HOW PHYSICAL AND SOCIAL FACTORS AFFECT VILLAGE-LEVEL IRRIGATION:

AN INSTITUTIONAL ANALYSIS OF WATER GOVERNANCE IN NORTHERN CHINA

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Abstract

The paper analyzes village-level irrigation management in water scarce northern China. Locals' livelihoods in the research area are highly dependent on the appropriation of water due to limited livelihood alternatives and demographic structure with the elderly as the majority. Two case studies of surface irrigation management have been conducted in order to explore the institutional dimension of irrigation management in the villages. We also examined the bottom-up groundwater initiative in one of the cases to understand the physical attributes and social factors influencing its emergence and development. We argue that both physical attributes of natural resources and social attributes of the community jointly shape village-level irrigation management. They affect the monitoring and enforcement costs as well as the water delivery cost, and locals tend to use water collectively based on their understanding of existing physical and institutional settings. Well-organized water delivery sustains water users' agricultural production and livelihood as well as reducing water use conflicts. However, in both cases of surface irrigation, management was not transparent and self-organization of groundwater irrigation is vulnerable to the wider institutional environment. This could be improved in future by introducing water users associations into surface irrigation management and devolving this management directly to water users along with participatory land planning.

Keywords: village-level irrigation management, physical attributes of resources, attributes of communities, northern China

1 Introduction

China is facing severe water scarcity. The total renewable water resource per capita was 2,259 m^3/ year in 2002 (UNESCO 2003) and steadily declined to 1,785 m^3/capita year in 2009 (Qu *et al*. 2010). The Guanting Watershed, a sub-basin of the Haihe River Basin in northern China, is facing particular water shortage with the per capita surface water availability being around 251 m^3/year (Wechsung 2007). Meanwhile, there is competition for regional water use. Since the Guanting Reservoir, one of Beijing's two key reservoirs, is directly affected by the conditions of the upstream Sanggan River and its tributaries in Hebei Province and Shanxi Province, the water authorities impose constraints of water use in these areas in order to guarantee water availability in Beijing. Farmers in the rural area of the Guanting Watershed are highly dependent on irrigated agriculture for their livelihood and facing the challenge of poverty (ADB 2004) as well as regional water competition.

Policies of irrigation management in China are primarily concerned with the technical aspects of water projects, whilst managerial aspects of water projects are rarely considered (Barnett *et al*. 2006). Establishing effective irrigation water governance by focusing on its institutional dimension at the village level can help farmers in the competition for increasingly scarce water, and thus sustain water use and the smallholders' livelihood (Bromley 1982; Coward 1977).

Irrigation water, as a common-pool resource, is described as having both non-excludability and rivalry of water use (Ostrom 2005: 24-26). There is extensive theoretical literature on common-pool resource management (Bromley 1992; Agrawal 2001; Ostrom 2005; Hagedorn 2008) and empirical research on village irrigation water management in India, the Philippines, and other developing countries (Aggarwal 2000; Fujiie *et al*. 2005; Araral 2009). Recent studies of irrigation management in China find that surface irrigation in villages is managed with contractual forms or by water users associations rather than the traditional village committee[1]-led form (Huang *et al*. 2008; Wang *et al.* 2006). Identified factors affecting village irrigation management included the degree of land fragmentation, dependence on irrigation, group size of water users, and land quality, etc. (Huang *et al*. 2008; Mushtaq *et al.* 2007). Bluemling *et al*. (2010) displayed three different rules in terms of groundwater allocation in northern China: the spatial order, lottery, and first come first served. It is worth mentioning that most studies of irrigation management in China focus on the organizational dimension, whilst failing to analyze the institutional arrangements which are essential to the management of such systems.

The effectiveness of irrigation rules is crucial to the performance of irrigation management in villages. As suggested by Ostrom (2005), in order to understand

[1] A village committee refers to the formal organization in an administrative village, consisting of a village director, a party secretary and several party members.

institutions, researchers need to know what rules-in-use are, what their consequences are, and how and why they are crafted and sustained. This paper addresses the above-mentioned puzzles by answering the following specific questions: (1) how the provision of irrigation water is governed in terms of institutional arrangements and organizational forms in the field; (2) what is the performance of irrigation management; and (3) how the physical and social factors affect the institutional dimension of irrigation management?

The remainder of this paper is organized as follows. Section 2 introduces the analytical framework guiding the empirical research by reviewing theoretical and empirical literature. Section 3 provides information on research area and data collection techniques employed in the research. Section 4 introduces two cases of village-level irrigation management with particular focus on the physical attributes of irrigation, actors' characteristics and institutional environment. Discussion in terms of how these factors interplay with each other and affect the irrigation management is provided in Section 5. Concluding remarks and policy implications are incorporated into Section 6.

2 Analytical framework for understanding institutional arrangements

To understand institutions of irrigation management, we need to know their rules-in-use, why they are established, and their performance (Ostrom 2005). Considering that the focus of the paper is to understand institutional dimension of village-level irrigation management, we propose to use the Institutions of

Sustainability (IoS) framework developed by Hagedorn (2008) to facilitate empirical study and analysis. The IoS framework provides a powerful tool for analyzing the institutional arrangements of irrigation management, centered on human-nature interaction, and helps answer the fundamental question of why certain rules of irrigation management are created.

