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Success Factors of Irrigation Projects Based on A "Public–Private Partnership" Model in A Mountainous Area: A Case Study in the Nujiang River Valley, China

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Abstract: Irrigation systems are critical for food security and drought adaptation in mountainous areas. However, lack of funding and low efficacy of government-funded irrigation projects hinders irrigation infrastructure development. A public–private partnership (PPP) model is recommended for irrigation development, but its application in mountainous areas has not been well-documented and analyzed. Based on a case study of pumping station projects in the Lujiang Flatland in the Nujiang River Valley of Southwestern China, this paper aims to reveal the critical success factors of the PPP model in the development of agricultural irrigation infrastructure in mountainous areas. Results showed that the basic models of PPP projects in the study area can be described as follows: (1) private companies invested in and constructed pumping stations; (2) communities operated the stations; (3) farmers paid for the services; and (4) private companies profited from charging water fees, obtaining policy supports, or utilizing farmlands. The main success factors include: (1) rational project design according to local conditions; (2) multi-centered management mechanisms; (3) balanced cost- and risk-sharing mechanisms; and (4) building mutual trusts among stakeholders. This study offers applicable lessons and useful insights for irrigation water development projects and adaptation to drought in mountainous rural communities.

Keywords: public service; irrigation infrastructure; mountain community; public–private partnership; co-management

1. Introduction

Mountainous areas become increasingly vulnerable to food insecurity because of limited arable land, growing population pressure, and negative influences from climate change. Limited by local climate and topography, about 40% of human populations in mountainous areas face food shortage [1]. Irrigation facilities and infrastructures are crucial for the increase of agricultural productivity and the improvement of agricultural drought resistance [2], especially given that drought is expected to increase in frequency in many regions under climate change scenarios [3]. However, the irrigation

facilities and infrastructures are often underdeveloped in mountainous areas due to multiple natural and social factors, such as the complex terrain, scattered farmland, small-scale agricultural production, funds shortage, and inefficient investment.

Irrigation infrastructures serve as types of public goods. Though their initial investments are normally high, irrigation infrastructures can favor a large number of users at low cost. Public goods are commonly provided by governments; however, the quantity and quality are often limited due to insufficient funds and limited efficiency [4]. A public–private partnership (PPP) model is an institutional innovation, and acts to address those issues. Broadly speaking, the PPP refers to certain framework arrangements in which the private sector, instead of the government, becomes the main source of investment for the public domain and then provides goods and services [5]. The principal benefits of the PPP model for the government are several; this mechanism helps to (1) lighten the government's financial burden, (2) improve the efficiency of project implementation, (3) make use of advanced technology from the private sector, (4) share risks with the private participant, and (5) produce innovative public services [6,7].

The PPP model has been widely used in a variety of public services worldwide, such as energy, transportation, sports facilities, municipal water supplies, and sewage treatment. However, its application in agriculture is not as common as other sectors, given the high risk and low profit of agricultural production. Several PPP projects were reported in the fields of crop variety development and extension [8], agricultural extension [9], irrigation management [10], agricultural insurance [8], and agricultural products marketing [11]. Some scholars have suggested that the PPP model should act as an institutional innovation to improve irrigation infrastructure and services [2,12–15]. Several cases of the PPP model in irrigation governance have been reported and analyzed in Australia [16], Morocco [17], Pakistan [18], Burkina Faso [10], and China [2,13]. However, most of them were large-scale irrigation systems and implemented in plain regions and very few were reported in mountainous areas [2]. Mountainous areas are characterized by several unique natural and social conditions, including complex landforms, scattered farmlands, high-risk agricultural activities, remoteness from markets, lack of modern technology and information, as well as lack of trust between local communities and private companies. These characteristics induced great technical and governance challenges in applying the PPP model in irrigation infrastructures. Whether the PPP model feasible in such circumstances and how to manage these challenges for successful projects become important questions to answer for sustainable development of agriculture and livelihood in mountainous areas.

