Farmer Participation and Irrigation Performance:

A Case Study of Nam Thach Han irrigation System, Vietnam

A thesis

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LOI HANH TRAN

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Abstract

This thesis assesses the determinants of farmer participation in irrigation management and the impact of participation on irrigation quality and agricultural production in the Nam Thach Han irrigation system, Vietnam. Many governments have attempted to increase farmer participation in irrigation system management through participatory irrigation management (PIM). This approach aims to reduce government financial burdens, improve the quality of irrigation management, and in turn, enhance agricultural production. However, the results of PIM have been mixed and the factors affecting its success or failure remain a topic of much debate.

Using survey data from 391 households of 11 agricultural cooperatives (ACs) in the Nam Thach Han irrigation system, this study examines (i) the factors that influence farmer participation, (ii) the impact of collective action on irrigation quality (sufficiency and timeliness), and (iii) the impact of irrigation quality on rice farming technical efficiency, while controlling for environmental factors.

Four main findings emerge from this thesis. We find that (i) institutional factors at the AC level such as inclusion in the PIM project, information transparency and democratic decision-making have a positive impact on participation, but sharing second-level canals between ACs reduces participation; (ii) higher participation rates are associated with a higher probability of receiving sufficient and timely irrigation; (iii) plots and households receiving sufficient water are more likely to attain higher levels of technical efficiency and; (iv) use of household-level data can provide approximately unbiased estimates of technical efficiency provided environmental factors are controlled for.

This thesis provides several contributions to the literature. Participative approaches have been widely adopted in Vietnam but this is the first empirical study to use econometric models to examine the determinants of participation and the effect of collective action on irrigation quality. This is achieved using an improved set of participation indices, constructed using principal component analysis. This thesis also provides the first analysis of the effect of sufficient and timely irrigation on rice farming technical efficiency while controlling for plot-specific environmental factors.

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List of abbreviations

AC	Agricultural Cooperative
ADB	Asian Development Bank
CPIM	The Centre for Participatory Irrigation Management
CPR	Common pool resource
CRWR	The Central Region Water Resource Project
DEA	Data envelopment analysis
GDP	Gross domestic product
GSO	The General Statistics Office of Vietnam
IMT	Irrigation Management Transfer
IME	Irrigation Management Enterprise
MARD	Ministry of Agriculture and Rural Development
NGO	Non-Government Organisation
NTH	Nam Thach Han
NTHIME	Nam Thach Han Irrigation and Management Enterprise
PCA	Principal component analysis
PIM	Participatory Irrigation Management
SA	Summer-Autumn season
SPF	Stochastic production frontier
TE	Technical efficiency
VND	Vietnam dong (unit of currency)
WUO	Water user organisation
WUG	Water user group
WUA	Water user association

Chapter 1 - Introduction

1.1. Background

Irrigation provides 44% of global crop production from only 16% of the world's cropped land (Alexandratos & Bruinsma, 2012) and 2.4 billion people rely on irrigated agriculture for their food and livelihoods (Comprehensive Assessment of Water Management in Agriculture, 2007). However, irrigated agriculture consumed 70% of all water withdrawals in 2010 and this is projected to increase by 5.5% by 2050 (Food and Agricultural Organization, 2010, 2011). Countries that heavily rely on irrigation have been trying to ensure food security while limiting pressure on their water resources. The United Nations has promoted the view that more effective governance is the best way to tackle this issue and achieve sustainable management of water resources (United Nations World Water Assessment Programme, 2006, 2012).

Over the last four decades, many countries and international development organisations have attempted to improve irrigation water governance through Irrigation Management Transfer (IMT), Participatory Irrigation Management (PIM), Public-Private Partnership (PPP) and market instruments. Amongst these, PIM, which promotes the involvement of local water users in all aspects and at all levels of irrigation management, has been the most widely adopted. PIM has greatly increased in popularity since the 1980s, when many developing countries were struggling to maintain large-scale irrigation systems after the vast expansion of irrigation infrastructure in the 1960s and 1970s (Barker & Molle, 2004). PIM aims to reduce state financial burdens and improve irrigation performance and agricultural production. It has been implemented in nearly 60 countries as a remedy for poor irrigation performance. Despite its widespread application, no clear consensus has been reached on the impacts of the PIM approach and conditions for success or failure (Araral, 2010; Meinzen-Dick, 1997; Senanayake, Mukherji, & Giordano, 2015). This remains a topic of much debate and contestation.