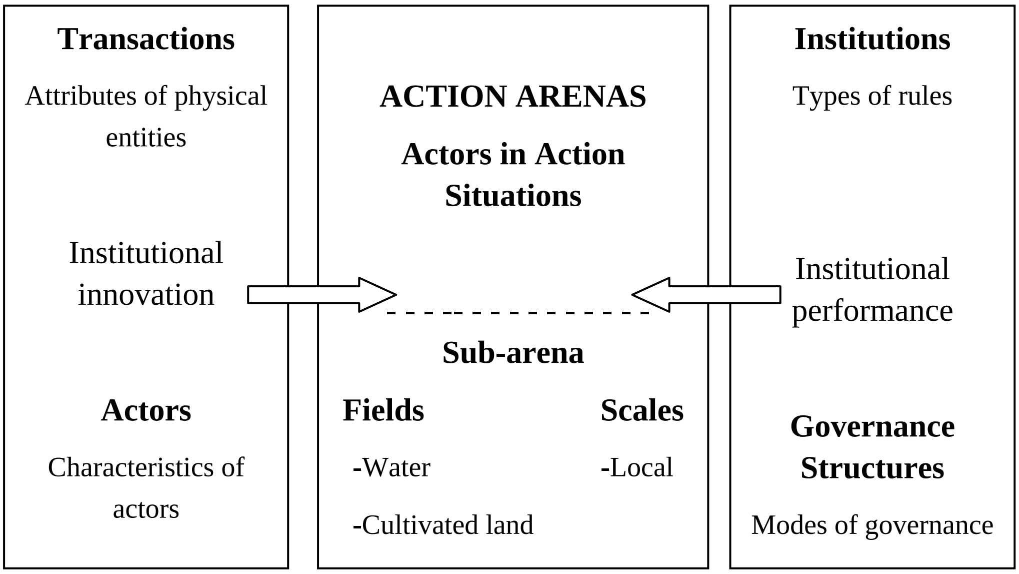

Figure 1: Institutions of Sustainability Framework

Source: Adapted from Hagedorn (2008)

As shown in Figure 1, institutional analyses of irrigation management has to incorporate the physical attributes of water, cultivated land, and channels, because irrigation not only deals with water, but also with other natural resources. We are considering water delivery which, as a natural-related transaction, will be viewed in terms of its physical properties. Actors within the action arena are the main instigators of institutional and organizational arrangement. The characteristics of actors could affect their perception of properties of water delivery which in turn could affect their decision about the irrigation management in village. It is noticeable that actors do not make their decisions in a vacuum but are embedded in an institutional environment. The institutional environment is composed of governance structures and rules that structure human-nature interactions. Governance structures refer to an institutional framework within which transactions are organized (Williamson 1979). Transactions could be organized either through a market exchange, internally through a hierarchy (bureaucratic firm or state) or through hybrid arrangements such as cooperative organizations that operate in between markets and hierarchies. Transaction costs determine which governance structure will be chosen for a particular transaction (Coase 1937; Williamson 1985). Furthermore regarding different types of rules, we follow the classification of rules based on the A*I*M[2] component and distinguish seven broad types of rules including position, boundary, choice, aggregation, information, payoff, and scope rules for common-pool resources management (Table 1).

Table 1: The A*I*M component of seven categories of rule

Type of rule	Basic A*I*M verb	Regulated component of action situation
Position	Be	Position
Boundary	Enter or leave	Participants
Choice	Do	Actions
Aggregation	Jointly affect	Control
Information	Send or receive	Information
Payoff	Pay or receive	Costs/benefits
Scope	Occur	Outcomes

[2] A*I*M is a holder that describes particular actions or outcomes in the action situation to which the deontic (i.e. permitted, obliged and must not) is assigned (Ostrom 2005).

Source: Adapted from Ostrom (2005).

3 Methods

3.1 Research area

The empirical research was conducted in Zhuolu County, Hebei Province in northern China. The county is located in the Guanting Watershed (Figure 2). The Sanggan River is a cross-region river in the Guanting Watershed, starting from Shanxi Province, crossing Hebei Province, and finally reaching the Guanting Reservoir in Beijing. Constraints of surface water use in the upstream of the reservoir are imposed by water authorities to guarantee water use in Beijing. Zhuolu County remains one of the principal agricultural producing counties in the region and has 29,418 ha of cultivated land, 74% of which is irrigated land. Agricultural production largely depends on the use of surface water provided by the Sanggan River supplemented by groundwater. The GDP per capita was 2,488 US dollars in 2010, i.e. one of the poorest counties in the area, and agricultural production remains important to the economy, by contributing 31% of GDP and 66% of employment in the county. The county experiences a temperate continental monsoon climate, with 476.1 mm of annual precipitation. The surface water availability on average is around 251 m^3 per capita per year, which indicates the extreme water scarcity in the country.

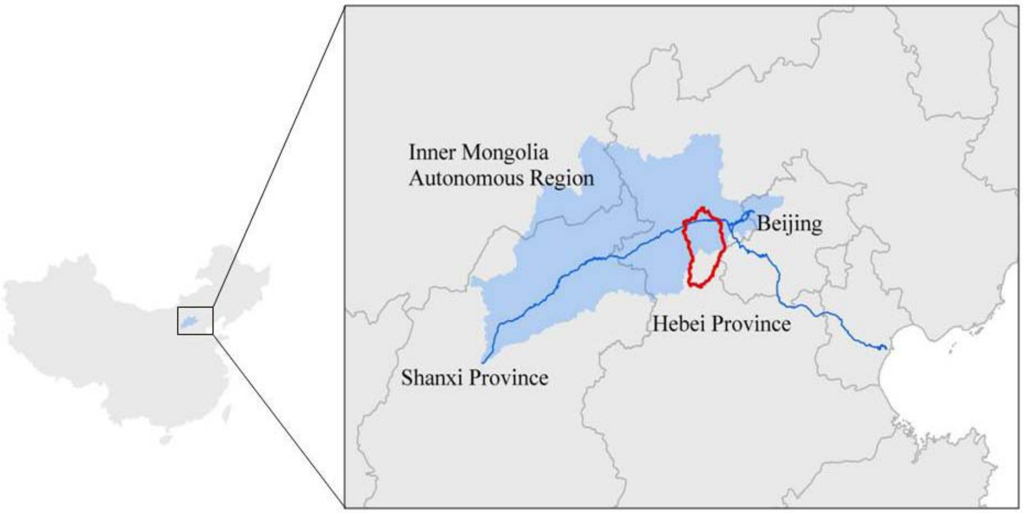

Figure 2: The location of Zhuolu County (read line area) and the Guanting Watershed (Blue area)