Based on comparative case analysis in the Lujiang Flatland (LJF) in the Nujiang River Valley of Southwestern China, this study presents the application of the PPP model in the development of irrigation infrastructure and explores the critical factors influencing the success of project. Although this study was conducted at a local level, the major findings provide applicable lessons for other mountainous areas, such as the China–Myanmar border region. Given their similar natural, economic, and social conditions, mountain communities within the international river basins along the China–Myanmar border face the common challenges from rapid global changes and could benefit from the useful insights this paper presents.

2. Materials and Methods

2.1. Study Area

The LJF of Baoshan Municipality in Western Yunnan in Southwestern China was chosen as our study area. This area, within an international river basin of China-Myanmar border region, is located in an alluvial valley of the middle Nujiang River (also the Upper Salween River) with altitude ranging from 640 to 1400 m (Figure 1). Local climate, in comparison with surrounding areas, is characterized by relatively high average annual temperature (21.3 °C), low average annual precipitation (746 mm), and high average annual evaporation (2101 mm) [19]. Arable lands are topographically limited and scattered, and mainly distributed in alluvial flatlands of the lower reach region. Favored by the distinct

agro-climatic resources [20], the LJF has been widely recognized as an important agricultural area in Yunnan Province with the high-production of a variety of food and cash crops. The main crops include rice, corn, vegetables, fruits, and coffee. Because of the high quality and yield of coffee, the LJF is recognized as one of the largest regions in China for improved coffee varieties. The local population is composed of many ethnic groups, mainly including Han, Dai, and Yi people, while Han people make more than 90% of the total population. Vegetable and fruit cultivation were the key source of income for local communities.

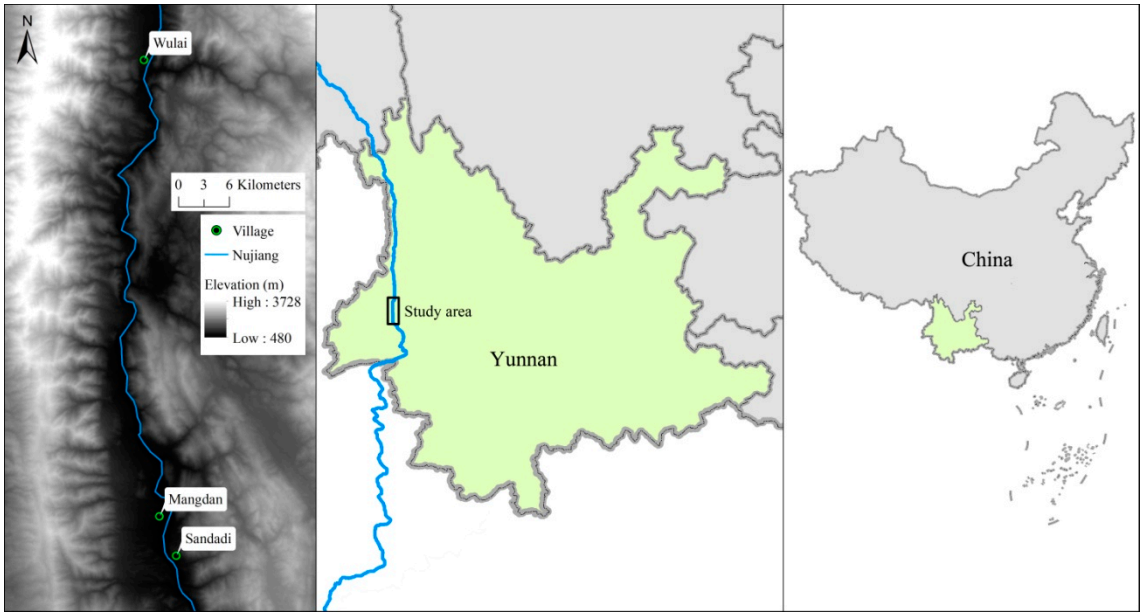

Figure 1. Case study area in the Lujiang Flatland of the Nujiang River Valley, Southwestern China.

Currently, the principal source of irrigation water in the LJF is natural rainfall and river water. A few of the villages in this area depend on reservoir water for agricultural and domestic use. The irrigation infrastructures in these areas are poorly constructed and maintained due to topographic restraints and the lack of funds, increasing the vulnerability of local livelihoods to climate change and induced drought stress. In recent years, the requirement for irrigation water by local agricultural systems has increased significantly to meet the demand of fast-growing vegetable markets, especially in dry seasons when the natural rainfall is low. Frequent droughts in recent two decades also causes negative influence on local livelihoods.