In Vietnam, irrigation has played an important role in the development of the agricultural sector, which contributes 17% of gross domestic product (GDP) and employs 45% of the labour force (World Bank, 2019). With an abundant endowment of nearly 3,500 rivers[1] and plentiful rainfall of 2,000 mm per year, expansion of the irrigated area and improvements in water control were the main drivers that allowed Vietnam to switch from being a net rice importer to being the second-largest rice exporter. Irrigation also helped Vietnam to become the largest producer of black pepper, the second-largest coffee producer, and the third-largest aquaculture producer (Barker & Molle, 2004; World Bank, 2019).

Irrigation has absorbed the majority of government spending on the agriculture sector over the last 60 years, accounting for between 50% and 70% of total agricultural expenditure in the 1990s (Barker & Molle, 2004) and 65% to 70% in 2009-2012 (Government of Vietnam & World Bank, 2017; Hoang, 2014). By 2018, Vietnam had 904 diversion structures each serving more than 200 hectares, 6,000 irrigation reservoirs, 13,000 large pumping stations and 235,000 kilometres of canals. These well-developed irrigation systems provide water for 7.5 million hectares (ha) of paddy land, 1.6 million ha of other crops, and 0.4 million ha of aquaculture (MARD, 2018 cited in World Bank, 2019).

However, these irrigation systems operate at only 50% to 60% of their designed capacity. Around 1,500 small and medium-size dams and reservoirs need to be rehabilitated while only 26% of canal length is described by the World Bank as being "fully functional" (World Bank, 2019, p. 18). This poor performance is caused by low quality and/or incomplete construction, infrastructure deterioration, and poor management. Many of these issues can be traced back to the low level of government expenditure on operation and maintenance (less than 5% of the total government budget for irrigation sector), low farmer irrigation fees and significant levels of non-payment. In addition, Irrigation and Drainage Companies have limited

[1] These rivers are of more than 10 kilometres in length.

accountability to Water User Groups since they are now funded by the government (Barker, Claudia, Minh Tien, & Mark, 2004; Pham, 2013; Pham, 2004; Vietnam Academy for Water Resources, 2007; World Bank, 2019).

In the 1990s, in line with a wave of global institutional reform, the Vietnamese government, with the support of international development agencies, started to modernise the irrigation sector using the concepts of Participatory Irrigation Management (PIM) and Irrigation Management Transfer (Huynh & Tessier, 2020). The concept of PIM was introduced in Vietnam for the first time through the Irrigation and Flood Protection Rehabilitation Project funded by the Asian Development Bank (ADB) in 1995 (Nguyen, 2011). In 1997, the Ministry of Agriculture and Rural Development (MARD) organised the first national workshop on PIM which was supported by the ADB, the World Bank, and the International PIM Network (Benedikter & Waibel, 2013). Since that time, PIM and IMT have been increasingly included in policy documents. By 2013, 49 out of 63 provinces had issued policies to support PIM/IMT and nearly 30 provinces had adopted PIM/IMT with the establishment of 16,238 water user organisations (WUOs[2]) (MARD, 2013).

Currently, PIM is usually adopted in new irrigation projects, especially those funded by international development agencies (Nguyen, 2008b; Tran, 2019). The 2017 Law on Hydraulic Works (Articles 50–52) provides for farmer participation in investing and managing small-scale and on-farm irrigation infrastructure. Also, the irrigation strategy for Vietnam, developed with the assistance of the World Bank in 2017, proposed the idea of "devolving power and responsibility to farmer organisations to operate and maintain larger sections of the irrigation network and to pay the full costs of water service provision" (World Bank, 2019, p. 26). This again underlines the importance of the participatory approach to irrigation management.

[2] WUOs in Vietnam have different names such as Water User Groups, Water User Associations, Agricultural Cooperatives, Irrigation Management Board

1.2. Research problem and justification for this thesis

PIM is expected to enhance irrigation performance[3] by increasing the involvement of water users in irrigation management. However, in many cases, this approach has not led to high levels of farmer participation and improvements in irrigation performance. Participation is often limited to contribution of labour and money rather than participation in decision making such as planning irrigation schedules and designing canals (Department of Water Resource, 2008; Huynh & Tessier, 2019; Le, Huynh, Dinh, Nguyen, & Thao, 2015; Nguyen, 2008b). Farmers are mainly passive spectators in design and monitoring with little opportunity to influence system design or operation (Huynh & Tessier, 2019). Water disputes between farmers continue to be a problem and WUO Management Boards do not have sufficient incentives to properly undertake their irrigation management duties (Department of Water Resource, 2008). A survey conducted across 15 provinces suggested that, in most cases, irrigation management models established under the PIM project could not expand or would stop working after the project finished (Nguyen, 2008b). This reality raises serious concerns for policymakers on the sustainability and impacts of the current PIM approach.