Two villages, identified as Village SG (for a combination of surface and groundwater irrigation used in the village) and Village S (where there is only surface water irrigation), in the Qiyi Irrigation District of the county were selected for case studies. This was based on the recommendation of Chinese project partners as they represent the two most frequently used types of irrigation organization (Table 2). The main crops in both villages are maize, grapes, apples, and apricots. Agricultural production in Village SG is dependent on surface irrigation supplemented by groundwater, while in Village S, it relies on surface water. Population and cultivated land area vary across villages. It is often the case that the larger population, the greater the arable land area in the villages. It is worth mentioning that approximately 700 residents of Village SG, and 3,139 residents of Village S are the left-behind elderly people, children and women as others permanently or temporarily migrate to urban areas. Compared to

Village SG which has cheap and easy access to the transportation infrastructure, Village S is remote from the township and it is difficult and costly to obtain transport.

Table 2: Characteristics of the villages

	Population	Cultivated land area (ha)	Distance of the village to the road (m)	Types of major crops	Water sources
Village SG	1166	143.13	10	Maize; grapes; apples; apricots	Surface water; groundwater
Village G	4639	306.67	950	Maize; grapes; apples; apricots	Surface water

3.2 Data and collection techniques

Data collection was conducted in May and June 2011, with methods including participant rural appraisal, semi-structured interviews, and household interviews. We have broadly followed the triangulation approach that combines different methods to cross-examine answers to one question to check whether answers with different methods lead to a similar result (Denzin 1978). This approach was employed due to low data availability and low reliability of secondary sources such as county level statistics.

Participant rural appraisal, being the data collection method involving the participation of water users, members of the village committee and contractors, was applied to obtain general information about the village. In particular, the cropping calendar was used to understand the cropping patterns and farming activities, especially the irrigation seasons. The method of participant observation was applied to identify rules-in-use practiced by water users in the villages, since actors interviewed do not explain their actions to outsiders in the same way they explain them to fellow participants (Ostrom *et al*. 1994; Theesfeld 2004). Additionally, semi-structured interviews were conducted with key informants. Twelve officials from local water bureaus were interviewed about water policies and regulations. Members of the village committee were interviewed about the history of irrigation and the current irrigation management in the village. Contractors from each village (3 in Village SG and 7 in Village S) were asked about surface irrigation management. Moreover, household interviews with questionnaires were conducted to collect information about the water users' household characteristic (i.e., age, household size, household income and sources, farmland size), agricultural activities and irrigation activities in the village. In each village, to select the sample as randomly as possible, every 10^{th} villager from the list of those receiving a subsidy for seeds and fertilizer was picked in Village SG, and every 20^{th} villager was selected in Village S. The reason for using the list of those in receipt of an agricultural subsidy was to provide a good population of water users, since farmers are often the water users in the villages. If a farmer selected was not present or refused to answer the questions, then the next household on the list was selected. Thirty seven of around 364 households in Village SG and 47 of 853 households in Village S were selected. In total, 76 valid questionnaires were collected with 33 coming from Village SG, and 43 from Village S. Household interviews with noteworthy findings were followed-up with deep semi-structured interviews of the water user.

4 Empirical results

In this section, an institutional analysis guided by the IoS framework is employed to understand physical and institutional settings in which the irrigation management is embedded. Observing the different performance of irrigation management in terms of water use efficiency as well as water users' perception of the current irrigation management leads us to further explore the underlying physical and social factors: physical attributes of water delivery, characteristics of actors, governance structures and types of rules-in-use.

4.1 Institutional performance of irrigation management

Performance of irrigation management is firstly evaluated in terms of water use efficiency. The amount of surface water extracted by individual water users is obtained from the household interviews with 33 and 44 responses in the two respective villages, whilst data on the average amount of water is collected through interviews with the contractors in the villages. The average amount of water appropriated for irrigation is lower when water fees are charged according to the duration of irrigation than by irrigated area (Table 3). According to our interviews, this agrees with the perceptions of other individual water users' water extraction behavior and indicates that water users' withdrawal behaviors are structured by the rule of water fees.

Table 3: Amount of surface water extracted by water users for irrigation

The rule of water fees	Average water used for winter irrigation (m^3/ha)	Average water used for summer irrigation (m^3/ha)	Percentage of water users extracting water as much as possible
Charged according to the area in Village SG	3000-3750	4500-5250	100%
Charged according to the time in Village S	3000	3000	13.95%

Figure 3 indicates water users' attitudes towards the performance of the irrigation management. In general water users in Village SG are more satisfied with the surface irrigation management than the water users in Village S. In particular, a high proportion of water users in Village SG consider that it is easy to collect water fees and that the water allocation is fair. Regarding the perception of the frequency of water user conflicts, water users from Village S and Village SG hold similar views. Water users from both villages regard the surface irrigation management is ill-performed in terms of channel maintenance and management transparency.