To alleviate water deficit during dry seasons, local farmers increase their water supply by various methods, such as pumping water from the Nujiang mainstream, extracting groundwater, constructing more ponds and cellars, and adopting sprinkler irrigation techniques [2]. Among these measures, pumping water from the Nujiang mainstream is regarded as the most effective and promising solution to address water shortages. In some villages, local farmers mainly use small gasoline pumps to draw water at certain distances, and relevant costs range between 50~70 CNY per mu (1 CNY=0.1425 USD; 1 mu =1/15 hectare). At least 2 adults are required for normal irrigation operations. Otherwise, farmers had to put up with harvest reduction due to lack of water. As a result, local farmers need a better water withdrawal method to reduce the cost of per farming household. Water withdrawal from the Nujiang mainstream by pumping stations has been widely recognized as the most effective measure to improve irrigation capacity and reduce irrigation costs at the same time [2]. Therefore, several pumping stations have been established in the LJF area, and some of them are built, managed, and operated through PPP models.

Based on pre-investigation of irrigation management in the LJF area, we selected the pumping station projects in three villages (Mangdan, Sandadi, and Wulai) as our cases, which were of different

degrees of success. The projects are all small-scale, with an investment around 1.6 to 2.4 million CNY. However, their performance, i.e., whether they could provide irrigation services sustainably, are quite different. The project in Mangdan is successful. The project in Wulai is moderately successful. The project in Sandadi is unsuccessful. These three projects provide good ground to compare and explore success factors. The basic characteristics of the three villages were shown in Table 1.

Table 1. Characteristics of case study villages in the Lujiang Flatland (LJF) in the Nujiang River Valley, Southwestern China.

Particulars	Mangdan	Sandadi	Wulai
Bank of the Nujiang River	Western	Eastern	Western
Elevation (m)	650	680	860
Landform	Relatively flat with a large area of contiguous farmland.	Relatively steep with scattered farmlands.	Relatively steep with scattered farmlands.
Number of households	755	731	835
Total population	2995	2936	3277
Ethnicity	Mainly Dai	Mainly Han	Mainly Dai and Yi
Percentage of working population (%)	76	52	56
Farmland area (mu*)	4260	6405	5580
Per capita farmland area (mu)	1.35	2.25	1.65
Main cash income source	Coffee; sugarcane	Vegetables; coffee	Sugarcane; tobacco
Main water source	Seasonal springs; small reservoir; rainfall	Reservoir; Nujiang River; rainfall	Seasonal springs; river; rainfall

Source: Local governments; Field survey, 2014; * 1 mu =1/15 ha.

2.2. Data Collection and Analysis

This study used comparative methodology to investigate the critical success factors of typical PPP pumping stations in the LJF. Key informant interviews and ground-based surveys were conducted for data collection in September 2014 and October 2015. People who were responsible and knowledgeable of the implementation of pumping stations were chosen as key informants, who include government officials, village leaders, and company representatives. At least 3~5 persons from each sampled village were interviewed, and a total of 15 key informants were involved in this research. The interviews were conducted in an open-ended manner around the topics of the background, process, implementation, and performance of the PPP project. This method makes it possible to collect all the relevant information of the projects as well as the subjective opinions of the interviewees. An interview lasted for half an hour to one hour. Ground-based surveys were conducted with the aims of investigating the basic situation of pumping stations in sampled villages and then verifying information from key informant interviews.

A comparative method was used among the three projects with different degrees of success (successful, moderate successful, not successful) to identify the critical factors that influenced the success of the PPP model in the study area. Based on review of relevant literatures and the cases, several relevant factors were chosen for qualitative comparation, including role of participant, profit-making mechanism for private companies, and sharing of costs and risks among different partners. A factor was identified as a success factor if it existed in the successful cases but not in the unsuccessful cases. Collected information/data from key informant interviews were organized and categorized for the identification of key indicators relevant to pumping station performance in all three case villages. Relevant handwritten/typed notes and observation records were carefully reviewed and edited. Content-based data from interview notes were input into Excel (Microsoft Corp., Redmond, WA, USA) spreadsheets and analyzed for key results and discussion.