Many researchers have investigated these issues. However, previous PIM related studies in Vietnam mostly focus on the external institutional factors that impact the establishment of WUOs and the degree of WUOs' involvement in management processes. They also investigate the relationship between WUOs and the other stakeholders involved in irrigation management, from central to local level (Benedikter & Waibel, 2013; Evers & Benedikter, 2009; Fontenelle, 2001; Nguyen, 2008a, 2009; T. Pham, 2017; Pham, 2013; Tran,

[3] Irrigation performance is defined here as including both irrigation system activities, such as attaining inputs and transforming inputs to outcomes; and the effects of those activities on the irrigation system itself and on the external environment. A more detailed definition and indicators of irrigation performance are presented in section 4.2.1.

2019). These studies mainly adopt qualitative and institutional analysis and do not analyse the determinants of farmer participation within their own local WUOs. It needs to be emphasised that the involvement of farmers in WUOs is the initial step through which they can raise their voices and interact with other stakeholders in the higher levels of the irrigation bureaucracy as well as secure sustainability of WUOs. Therefore, there is value in examining farmer participation in the everday irrigation management activities of WUOs and investigating the direct link between farmer participation and the quality of irrigation they receive.

Moreover, the question of whether participation contributes to the improvement of irrigation performance has only been investigated in a handful of previous studies (T. T. T. Pham, 2017; Tran, Gupta, Babel, & Clemente, 2005; Tuan & Nagaki, 2004) and has not been properly answered. These authors evaluate the impact of PIM on irrigation performance at the scheme level or compare irrigation performance before and after or with and without the project. They do not directly investigate the correlation, if any, between farmer participation and irrigation performance. Unsustainable WUOs and the low level of farmer participation reported in previous PIM projects suggest that PIM may not be accompanied by higher levels of effective farmer participation and that the outcomes recorded in these projects may result from the infrastructure improvements which are generally included in PIM projects, rather than PIM itself. Therefore, the examination of the direct linkage between farmer participation and irrigation performance detailed in this thesis, is able to shed new light on the real impact of the participatory approach.

Since the Vietnam government's main target in developing irrigation systems is to increase rice production and improve food security, it is not surprising that some previous studies have investigated the linkages between PIM, irrigation and rice production. However, this thesis brings an additional perspective to investigating this relationship.

First, scope for increasing rice production by increasing cultivated area or labour input in Vietnam is limited, due to increasing conversion of farmland to non-agricultural uses

(Alcaide Garrido et al., 2011), a steady flow of labour away from agricultural activities (Kinghan & Newman, 2017) and increasing migration from rural to urban areas (Amare & Hohfeld, 2016; Narciso, 2017). These realities impose a requirement to focus on maximising output per unit of input under cultivation. Therefore, an examination of rice farming technical efficiency[4] is more relevant than a simple focus on production.

Second, irrigation can be considered as a service provided to farmers and one of several off-farm factors that may affect the efficiency of rice farming. Given that 96% of rice in Vietnam is grown under irrigation and that the quality of irrigation management is thought to be a limiting factor (World Bank, 2019), an evaluation of the impact of irrigation quality[5] – the sufficiency and timeliness of irrigation - on rice farming technical efficiency is essential. Moreover, Vietnam is strongly impacted by climate change (Chen, McCarl, & Chang, 2012) and farmland is fragmented with small plot size (Markussen, Tarp, Thiep, & Tuan, 2016; Van Hung, MacAulay, & Marsh, 2007) thus creating much heterogeneity in local conditions. Therefore, plot-specific environmental factors will be taken into account and analysis of the impact of irrigation quality on technical efficiency at plot level will provide improved insight compared to farm-level analysis.

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[4] Technical efficiency can be defined as the ability of a decision-making unit to produce the maximum output from a given set of inputs and technology, or as the ability to use a minimum amount of input to generate a given amount of output. A more detailed definition of technical efficiency is presented in section 5.2.1.