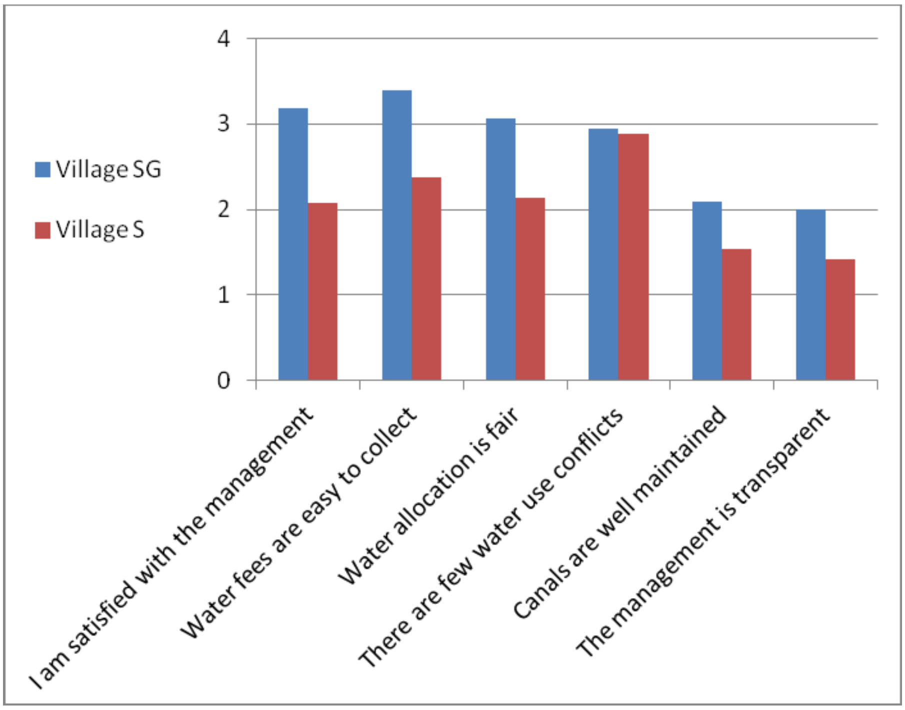

Figure 3: Water users' attitudes towards the performance of surface irrigation management in the villages
(Note: 1= fully disagree, 2= rather disagree, 3= rather agree, 4= fully agree.)

From interviews of water users who access groundwater in Village SG, the average amount of groundwater used for irrigation is between 3000 and 3750 m^3/ha, and all the water users in the village only appropriated the amount of water needed, because groundwater irrigation is costly and charged according to the irrigation time. Groundwater irrigation management not only achieves high water use efficiency, but appears to perform better than surface irrigation management, since all the users of groundwater reported that other users are compliant with the irrigation rules and that the management is transparent.

4. 2 Factors affecting the irrigation management

The question of which factors affect irrigation management is raised by the primary results elaborated above. In the research area, we identify four major factors:

physical attributes of natural resource sectors (i.e., water, irrigation infrastructure and cultivated land, etc.); characteristics of actors (i.e., water users, contractors); governance structures, and types of rules-in-use regulating water use.

4.2.1 Physical attributes of water delivery

Irrigation often takes place in November for single winter irrigation before planting crops, or in February of the following year for single early spring irrigation. If plots have winter irrigation, then they are not irrigated in early spring. During May and June every year, there is late spring irrigation for fruit trees to improve production. Times of late spring irrigation depend on the water availability. Single summer irrigation is often carried out in July for maize, grapes, and apples, to ensure production. When there is not enough surface water, water users often switch to groundwater for late spring irrigation and summer irrigation. Water users who are not able to use groundwater for irrigation have to face reduced production when surface water is scarce.

Surface irrigation differs from groundwater irrigation in terms of resource characteristics (Table 4). The water flow rate of surface water is greater than that of groundwater. Surface irrigation involves almost all the water users in a village, which leads to longer length of channels and larger amount of arable land area, while groundwater irrigation only covers some water users with shorter channel length and a smaller amount of land. Most channels in the two villages are built with earth in a traditional way. The effective water delivery rate of traditional earth-made channels is approximately 50% indicating that only half of water is delivered to cultivated land. One more difference between the two irrigation systems is that groundwater can be stored by turning off the pump, whereas this option is not available for surface water.

Table 4: Physical characteristics of irrigation systems in the villages

Irrigation systems	Water flow rate (m^3/h)	Group size (number of water users)	Length of channels (m)	Cultivate land area (ha)
Surface water	360 ~ 1440	364 ~ 853	12239 ~ 16100	143.13 ~ 306.67
Groundwater	80	6 ~ 20	20 ~ 600	2.33 ~ 7.75

Land fragmentation associated with diverse cropping patterns commonly exists in the villages (Table 5). The degree of fragmentation ranges from a minimum of one piece of land, to a maximum of 15 scattered pieces of land in Village SG, while in Village S, the degree of fragmentation varies from two to twelve. A mean degree of fragmentation is around five in both villages, which indicates, on average, a water user has five separated pieces of land in the village.