3. Results

3.1. The Mangdan Village Case

The development of the pumping station project in Mangdan Village could be traced back to 2013, when the local government invested over 10 million CNY to convert 560 mus of barren hills into cultivable lands. However, due to the lack of basic irrigation conditions, these lands were unable to be effectively developed given the local situation of skills and technologies. Farmers in Mangdan Village repeatedly proposed that the local government build pumping stations to fulfill irrigation demands, but no positive responses returned from local governments. The situation changed in 2015. Under the coordination of the town government, a private company from Baoshan Municipality was invited to negotiate with the villager committee for a cooperation project. The company won the contract and then signed an agreement with the village committee after a competitive bidding process.

According to the project agreement, the company was fully responsible for the construction and management of two pumping stations in Mangdan Village. One station was cooperatively designed and constructed by both villagers and the company, but exclusively used by villagers for irrigation purposes, which could irrigate 400 to 500 mus of farmland. The other one belonged to the company and was used for plantation. The investment was around 1.6 million CNY and was completely covered by the company. In exchange, Mandan villagers transferred the use right for the 560 mus of arable lands to the company under a 10-year lease. In China, most farmlands were collectively owned by the village; thus, the ownership of farmlands could not transfer to individuals or private companies, only the use right could. The company could use the lands without charge for the first four years, and then would pay 500 CNY per mu yearly after that. The company was granted the right to manage the lands during the lease term and could sub-lease to a third party as long as land utilization remained unchanged. Farmers in Mandan Village established an irrigation cooperative to organize their own irrigation schemes, and cooperative members paid for water fees to cover the operation costs. After the contract expiration, the cooperative could negotiate with the company whether to extend the contract or simply assume direct ownership of the pumping station.

At present, two pumping stations of this project were properly operational. The pumping stations were built near the Nujiang main stream and pumped and stored water in a large tank reservoir on the hill. Stored water would be released and allocated through a pipeline network. Farmers paid for the water fee at 10 CNY per mu. The project provided reliable irrigation water to the farmers, so that the productivity of their vegetables increased than before the project, which means the income would increase by 0.5 ~ 0.75 million CNY in drought years. Conflicts among farmers regarding water resources also decreased due to increased water supply. As for the private company, it received two principal benefits from this PPP model. Firstly, the company could enjoy the preferential electricity pricing at 0.425 CNY/kWh with the support of the local government. Secondly, after the land transfer was completed, the company opted not to develop and utilize the lands, but to lease them for 1000 to 1200 CNY/mu to a local large household for plantation of high-value cash trees. To date, this PPP project has functioned well and greatly favored the production of off-season vegetables in Mangdan Village.

3.2. The Sandadi Village Case

Under government coordination and supervision, a private company from Baoshan Municipality, which had invested some pumping stations in a neighboring village, got in touch with the village committee of Sandadi Village and proposed to build a pumping station in 2013. According to the design, the project was expected to provide irrigation services to around 2000 mus of farmland and farmers would pay for the services at a cost of 50 CNY per mu, of which standard was set by the company based on calculation of costs and farmers' affordability. Expecting to reduce half of the farmers' irrigation costs, the village committee agreed to the proposal, but no formal agreement was signed between the company and the villagers. The whole design and construction process was completed in 2014 through the exclusive consultation between the company and the town government,

with an investment of 2.4 million CNY, which was fully covered by the company. Local communities had no participation in the design process. According to the primary arrangements of this project, the company would hire a local people to manage this project after the construction was completed, and farmers would pay for the service according to area of irrigation after the completing of the pumping station.