[5] Irrigation quality refers to both the sufficiency and the timeliness of the irrigation that farmers receive during the irrigation-rotation period. A more detailed explaination of sufficient and timely irrigation is presented in 4.3.2.

1.3. Objectives and research questions

This thesis describes the determinants of farmer participation in irrigation management and the impact of participation on irrigation quality and irrigated agricultural production in the Nam Thach Han irrigation system in Vietnam. Specifically, the analysis in this thesis is divided into three distinct objectives, each associated with one or more research questions.

Objective 1: To describe and assess the factors affecting farmer participation in irrigation management

Research questions:

- What is the level and form of farmer participation in irrigation management?
- What factors affect farmer participation?

Objective 2: To assess the impact of collective action on irrigation quality

Research question:

- Is a higher proportion of farmers participating in collective action associated with more sufficient and timely irrigation (irrigation quality)?

Objective 3: To assess the impact of irrigation quality on rice farming technical efficiency

Research questions:

- Is there a significant correlation between irrigation quality and technical efficiency (TE) in rice farming?
- Is the impact of irrigation quality on technical efficiency under-estimated when we fail to control for environmental factors?
- Does aggregate household-level data give the same estimates of TE as unaggregated plot-level data if we control for environmental factors?

The linkage between research objectives is illustrated by the overall conceptual framework in Figure 1.1. Two key concepts in this framework are farmer participation and irrigation performance. Irrigation performance is measured by the quality of the irrigation service provided to farmers and the rice farming technical efficiency that farmers attain. The conceptual framework starts from the first research objective which hypothesizes that three local contextual factors, including the characteristics of WUOs, the condition of irrigation systems, and the attributes of farmers and their farms, may impact on farmer participation. Then, the first objective connects with the second and the third one as we hypothesise that participation may explain variation in irrigation quality which in turn influences the technical efficiency of rice production. We estimate the relationship between farmer participation and irrigation performance while controlling for local contextual factors.