Table 5: land fragmentation in the villages

Variable	Obs (N)	Mean	Sd	Min	Max
land fragmentation in Village SG	33	4.88	2.87	1	15
land fragmentation in Village S	40*	4.70	2.33	2	12

(Note: *three observations in Village B are missing because they refused to answer the question; 1= one separated plot, 2= two separated plots … n= n separated plots)

4.2.2 Characteristics of actors

Water users are featured with old ages, and a lack of alternative livelihood strategies, making them heavily dependent on irrigated agriculture (Table 6). On average, irrigated agricultural production counts for about 61% of a water user's income in Village SG, while in Village S it is much higher, around 77%. Dependence on irrigated agriculture and the nature of plant growth mean that irrigation is a recurrent transaction and water users face high opportunity costs if they do not follow certain rules of irrigation management. Regarding water availability, although water users in both villages perceive the water scarcity, users in Village S see less water availability than those in Village SG.

Table 6: Descriptive statistics of water users' household characteristics in the villages

Variable	Obs (N)	Mean	Sd	Min	Max
Age of water users in Village SG	33	55.36	10.19	35	80
Age of water users in Village S	43	59.70	10.13	40	84
Percentage of agro income of water users in Village SG	33	60.66	28.16	20	100
Percentage of agro income of water users in Village S	43	76.86	29.03	0*	100
Perception of water scarcity# in Village SG	33	1.66	0.49	1	2
Perception of water scarcity# in Village S	43	1.07	0.26	1	2

(Notes: * the water user does not have agricultural income because he rents out his land to another water user; # perception of water scarcity is measured with continual interval from 1 to 4 indicating the degree of water availability from low to high.)

Contractors of the surface irrigation management are also water users and share similar features as other water users (Table 7). Their average age is around 56 years old and about 83% of their income comes from irrigated agriculture. The only difference is that by renting from famers in their villages, contractors have more arable land than other water users who have approximately 0.5 ha of land per household.

Table 7: Characteristics of contractors in the villages

Variable	Obs (N)	Mean	Sd	Min	Max
Age of contractors	9	55.44	4.48	50.00	63.00
Percentage of agro income of contractors	9	82.97	22.07	50.00	100.00
Arable land area of contractors (ha)	9	11.94	5.71	6.50	22.00

The villages in the Qiyi Irrigation District have a long history of irrigation with rich experience in irrigation management. Water users in the community share a common understanding about the importance of irrigation management, which helps facilitate it. Generating a significant proportion of agricultural production, water users create internal impressions about the importance of irrigated agriculture to their own livelihoods. Water users from the same village with the same irrigation circumstances often have a similar understanding of the problems and potential resolution. They are aware of the necessity of well-organized irrigation management, and believe that irrigation would be unaffordable without a collectively organized system. Historically, water users believe that surface water is a public good and should be free to use. Within the people's commune before 1982, surface water was under the management of the production team (the former organization of the village committee) and was free of charge. Hence, the belief that surface water should be free is still prevalent in many water users' minds.

4.2.3 Governance structure

In the irrigation district, the Irrigation District Commission (IDC), a subunit of the local water resource bureau is responsible for delivering surface water to villages and maintains the main channel. The amount of surface water for irrigation depends on the cropping patterns and cultivated land area in the village. The order of water delivery depends on the sequence of submission of water fees by villages; the sooner the village submits water fees to the IDC, the quicker the village can access surface water for irrigation. In 1989, the IDC began to charge water fees for surface irrigation according to the amount of water used. The water price is 0.016 US dollars/m^3, set by the Provincial Price Bureau. Measuring weirs are built to measure water volume flowing through the gate that connects the Qiyi main channel with the head of primary channels leading to villages.

Once water is delivered to the villages, it becomes common property under the nominal control of the village committee. In fact, surface irrigation in all the villages is managed with the contractual form, a mechanism by which the village committee establishes a contract with one or more contractors, who are often water users in the village, to take management responsibility of the village-level surface irrigation to earn a profit (Figure 4). Sequential allocation is commonly used to allocate water in the village, and is a mechanism through which water users irrigate their plots according to the sequence of the location of plots along a channel. Water allocation relies on contractors to monitor the water flow as well as its appropriation by water users. Groundwater irrigation is organized by the group of water users with bottom-up initiatives which are the collective action of water users for organizing irrigation based on voluntarism and trust without involving profits (Figure 4). Water users adopt the sequential order to allocate water and monitor each other’s water use.

Regarding the governance structure of irrigation management, surface water delivery is managed more hierarchically through the contractual form, which rarely involves the decision making of water users, while groundwater is managed through the cooperative organization, the hybrid governance structure operating between markets and hierarchies.