However, this pumping station was suspended after a short-term operation. There were four specific reasons as follows: (1) The project was poorly designed and the efficiency was lower than expected due to the mismatch between the pipe and the pumping capacity; (2) the water storage capacity of reservoir was limited due to topographic restraints. The water supply could only meet the needs of one village group while the others had to set up extra pipelines to access water, resulting in poor organization and low efficiency; (3) the project failed to enjoy the preferential electricity price, so the electricity price (about 1.1CNY/kWh) was over two times the preferential electricity price. Meanwhile, serious leakage problems of ditches further lowered irrigation efficiency due to poor maintenance. To cover its costs, the company had to repeatedly raise irrigation fees from the initial 50 CNY/mu to the current 90 CNY/mu. However, this action led to strong dissatisfaction and widespread complaints within local communities; (4) there were conflicts in irrigation arrangements among the community members. Due to the complex landforms, the farmlands were scattered with diverse crop choices, which constrained the effective allocation of irrigation water. Different crops were cultivated in this community with different water needs due to varying topography. Because of this, the community members have different water needs and find it difficult to reach agreement. Low storage capacity means that water must be used immediately. Some water leaks to lands that do not need it, and the excess water may damage crops. Irrigation water quantity and schedules could not be flexibly adjusted to meet the actual needs of villagers. Therefore, conflicts in irrigation arrangements happened within the community.

Due to the above reasons, local farmers refused to pay for water utilization, and the financial performance of the company was poor. Currently, the pumping station is temporarily closed and is not providing irrigation services. The company also stopped maintenance of the system to reduce further costs.

3.3. The Wulai Village Case

The pumping station in Wulai Village was built in 2015. Unlike the other two cases with the direct involvement of governments, this project was initiated and implemented through a bottom-up approach. During 2013–2014, a severe drought caused significant water shortage and agricultural losses in this village. That year, a successful businessman visited his brother in this village and noticed the serious water shortage problem. Local villagers (some of them relatives of the businessman) suggested that he invest in a pumping station and promised to contribute in the organization and coordination at community level. Considering the potential benefits under scenarios of frequent droughts, the businessman agreed to build and run a pumping station in Wulai Village. Through the coordination of village committee, the town government committed to provide necessary technical supports during the construction process and granted a subsidy to cover 50% of the construction cost after it was completed.

Under the guidance of the water agency of the township government, this businessman invested 1.4 million CNY for this project and had its complete ownership. According to the project design, it would provide irrigation services for 2200 mus of farmland. The farmers were expected to obtain reliable irrigation water, thus to reduce crop failure during drought. A farmer from Wulai Village (also one of his relatives) was hired as the business representative for regular management. This pumping station drew water from the Nujiang mainstream into a 300-cubic-meter tank at the middle of the hill. Irrigation services were provided according to farmers' actual demands. Farmers paid the water fee at the cost of 1.5CNY/m3 (or 30 CNY/mu for vegetable irrigation), which was set by the company based on calculation of costs–revenue, and consultation with local water agency. In 2017, an irrigation

cooperative was set up in Wulai Village with the help of the village committee, incorporating the pumping station as a part of the cooperative components. Therefore, the pumping station could enjoy the preferential electricity price that was significantly lower than commercial uses.

Unfortunately, the project is currently at a standstill, and several reasons were revealed in our study. Firstly, the surprisingly abundant rainfall in 2016 made the irrigation demand significantly decreased. Secondly, local governments made considerable efforts in repairing ditches and relevant facilities, successfully improving the availability of old irrigation system. Moreover, the subsidy promised by the government had not yet materialized, bringing certain financial pressures to this project. The project was only used occasionally since it was completed. However, the investor was still optimistic about his endeavors in the near future and kept maintenance of the system because the increasing demand for irrigation water under the fast-growing cash crop cultivation in Wulai Village could, at a certain level, increase the business of the pumping station and ensure long-term profits. The basic information of the three pumping station were summarized in Table 2 for comparison.

Table 2. Summary of the three pumping stations based on the public–private partnership (PPP) model.

Cases		**Mangdan**	**Sandadi**	**Wulai**
Initial investment		**1.6 million CNY**	**2.4 million CNY**	**1.4 million CNY**
Area designed to irrigate		**400 mu ~ 500 mu**	**Around 2000 mu**	**2200 mu**
Roles of the participants	Government	• Initialized and coordinated the project in its early phase. • Supervised the agreement between the company and the community. • Policy support (preferential electricity price)	• Initialized and coordinated the project in its early phase.	• Financial supports (subsidy). • Policy supports (preferential electricity price). • Technical supports (design) to the project.
	Private company	• Financed, designed, and constructed the project.	• Financed and constructed the project. • Managed the project.	• Financed and constructed the project. • Operated the project with an agent from the community.
	Community/ famers	• Participated in the design of the project. • Operated the pumping station. • Organized irrigation activities. • Pay service fees.	• Organization of irrigation activities. • Pay service fees.	• Organization of irrigation activities. • Pay service fees.
Benefits to the participants	Government	• Provide irrigation service to local communities with low cost.	• Expected to provide irrigation service to local communities with low cost. • Increased distrust by famers in fact.	• Expected to provide irrigation service to local communities with low cost. • No benefits to government in fact.