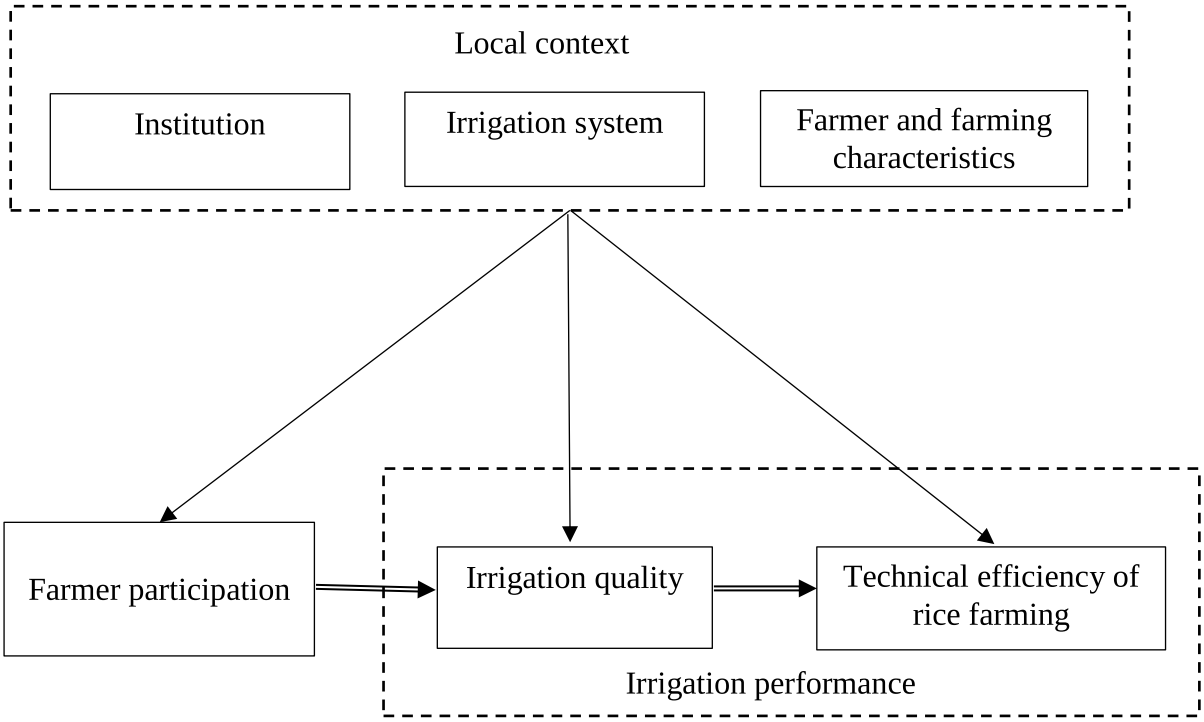


Figure 1.1. Conceptual framework of the thesis

1.4. Overview of this thesis

This thesis describes the relationship between farmer participation and irrigation performance from the farmer perspective. It comprises three analytical chapters corresponding with three research objectives (Chapter 3, 4 and 5), this introduction (Chapter 1), a description of the study site and data collection (Chapter 2), conclusions (Chapter 6) and limitations

(Chapter 7). Each analytical chapter is deliberately formatted as an independent essay with research questions, literature review, analysis methods and results. As all three analytical chapters use the same survey data set; detailed information about the study site, data collection process and summary statistics for sample households and agricultural cooperatives (ACs) are presented separately in Chapter 2. In the three following chapters, the data sections do not include these full details, to avoid repetition.

Chapter 2 aims to provide an overview of the socio-economic context of the study site in general and the sample households and ACs in particular. It uses summary statistics of secondary data collected from districts and agricultural cooperatives, and primary data collected from survey households. Chapter 3 investigates the level and dimensions of farmer participation by using principal component analysis, then the determinants of farmer participation are analysed using OLS regression and the institutional analysis framework developed by Ostrom (1994). Chapter 4 examines the linkage between collective action at the AC level and the irrigation quality received at the plot level. The logit model is used and the model specification is based on the institutional analysis framework developed by Tang (1992). Chapter 5 provides a detailed analysis of rice farming technical efficiency and the impact of irrigation quality on technical efficiency using stochastic production frontier analysis with the one-step approach. Chapter 6 summarises the findings, draws some policy implications, summarises the contributions made by this thesis and offers suggestions for further research. Chapter 7 details some limitations of this thesis.

Chapter2 - Study site and data collection

2.1. Description of the study site

2.1.1. Nam Thach Han irrigation system

The Nam Thach Han irrigation system is located in Quang Tri province to the north of Vietnam's Central Region as indicated in Figure 2.1 below. It is the largest irrigation system in the province and was built in 1978 to bring water from the Thach Han river. The system stretches through 14 communes in Trieu Phong district, 11 communes in Hai Lang district, and two wards in Quang Tri town. It consists of two dams, seven reservoirs and two spillways (CPIM, 2010). There are also 66 pump stations which supply or drain irrigation water. By 2017, the irrigation canal network included 16 kilometres of main canal, 69 km of first-level canals, 278 km of second-level canals and 405 km of third-level canals. 95% of the main and first-level canals have been lined but only 55% of second-level and 18% of third-level canals (NTHIME, 2017a).

According to data provided by the Nam Thach Han Irrigation Management Enterprise (NTHIME), the total irrigated area increased from 14,074 ha in 2009 to 15,519 ha in 2017. The average volume of water supplied per hectare, measured at the head of the first level canals, was around 11,300 m^3 in the Winter-Spring season and 10,800 m^3 in the Summer-Autumn season (NTHIME, 2017b, 2017c). However, according to the NTH Director, 30-40% of water is lost before it reaches agricultural cooperatives (ACs hereafter); a situation which is typical of irrigation systems in Vietnam (Nguyen, Dao, Nguyen, & Ha, 2018). He also reported that this volume of water is generally enough for farmers to achieve good yields in the Winter-Spring season, but water shortage in some irrigation rotations is common in the Summer-Autumn season. The capacity of the Nam Thach Han (NTH) system has been gradually increased through several infrastructure upgrades and improvements in irrigation management.

Source: Asian Development Bank (2013)

Figure 2. 1. Map showing the six provinces included in the CRWR project

Between 2009 and 2017, around 70% of the irrigated area was served by gravity irrigation, with the remaining 30% being served by pumps. Rice is the dominant crop making up 93% of the total irrigated area in 2017, although the non-rice irrigated area almost doubled from 264 ha in 2009 to 441 ha in 2017 (NTHIME, 2017b).

The Irrigation and Drainage Management Company of Quang Tri province is in charge of the overall management of all large and medium irrigation infrastructure in Quang Tri and the NTH irrigation system is one of them. One of its sub-units, NTHIME, has direct responsibility for operation, maintenance and management of the NTH irrigation system. NTHIME manages the headworks, main canals, first-level canals and second-level canals which serve several ACs, where the total irrigated area is larger than 100 ha. NTHIME assigns management responsibility for other second and third-level canals, to 114 ACs (CPIM, 2010).