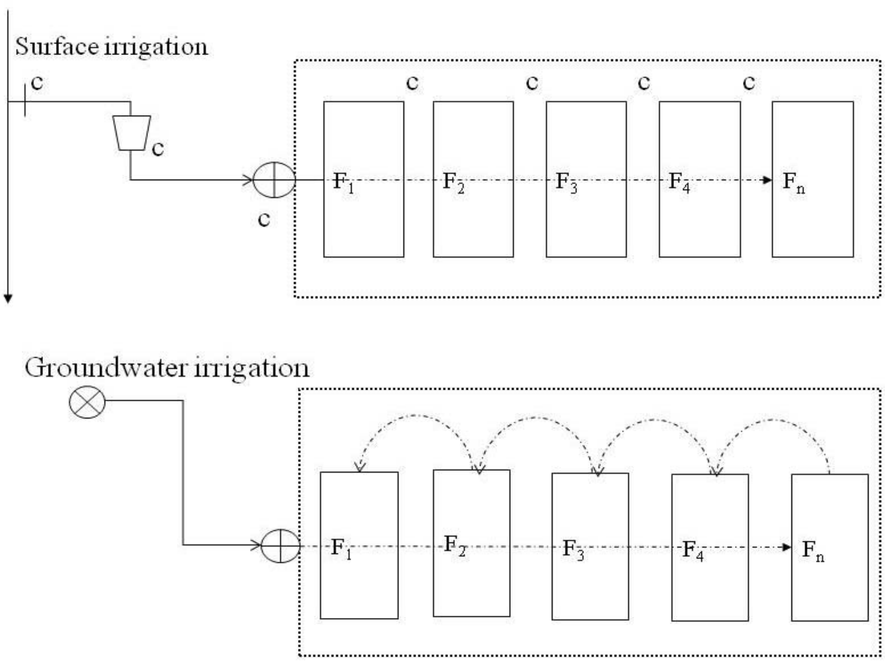

Figure 4: Surface and groundwater irrigation management in the village

(Notes: F1 refers to a water user; F2 is subsequent water user in irrigation; C are contractors; the main channel in the irrigation district; a gate connecting the main channel in the irrigation district and a tributary channel in a village; a tributary channel with a measuring weir in the village; ⊕ a diversion of a channel; the direction of water allocation; □ water users' plots; ⊗ a pumping well; is direction of monitoring.)

4.2.3 Types of rules

In this section, we present the rules-in-use in terms of water allocation and water fees collection in seven categories of rules, suggested by Ostrom (2005): position, boundary, choice, aggregation, information, payoff and scope rules. In surface irrigation, aggregation rules are largely missing, due to the hierarchic structure which does not involve participation of general members of the system. Regarding the information rules that define the information availability, although water users are aware of the price of surface irrigation, they are not told how the water fees collected by the contractors are used. Scope rules, in the case of surface irrigation, determine that surface water can only be used for irrigating crops. Therefore, we mainly focus on the position, boundary, choice and payoff rules in the surface irrigation.

Positions rules define the possible positions for actors (Ostrom 2005). In surface irrigation, water users are the members of a surface irrigation system, while contractors are managers and guards. The village committee, however, is either the co-manager or the supervisor, that is, a third party of the irrigation system. Actors' different positions define their corresponding authorized actions in terms of rights and duties. Taking surface irrigation in Village SG for instance, the village committee is primarily responsible for organizing a bid for the selection contractors, while contractors are managing the water delivery in the field, in return for charging water fees. Water users pay water fees to contractors for using surface water. In Village S, the village committee serves as a co-manager by managing the water delivery for profits, while contractors work as water guards on behalf of the village committee.

Water users in both villages share a common position as the general members of the systems (Table 8).

Table 8: Positions of actors in surface irrigation systems

Actors	Positions in Village SG	Positions in Village S
Contractors	Irrigation managers	Water guards
Village committees	Supervisors of contractors	Co-managers
Water users	General members	General members

The boundary rule defines who is eligible to enter a position (Ostrom 2005). Due to the common property of irrigation water in villages and the affiliation of water rights with land tenure, all the famers in the villages are automatically members of the irrigation system. Regarding the position of contractors as managers, this is determined either indirectly or is directly appointed by the village committee. The process of selecting contractors varies among villages.

In order to determine the water price of surface irrigation in Village SG for example, the village committee sets up a basic water price and then invites bids to issue a contract for management of the irrigation. The candidate who places the lowest bid is rewarded with the contract to manage surface irrigation for the next year, because the village committee wants the water price to be kept low to reduce water users' agricultural production costs. The bidding process enables members to be transformed to the position of manager.

In Village S however, contractors are directly appointed by the village committee. They function much more like water guards, because the village committee is a co-manager of the surface irrigation which sets the water price.

Choice rules define the action options of actors in a certain position (Ostrom 2005). In the case of surface irrigation management, it defines how to collect water fees and allocate surface water (Table 6). The village committee of Village SG has decided that water fees are to be charged according to irrigated area, while the committee of Village S charges water fees based on irrigation time. In terms of the rule of water allocation, the village committee in both villages allows contractors to choose the method of water allocation. This theoretically could be sequential allocation, random allocation, or lottery allocation; however, in practice, the sequential allocation rule is adopted to deliver surface water to farmers according to the order of plots along a channel.

Payoff rules assign external rewards or sanctions to particular actions that have or haven’t taken place. In Village SG the water price is determined through the bidding process by the contractors, while the water price in Village S is decided directly by the village committee (Table 9). In Village SG, the water price for winter irrigation is 79.20 US dollars/ha, while for summer irrigation it is 97.83 US dollars/ha. In contrast, the water price for both winter and summer irrigation in Village S is 0.04 US dollars/min. In a surface irrigation system, there is rarely a sanction for violation of rules; formal sanction mechanisms are largely missing. Nevertheless, the threat of exclusion, or the embarrassment of the water users refusing to pay, serves as social sanctioning measures.

Table 9: Rules-in-use of surface irrigation

	Choice of rules		Decision makers		Payoff	
	Village SG	Village S	Village SG	Village S	Village SG	Village S
The rule of water fees	According to irrigated area	According to irrigation time	Contractors, Village committee	Village committee	79.20~97.83 USD/ha	0.04 USD/min
The rule of water allocation	Sequential order	Sequential order	Contractors	Contractors	N/A	N/A

(Note: N/A indicates non-applicable.)

Rules of groundwater irrigation are slightly different from those of surface irrigation. Water users' rights to the use of water, as a boundary rule of groundwater irrigation, define each water user's accessibility to the groundwater. By interviewing officials from the prefectural water resource bureau (WRB) and the county WRB, it is found that water users' rights are fully recognized by multiple levels of water agencies. Without significant intervention by the village committee, as in surface irrigation systems, water users are not only general members of a bottom-up initiative, but also the decision makers who create the rules of water fees and water allocation.. Water fees are 0.11 US dollars/min, equivalent to the electricity and maintenance costs of a pump well and there are no extra fees for using the groundwater. The water is allocated by sequential order as in surface irrigation, however in contrast to the monitoring mechanism in the surface irrigation, peer pressure among water users of the bottom-up initiatives serves as a monitoring and enforcement mechanisms of the rules.