Table 2. *Cont.*

Cases		Mangdan	Sandadi	Wulai
Initial investment		**1.6 million CNY**	**2.4 million CNY**	**1.4 million CNY**
Area designed to irrigate		**400 mu ~ 500 mu**	**Around 2000 mu**	**2200 mu**
	Private company	• Benefits from the use rights of the community farmland. • Annual revenue of 0.616 million CNY in the first four years and 0.336 million CNY in the last six years.	• Expected to benefit from water fees from the farmers with annual revenue of 0.32 million CNY. • No revenue in fact.	• Expected to benefit from water fees from the farmers with annual revenue of 0.21 million CNY. • The de facto annual revenue was −6000 CNY.
	Community/ famers	• Irrigation services at cost of 10 CNY/mu. • Increased reliability of irrigation water thus indirectly increased total income of 0.5 ~ 0.75 million CNY per year. • Reduced conflicts among famers over water resources.	• Expected to obtain irrigation services at cost of 50–90 CNY/mu. • Expected to reduce total irrigation costs by half a million CNY per year. • No benefits in fact.	• Expected to obtain irrigation services at cost of 30 CNY/mu. • Expected to increase reliability of irrigation water thus indirectly increase total income of 2 ~ 3 million CNY per year. • No benefits in fact.
Current status of the project		Under normal operation; greatly favored the production of off-season vegetable.	Suspended due to design flaws, conflicts with villagers, and lack of policy supports (high electricity price).	Suspended temporarily due to decreased irrigation demands, and unfulfilled subsidies.
Performance evaluation		Successful with optimistic prospects.	Unsuccessful with pessimistic prospects.	Unsuccessful with optimistic prospects.

Note: The revenues of the company did not account for the depreciation cost. The benefits of farmers were estimated based on the improvement in crop production in Mangdan village and Wulai village as the farmers did not irrigate crops with individual pump machines before the projects thus did not involve irrigation cost.

4. Discussion

The success of the PPP project was mainly assessed by whether the project was under proper operation and whether it had potential to be profitable. Through the comparative analysis of these different cases, we summarized the critical factors that possibly affected the success of the PPP pumping station projects in the study area as shown in Table 3. We discussed how these factors impacted the success of the PPP projects in the following sections.

Table 3. Identification of success factors affecting the PPP projects.

Cases	Design according to local conditions?	Multi-stakeholder management mechanism?	Participation of local community in project design?	The community is able to organize irrigation effectively?	Cost sharing by government?	Equally sharing of risks?	Mechanism to improve mutual trusts?
Mangdan	Yes	Yes	Yes	Yes	Yes (preferential electricity price)	Yes	Yes (formal agreement; community participated in project design)
Sandadi	No	Yes	No	No	No	No	No
Wulai	Yes	Yes	Yes (indirectly)	Yes	Yes (preferential electricity price)	No	Yes (personal bond; community participated in project design)

4.1. Rational and Feasible Design of the Project According to Local Conditions

Rational and feasible design of the project according to local conditions is vital to the success of the pumping station project. Once technical failures occur, not only can the entire system not function properly, but the cost for following technical adjustment and equipment replacement would be high. In this study, the primary reason for the project failure in Sandadi Village was a technical problem: The capacity of pump was low while the size of pipe was big, resulting in the low efficiency of water pumping, as well as the high operation cost. This problem stems from the initial design flaws, which ignored local topographic conditions.