The Nam Thach Han irrigation system was selected as the study site because it is located in the Central Coast region, the third-largest rice production region, with 1.2 million hectares (16%) of the national area of rice cultivated (GSO, 2018). Moreover, this region is one of the two poorest regions in Vietnam with the highest proportion of rural households involved in agricultural production (83%) (Liu, Barrett, Pham, & Violette, 2020) and it has been highly affected by climate change and natural disasters (Beck, 2017). Importantly, Participatory Irrigation Management (PIM) was introduced and adopted in the Nam Thach Han scheme under the Central Region Water Resource (CRWR) Project funded by ADB from 2007 - 2012.

In the CRWR project, six medium-sized irrigation systems in six coastal provinces (Thanh Hoa, Quang Binh, Quang Tri, Thua Thien Hue, Quang Ngai and Binh Dinh) were selected as subproject areas. The location of these subproject areas is highlighted in yellow in Figure 2.1 (above) with the NTH irrigation system being located in the province numbered 30.

The CRWR project aimed to increase agricultural production and reduce poverty through a user-oriented service approach that emphasised farmer participation in irrigation water management. Project activities can be categorised under two headings: improvements to the irrigation management system, and irrigation and drainage infrastructure improvements (ADB, 2013).

Improvements to the irrigation management system included:

(i) establishment of financially viable irrigation management companies with user-oriented irrigation services,

(ii) strengthening participatory irrigation management through the formation of water user groups (WUGs) and water user associations (WUAs[6]) on the basis of hydraulic boundaries;

(iii) developing on-farm irrigation infrastructure, and

(iv) operationalising a project performance management system.

In order to strengthen water user participation (ii above) three main activities were carried out:

a. forming or strengthening WUGs and WUAs with written charters and irrigation rules;

b. enhancing stakeholders' awareness of PIM; and

c. improving the capacity of WUG staff in business plan development and irrigation operation and maintenance (CPIM, 2012).

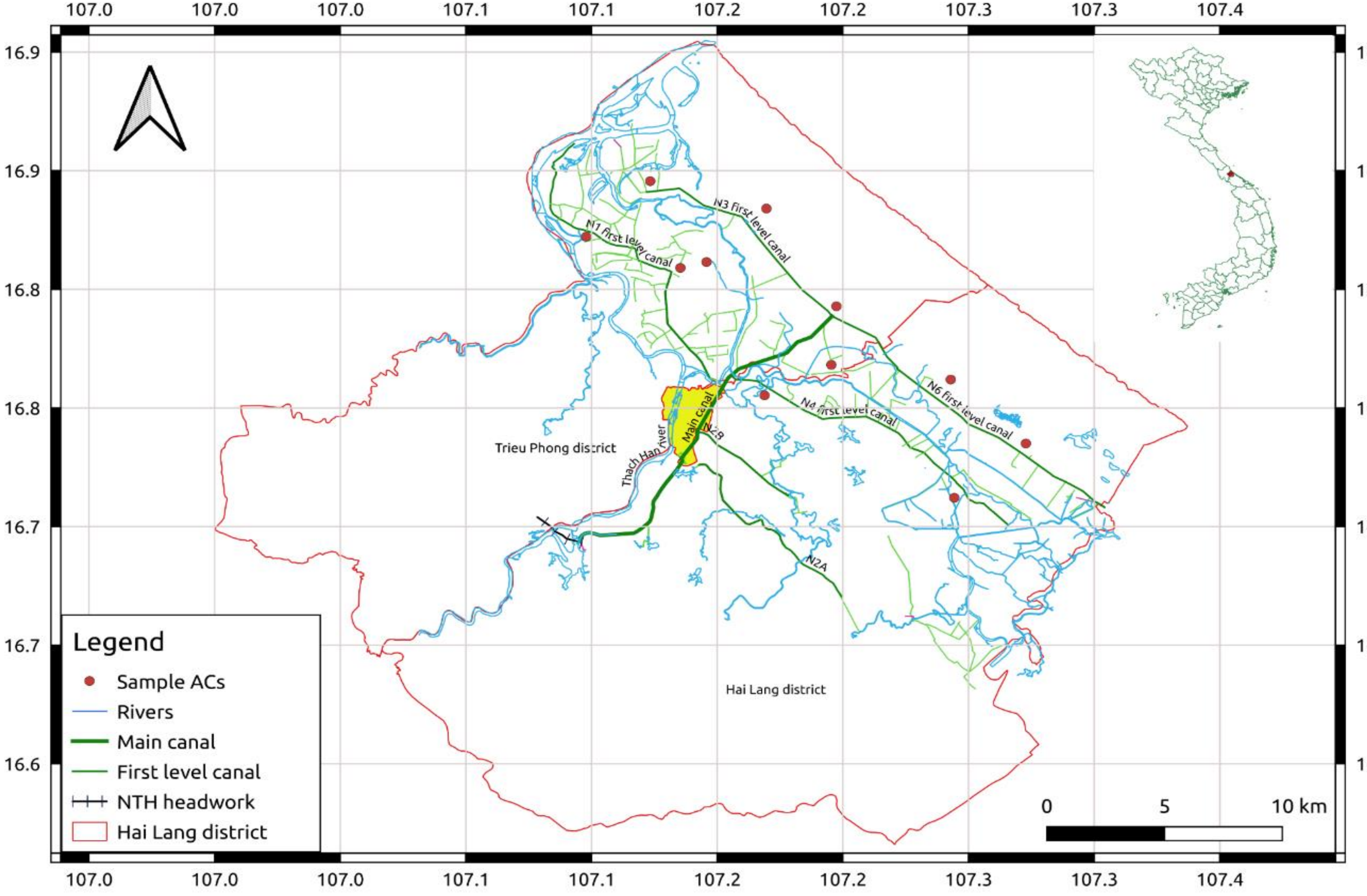
Since these activities focus on the PIM approach and this thesis focuses on farmer participation in irrigation management, so the CRWR subproject in Nam Thach Han irrigation system is referred as the PIM project hereafter in this thesis. Fifty two out of the 114 ACs in the Nam Thach Han irrigation system received PIM project support to increase farmer participation and improve in-field canal systems. Specifically, 387 people, including executive board members, water deliverers[7] and farmer representatives attended training courses; 223 third-level canals were partially lined, of which 127 canals were lined by ACs included in the