5 **Discussion**

In this section, we will argue that the physical attributes of water, channels and cultivated land, as well as characteristics of actors, governance structure and rules-in-use, jointly shape the institutional dimension of irrigation management. Several questions regarding the emergence of irrigation forms and difference of irrigation rules will be addressed sequentially to display the interaction of diverse factors and interdependence among all actors which affect the institutional performance.

5.1 Importance of physical and social settings

The emergence of the contractual mechanism in surface irrigation in the early 2000s leads us to examine the causes of the shift of governance structure from a state run hierarchy to the incorporation of market and hybrid solutions. We ask: *why surface irrigation is organized with the contractual form?* The following analysis shows that attributes of physical entities and actors in the communities influence the transaction costs of irrigation management, resulting in the change of governance structure.

Water delivery through channels for irrigation is affected by the properties of water, channels and cultivated land. Therefore, the attributes of these physical entities exert effects directly onto the irrigation management in terms of enforcement and monitoring costs. Basic attributes of water, such as mobility and storage, impose high monitoring and enforcement costs relating to the exclusion of other water users. The mobility problem in groundwater irrigation could be effectively overcome by the ease of storage of groundwater. This allows sanctions to be imposed on users refusing to pay the irrigation fee, whilst for surface irrigation there is no credible sanction equivalent to turning off the groundwater pump. Once surface water is delivered into tributary channels in villages, water flows through the head of the channel to the end, due to the lack of water storage methods in the village. Water users can still withdraw water in the next round of irrigation regardless of whether their water fee has been paid. The difficulty of storing surface water requires additional monitoring and enforcement to prevent water users from cheating and over-withdrawing water, which makes it costlier to manage.

The high water flow rate associated with surface irrigation also requires extra monitoring, since the width of the channels in the village is not standardized. The water flow rate is often around 1440 m^3/h, which requires much labor to monitor the water flow as well as to divert the flow in order to avoid water escape. The escape of water from the channels leads to increased water delivery costs and might destroy other crops in water users' plots located nearby. This leads to a higher cost of surface irrigation water management.

In addition to the physical attributes of surface water, the attributes of communities such as the group size of water users as well as users' belief that water is a public good, have an effect on management cost and monitoring. The relatively large group size of users in surface irrigation increases monitoring costs and reduces the effect of norms and conventions which would otherwise reduce these costs. In both villages, the group size is correlated with the cultivated land area (p-value: 0.000). The large service area implies a long channel and many plots requiring extra monitoring cost. The communication between water users whose plots are far from each other becomes difficult and the relationships between individual water users are rather anonymous in surface irrigation management. Communication only takes place between water users and contractors, and water saved by an upstream water user will not be noticed by water users in the tail of the channel. The surface irrigation requires more monitoring, compared with groundwater irrigation involving a relatively small group size. This is consistent with prediction of collective action theory (Olson 1994; Ostrom 1990; Ostrom 2010).

Norms and conventions directly affect the form of surface irrigation management by influencing water users' beliefs about irrigation water. Hagedorn *et al*. (2002) and Otto-Banaszak *et al*. (2011) hold the same opinion that actors' values and beliefs affect the mechanisms they choose in order to adapt to environmental stressors. It is commonly considered that norms in common-pool resource governance are solely positive; however, in practice it is evident that norms can at times impede irrigation management. Water users' belief that surface water should be free exacerbates the difficulty of surface irrigation management by the village committee.

The village committee fully or partly relinquishes the surface management to the contractors. This is due to the high costs of monitoring and enforcement caused by the storage attribute and high flow rate of surface water, inability to store surface water, relatively large group size of water users, and water users' belief about irrigation water. Compared to the surface irrigation management, groundwater irrigation can be organized in bottom-up initiatives. This is due to the ability to store surface water, the lower water flow, relatively small group size of water users as well as the trust and reciprocity between water users in a small group.

The cases illustrate the necessity of taking the physical attributes of natural related resource use into consideration and assessing their impacts on a case-by-case basis when designing the rules of resource use management. Hagedorn (2008) stated that the physical world (and the related physical properties of a transaction) is as important for institutional analysis as the social world (and the related physical characteristics of actors). It is hard to exclude the influence of the physical world during institutional analysis related to natural resource use. This helps to answer the second question: *why is the irrigation order implemented with sequential allocation?*

Attributes of physical entities increase the costs of water delivery. The long channels and low effective water delivery rate, the diversity of cropping patterns, and the high degree of fragmentation of cultivated land all contribute to the high cost of delivering water. Low effective water delivery is a typical characteristic of channels in rural China, leading to high water losses and thus imposing a high cost of water delivery. Moreover, the high degree of fragmentation of cultivated land associated with diverse cropping patterns in villages further intensifies irrigation time, which increases water delivery costs Water users have had the right to determine their own cropping patterns and cultivation methods since the implementation of the Household Responsibility System in 1982. This has created diverse cropping patterns of cultivated land in the research villages. Two pieces of farmland with the same crop are often separated by one or more plots with other crops requiring irrigation at different times. These attributes of cultivated land increase the delivery cost of water, especially in the late spring irrigation which is devoted mostly to fruit trees.