Participation of village in the design and construction phases is a critical success factor. In the early stages of the project design, design ideas based on local conditions are extremely important given agricultural diversity and complexity. As private companies are normally unfamiliar with local conditions, they lack sufficient indigenous knowledge on this issue. The participation of villagers can provide practical experiences and knowledge in the design phase of pumping station project. At Mangdan Village, the pumping station was originally designed as a facility powered by solar energy in order to lower energy requirements. However, local villagers advised that the pumping station could only work when sunlight was abundant. This design meant that the available irrigation period was restricted to daytime. However, during the growing season, the demand for irrigation was especially high, and farmers needed continuous watering even during the night. Therefore, the photovoltaic-driven pumping station could not meet such requirements. On account of villagers' advice, the pumping station was redesigned so it could be powered by electricity.

4.2. Multi-Stakeholder Management

The multi-stakeholder mechanism is a particular success factor for agricultural irrigation based on the PPP model. The mechanism reported in this article refers to the fact that multiple actors (local government, community, private investor) involved in water infrastructure projects potentially having shifting roles in the different phases (design, construction, operation, and evaluation) in view of the characteristics of different management processes. There are significant differences in the construction and operation of pumping stations in the three cases. During the construction phase, coordination of funds and utilization of technology is the key link in which private sectors have a particular advantage. During the operation phases, user coordination and organization play the key role while local community flexibility is important. The three cases studied all adopted multi-stakeholder mechanism at different degrees, i.e., private companies focused on the design and construction of

pumping station and the communities took charge of operation. In the study area, local communities formed effective self-organization mechanisms based on traditions of long-term irrigation management practices. The operation of a pumping station, together with the existing management experience at the village level, can significantly reduce the operational cost for the private sector. In Mangdan Village, the company directly handed over the pumping station to the village after its construction, and only responded for maintenance and consultation. In Wulai Village, although the company was still involved in the regular operation of the pumping station, the company representative was also a community member, and this social connection between different stakeholders strengthens the mutual trust and communication, which favors the proper management of project.

On the other hand, the ability of the community to effectively organize itself to manage the irrigation process is a key success factor for a PPP-based pumping station project, especially in places where infrastructure is inadequate and less developed. The major villagers in both Mangdan Village and Wulai Village are Dai people and they have high levels of social capital. Irrigation water could be effectively allocated and conflicts among villagers could be largely avoided. The residents of Sandadi Village are mainly composed of Han people with a relatively short residential history and agricultural experiences in LJF. The relatively low cohesion within the community results in villagers´ inability to solve disputes and to effectively allocate water resources.

4.3. Costs Sharing by the Government

Cost sharing, especially in the operational costs, could help to improve the financial feasibility of the PPP projects. Preferential electricity pricing for agricultural irrigation reduces the operation costs of the pumping station. At present, only the projects in Manda Village and Wulai Village enjoyed preferential electricity prices for the operation of pumping stations, while this policy had not been implemented in Sandadi village. High electricity price combined with other organizational problems doubled the irrigation fee in Sandadi, which contributed to the failure of the project.

4.4. Equally Shared Risk among Stakeholders

Many studies emphasize that a reasonable risk-sharing mechanism is one of the key factors for the success of the PPP model [21,22], and our findings support such statement. In the Mangdan case, the construction of pumping station and land transfer were tied together in the transaction, so the company not only benefited from the operation of the pumping station, but also gained sustainable profits from multiple sources, such as the land re-transfer and preferential policies. Therefore, the potential risks and uncertainties that the company might encounter would be shared by the government, the private sector, and the villagers. In the Wulai and Sandadi cases, the companies mainly benefit from water charges. Agricultural irrigation is strongly dependent on climatic conditions, and rainfall uncertainty causes great risks for private companies involved. The Wulai case, for example, illustrated that one of the most important reasons causing the project´s financial deficit was that local farmers used the pumping station less during a season with abundant rainfall. Moreover, in the Sandadi case, villagers refused to pay for the irrigation service due to poor coordination in irrigation arrangements. As a result, interests of both the company and villagers were damaged.