[6] WUAs are formed from groups of WUGs which share second-level canals.
[7] Members of irrigation teams who deliver water to farmer plots and operate and maintain AC irrigation infrastructure.

project (MARD, 2012); one new WUG and four WUAs were established and 47 pre-existing ACs updated their charters and irrigation rules based on the WUG model (CPIM, 2012).

After the end of the PIM project, funding for WUAs ceased and coordination of water delivery between ACs was left to informal arrangements between ACs. Also, after the promulgation of the Agricultural Cooperative Law in 2012, each AC generated its own charters and rules in line with the new law, but they did not include the specific rules covering irrigation that had been developed under the PIM project. As a result, in 2017 when the data for this study was collected, WUAs had ceased to exist and the irrigation rules developed under the PIM project were no longer used.

A map of the Nam Thach Han irrigation system is included in Figure 2.2. The main canal derives water from the headworks on the Nam Thach Han river and delivers water to six first-level canals. Four first-level canals (N2A, N2B, N4, and N6) mainly serve agricultural areas in Hai Lang district while two first-level main canals (N1 and N3) deliver water mainly to Trieu Phong district. Nearly all of the WUGs (also called agricultural cooperatives in our study site) and WUAs established under the PIM project are located along either first-level canals (N1, N3, N4, and N6) or the middle and tail section of the main canal. Eleven red dots indicate the locations of sample ACs in this study.



(Source: NTHIME)

Figure 2. 2. General layout of Nam Thach Han irrigation system

2.1.2. Some characteristics of Hai Lang and Trieu Phong districts

Hai Lang and Trieu Phong districts are located in the south of Quang Tri province. Hai Lang covers a total area of 425 km^2 while Trieu Phong stretches over a smaller area (353 km^2). Both districts have diverse terrain, sloping from the west to the east. This creates three natural geographical regions: the coast, the plains and the hills[8]. Eleven of the 19 communes in Hai Lang and 14 of the 18 communes in Trieu Phong are served by the NTH system. These irrigated areas in Hai Lang and Trieu Phong districts respectively make up 32% and 65% of the total area irrigated by the NTH system.