Hence, sequential irrigation can reduce the water delivery cost, compared to other water allocation methods. It is important to note that water fees for delivering water from the Qiyi main channel to the village are charged according to the duration of water delivery. Thus, it is reasonable for the contractors to adapt sequential irrigation to reduce the cost of water delivery. The inequality issue between upstream and downstream users in an irrigation system, often mentioned in the theoretical literature (Agrawal and Benson 2011), does not exist in the field. In depth interviews the water users considered sequential irrigation as fair, which is consistent with the findings of Tanaka and Sato (2005). This showed that water users accepted some superiority of upstream water users.

5.2 The capability of locals in self-organizing irrigation systems

Why does the rule of water fees in surface irrigation vary across villages? The analysis shows that the rule of water fees is connected to the perception of water scarcity by the locals in the village. Water users in Village S perceive the scarcity more than their counterparts in Village SG due to the higher proportion of arable land and reliance on surface irrigation. The village committee has changed the rule from charging water according to time rather than land area, responding to water users' perception of water scarcity. The change of this rule shows the ability of locals to self-organize the natural resource on which their agricultural production is largely dependent. This is consistent with other observations originated from common-pool source management in other regions or countries (Agrawal and Gibson 1999; Jones and Craswell 2004; Tyler 2006). Locals have greater interests in the continued existence and maintenance of resources because they rely on these resources for their livelihood and have few substitutes for their benefits (Agrawal and Chhatre 2007). Moreover, they have settled down in the community for a long time through which they have obtained unique time- and place-specific information and knowledge for dealing with complex resource use problems with better-adapted rules for governance (Agrawal and Chhatre 2007; Andersson and Ostrom 2008; Ostrom 1990；Tang 1992).

However, if the locals are capable of organizing themselves to provide irrigation management: *why do the bottom-up initiatives succeed in Village SG but not in Village S*? As well as affecting the cost of surface water delivery, physical attributes of resources also affect the cost of groundwater delivery. They provide an incentive for individual water users in Village SG to cooperate with each other to use groundwater. The irrigation order and water fees collection are well organized by water users themselves. Trust and reciprocity created by social connection, and peer pressure help reduce monitoring and enforcement costs for the bottom-up initiatives for groundwater irrigation. The role of mutual trust and reciprocity among resource users cannot be simply replaced by authorized sanctions. Such cooperation also guarantees lower transaction costs due to limited overheads and operating costs compared to those incurred by central decision making processes. Local residents sharing a collective interest in sustainable use of water are expected to solve internal free-riding problems amongst themselves (Ostrom1990). Bottom-up initiatives of groundwater irrigation, however, do not exist in Village S. The main cause is the violation of water users' rights to the use of groundwater. Water users' rights are associated with formally defined land tenure and although these are implicitly recognized by different administrative levels of water agencies, they are not always protected by the village committee in the field, being the authority in the village. A change of village committee could affect, or even impede, water users' property rights. In this example, the corrupted preceding village committee rented all the pump wells to a farmer for 20 years "for free", which excluded other water users from the access to ground water. The recognition and protection of property rights by authority systems is important for the sustainability of irrigation management (Vermillion 2001).

It is not the incapability of local people in terms of self-organizing resource use causing the absence of bottom-up initiatives in Village S. Instead, constraints imposed by wider economic institutions (i.e., property rights), limit their development. Compared to actions in other sectors, those in natural resource related sectors involve high interdependence among actors. There is the strong possibility that one actor's action may impact on the wider context of the physical or natural system and consequently affect other actors (Hagedorn 2008). It is not difficult to understand that water users' actions will affect others' opportunities to access and benefit from the irrigation service not only through direct water flow from upstream to downstream but also water availability. This poses the difficulty of dealing with the social dilemma but highlights the potential benefits of locals organizing themselves.

6 Conclusions

The research analyzes the role of four factors: physical attributes of water use, characteristics of actors, governance structures, and types of rules, in the irrigation management based on the cases studies in northern China. The study followed the Institutions of Sustainability Framework (Hagedorn 2008) that helps to understand human-nature interactions in institutional arrangements of village-level irrigation management. The empirical results show that surface irrigation can be managed with the contractual form, while ground water irrigation can be organized by water users based on voluntarism and trust, responding to physical attributes of resources and social attributes of communities. The rule of charging water fees for surface irrigation varies across villages but the method of sequential irrigation is often adopted for water allocation in channels. The creation of institutional and organizational arrangements for irrigation water governance are dependent upon the physical attributes of the natural resources involved in irrigation, water users' characteristics and the institutional environment. The research proposes that the four factors have jointly shaped the irrigation management. Thus we suggest that the organization of irrigation water should fit not only the physical environment but also the institutional context and there is no one-for-all for governing irrigation in the field. Instead of having a blue print for irrigation management reforms, there is diverse effective management in the field.

Regarding the performance of the irrigation management, it is noticeable that the contractual forms ignore the transparency of management. Hence, introducing measures to improve the management transparency is urged in future irrigation management reform. The research also indicates the capability of locals to organize themselves for better use of the natural resource on which their livelihoods are highly dependent. The water scarcity in the village could encourage institutional innovation, such as, for example, in the rule of charging irrigation fees. However, the detrimental influence of inappropriate economic institutions will undermine the potential of local innovation and participation. Thus we suggest the government should guarantee the water property rights and further devolve irrigation water management to water users so that they can craft suitable forms and rules to match the physical situation as well as hold the management accountable for most water users' benefits. In addition we suggest an integrated agricultural production plan, including all households in the village though participatory rural planning, to modify the current situation of scattering diverse crops into a whole system in order to use the water more efficiently. This would decrease the water waste due to land fragmentation.

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