-down management mode. Nevertheless, the suggestion to make the same management organizations responsible for both surface water and groundwater is supported by this research (Bredehoeft 2011 ; Evans et al. 2014). It can avoid conflicts of interest and facilitate the implementation of conjunctive management measures.

For Chinese policy makers three main messages can be based on this research. First, the research results underline that groundwater use in canal irrigation districts is a widespread phenomenon at least in Northwest China. Therefore, surface water and groundwater management decisions should not be made separately. It is particularly important to be aware that “water saving” by cutting surface water supply to agriculture can result in adverse effects. In recent years reducing surface water supply to agriculture is a common strategy in China to save more water for urban and industrial water use as well as environmental restoration purposes (Cai 2008). As shown in this research, a reduction in surface water supply to the agricultural sector is likely to trigger initial groundwater use for irrigation and eventually leads to an increase in total water use.

Second, the research shows that in the Chinese context surface water and groundwater management responsibilities should be shared by the same organization not only at the local (prefecture and county) level, but also at river basin level. When the river basin authority is only overseeing surface water allocation this may stimulate local authorities to be strict on surface water allocation but close an eye on farmers’ groundwater use. Moreover, when the collection of surface water and groundwater fees are separated over different agencies, revenue generation from groundwater fees may become an end itself.

Finally, the research results show that the use of tiered groundwater pricing as a regulation measure has many potential pitfalls, particularly in its implementation. This conclusion is supported by other recent research, which calculated that in the context of the Hexi Corridor groundwater prices need to be extraordinary high to actually affect farmers' water use decisions (Zhou et al. 2015). Currently the idea to use groundwater pricing as a regulation measure is gaining popularity in China. However, groundwater quotas seem to be a more feasible alternative to curb farmers' groundwater use.

5.4 Shortcomings and suggestions for further research

This research is mainly based on primary data, which is a valuable asset because data on conjunctive use in North China is scarce. Nevertheless, it also brings along certain limitations. In this research one important limitation of the survey data appeared only after data collection. It turned out that groundwater use of farmers within one farm group or one village hardly differs. Unlike in other contexts, farm households were found to be rather homogeneous within one village on the alluvial plains of the Hexi Corridor. This may be because the blue-prints from old farm collectives are still strongly pronounced in Gansu's rural society today. It means that even though a considerable sample of 300 farm households was collected, the heterogeneity between households was rather low. Through the data analysis only a few village level variables were found to be significant in explaining farmers' groundwater use. It might have been possible to tease out more explanatory variables at household level when the sample contained more villages and fewer households per village. Of course this would have substantially increased the survey costs.

Another important limitation of this research is the use of survey data to estimate farmers' water use for irrigation. Through the questionnaire it was not possible to collect data on exact water volumes. Therefore, the number of irrigation turns was used as a proxy for farmers' water use quantity. However, the water volume used per irrigation turn is not necessarily constant; it can differ depending on the irrigation technique, the soil-type and also farmers' personal habits. Whereas the irrigation technique turned out to be the same for 99% of the household sample, the other two uncertainties could not be fully disproved. To estimate the validity of the assumption that the number of irrigation turns corresponds to the water volume additional water measurements would have been helpful. Unfortunately such measurements were not made in the scope of this research.

The conditions under which primary data can be collected in China also represent a limiting factor for this research (Alpermann 2012). The time that could be spent in the field to carry out in-depth interviews was restricted. The field trips were short and only a small number of in-depth interviews could be carried out. Although the time was used efficiently and the purposeful selection of the interview partners was facilitated by the available survey data, many observations could not be explored in depth. This weakens the statements that can be made about institutional phenomena observed at village level or between villages. Observed phenomena (such as the coordination of the irrigation schedule between villages in Guazhou, or the emergence of collective action to deal with water scarcity in Minqin (see Aarnoudse et al. 2015) are often only based on one or two interviews. This makes it difficult to say whether it is a more widespread phenomena or a single outstanding case.

A final shortcoming of this research is the strong focus on household farming. Until recently, household farms were by far the main farm types found in the research area, but slowly the landscape is changing. Because many young people find work elsewhere, the average age of the farmers is increasing and the country side gets depopulated. Giordano (2009) argues that the depopulation of the Chinese country side will eventually be the solution to the problem of intensive groundwater use. However, this assumption is questionable, because in the resulting vacuum new farm types start to operate. For example, in one of the villages it was found that all land was rented out to a company who in return hired the land-owners as farm labour. Similar constellations were being discussed elsewhere. It would be interesting to conduct further research on the impact of new farm types and the consolidation of land on the use of water for agriculture. Do the same water policies count for agri-businesses as for farm households? Do agri-businesses use less water than smallholder farmers? What role does the access to water play in smallholder farmers' decision to quit agriculture and rent out their land?

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Eidesstattliche Erklärung / Declaration under Oath

Ich erkläre an Eides statt, dass ich die Arbeit selbstständig und ohne fremde Hilfe verfasst, keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt und die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

I declare under penalty of perjury that this thesis is my own work entirely and has been written without any help from other people. I used only the sources mentioned and included all the citations correctly both in word or content.

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Frankfurt am Main, den 16. November 2016

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