4.5. Mechanism to Improve Mutual Trusts among Stakeholders

Two mechanisms to improve mutual trust between communities and companies existed in the study area: (1) government supervision as in the Mangdan case and (2) personal bonds between the community and the investor as in the Wulai case. Particular difficulties exist in PPP project implementation due to the relatively low level of formal education and low connectivity with external markets in remote mountainous communities. Villagers might know little about the background information of the companies and find it difficult to trust these commercial arrangements. The government played an important role in linking rural communities and markets. Except for the case of Wulai Village, it was the government that introduced the companies to the communities. During the process of project

negotiation in Mangdan Village, the government served as an agent for local communities. The rights and duties were recorded in an agreement, which was supervised by the government. Participation in project design also increased the trust of community towards the private company, although doubts still existed regarding whether the follow-up agreement terms would be respected. In Wulai Village, the trust between the company and the investor came from their personal bonds. Based on the relationship of trust with the company, the village committee worked actively to establish the irrigation cooperative so that the pumping station project could enjoy preferential electricity pricing, which is vital to the success of the project.

At Sandadi Village, no mechanism existed to increase mutual trust. The company was introduced into the community by the government, no formal agreements were signed between the community and the company, and the participation of local community was absent during the design and construction stages of the project. This gave villagers the impression that this project would not satisfy the village interests and needs, but rather make the government look good. Neither did the villagers trust the company, but rather believed that it invested simply to take advantage of the existing preferential policies surrounding public resources. As a result, villagers blamed the company for the project failure. This kind of suspicion and negative attitude made the community unwilling to take proactive measures to solve problems when the project faced difficulties. Villagers did not feel that the project was "theirs".

5. Conclusions

Irrigation systems are critical for food security and drought adaptation in rural environments. However, lack of funds and low-efficacy of government-funded irrigation projects greatly hinders the development of irrigation infrastructure in remote mountainous areas. The PPP model is a promising innovation for solving the problem of under-investment in public infrastructure and has wide potential application in China. This approach is particularly promising for the improvement of water resource exploitation in the mountainous communities of western Yunnan Province. However, although the government is willing to introduce this model in the development of rural infrastructure, its application is still in a start-up stage and needs to be supported by more empirical evidence, especially in the remote mountainous areas. This research on pumping station projects explores the critical success factors of PPP application in the development of irrigation infrastructure through comparative studies of three village cases with different degrees of success.

Though specific arrangements vary among village cases, the basic models of PPP projects in the study area can be presented as follows: (1) private companies are in charge of investment and construction of pumping stations; (2) communities (or representatives of company from the community) are in charge of operation and management; (3) farmers pay for irrigation services; (4) private companies profit from charging water fees or utilizing of transferred farmlands; and (5) local government supports the PPP project through preferential electricity price, technical consultation, and coordination between companies and communities. Based on our findings, factors critically influencing the success of irrigation station project in mountainous areas mainly include: (1) reasonable and feasible technical project design with adequate consideration of local conditions; (2) multi-stakeholder management in different project stages of the project. Primary and secondary responsibilities may vary/shift during different stages of the project. The participation of communities in the design phase and a dominant role in organizing irrigation activities is especially important; (3) sharing costs and risks among companies, communities, and the government; and (4) building mutual trust among stakeholders.

This study strengthened the potential of the PPP mechanism in irrigation development and drought adaptation in mountainous rural areas. However, the applicability of PPP mechanism varies among regions. The three cases of PPP projects we explored have unique characteristics, such as the land lease in Mangdan Village and social connections in Wulai Village. Thus, their success experiences may not be able to be imitated directly. However, the key message we learn from these cases is to explore the endowment of local residents, connect the public resources with the interest of private enterprise and make the best use of them. Each community should explore its endowment and then

develop a diversified PPP project that best suits its realities. This requires much learning and adaptive processes to find suitable pathways.

There are two main limitations of this study that future studies could improve upon. First, this study depended on qualitative method as it is a preliminary attempt to identify the success factors of a PPP irrigation project in remote mountains area. Further studies could use qualitative methods with a consolidated framework and multiple case studies in larger area to obtain more robust conclusions. Second, we did not further explore why some success factors existed in some villages but not in the others; for example, the mutual trust and support among stakeholders. This is important for possible intervention. Further studies could contribute to better project design through in-depth exploration into how to foster mutual trust and cooperation among stakeholders, and leadership and cohesion within communities. Furthermore, more successful cases and diversified institutional arrangement could also contribute to better project design.

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