The climate in these districts is characterised by hot, dry southwest winds, storms and heavy rainfall as the province is located in the tropical monsoon zone. There are two distinct seasons; the rainy season is characterised by heavy rainfall and strong winds lasting from September to January while the dry season with low rainfall and hot dry winds extends from March to August (Asian Disaster Preparedness Center, 2003).

Selected socio-economic indicators for Hai Lang and Trieu Phong districts are set out in Table 2.1. It can be seen that the total population in 2016 was around 177,000 (Hai Lang ~85,000, Trieu Phong ~92,000) with population densities of 199 and 260 people/km^2. These districts are predominantly rural with these residents accounting for 96% of the population. Around 80% (78% Hai Lang, 82% Trieu Phong) of the labour force (15 to 64-year olds) work in the agricultural, aquaculture or forestry sectors.

[8] Hills between the mountains and plains, 50 to 250 meters above sea level.

Table 2. 1. Socio-economic indicators for Hai Lang and Trieu Phong districts (2016)

Indicator	Hai Lang	Trieu Phong
1. Population	84,839	91,990
Females (%)	50.6	51.0
Rural residents (%)	96.4	95.5
2. Population density (per km^2)	199	260
3. Workforce (15 - 64 yrs old)	43,626	48,597
Agr', Aqua' & Forest sector (%)	78.1	81.9
4. Total production value (million USD[9])	105.8	85.5
Agriculture (%)	57.8	63.9
Aquaculture (%)	10.7	13.9
Forestry (%)	6.1	5.9
Industry & services (%)	25.3	16.2
5. Cultivated area (ha)	11,879.8	16,730.5
Rice cultivated area (%)	62.3	67.7
6. Total area (ha)	42,479.6	35,336.1
Agriculture (%)	83.5	79.7
Crops (%)	33.5	38.5
Forestry (%)	64.8	59.1
Aquaculture (%)	1.6	2.2
Non-agricultural land (%)	12.7	17.0
Unused land (%)	3.7	3.3
7. Average Rice yield (t/ha)	6.2	5.5
Winter-Spring yield (t/ha)	6.3	5.6
Summer-Autumn yield (t/ha)	6.1	5.4
8. Percentage of poor households[10] (%)	8.6	12.7

(Source: Statistics Office of Hai Lang district; Statistics Office of Trieu Phong district, 2016)

The total value of production in Hai Lang was around USD 106 million in 2016, equivalent to USD 1,250 per head. Primary production (agriculture, forestry & fisheries) contributed 75% of the total value of production, with the remainder coming from the industry, handicraft, construction and service sectors. Trieu Phong has a slightly larger population but production was valued at only USD 86 million (USD 930 per head) with 84% coming from the primary sector.

Agricultural land comprises 84% of Hai Lang and 80% of Trieu Phong districts. Rice is the dominant crop accounting for two-thirds of the cultivated area. The average rice yield in

[9] USD values are based on an exchange rate of USD 1 = VND 22,700 (2017)

[10] Poor households are those whose income per capita is less than US$ 31 per month

Hai Lang was 6.2 t/ha in 2016, the highest in Quang Tri province (up from 5.6 t/ha in 2012). Rice yields in Trieu Phong were lower than in Hai Lang but also increased slightly from 5 t/ha in 2012 to 5.5 t/ha in 2016. The proportion of poor households in Hai Lang district is 8.6% while 12.7% of Trieu Phong households were categorised as poor in 2016.

2.2. Research design and data collection

2.2.1. Research design

To address targeted research objectives, I needed to design a data collection procedure and a sample that would capture spatial and temporal heterogeneity in farmer participation, irrigation quality, agricultural production and institutional aspects of ACs. After reviewing the available data, it became clear that it would not be possible to retrieve sufficient information from 5 years before when the PIM project finished. As a result, I decided that the most suitable approach would be to use cross-sectional data to compare key variables at household, plot and AC level, between areas included and not included under the PIM project.

In developing the sample design for this thesis, the main objective was to achieve a representative sample. The main theme of this study is farmer participation and irrigation performance. Moreover, it is widely known that different locations along irrigation canals experience different water accessibility conditions, associated with different levels of irrigation performance. The PIM project followed a participative approach to irrigation management which was expected to lead to increased levels of farmer participation, irrigation quality, and agricultural production. Therefore, sample design for this study includes observations for farmers who were involved as well as those not involved in the project, at different locations in the NTH irrigation system.

I used the multi-stage stratified random selection method. In the first stage, I randomly selected ACs from different locations on the scheme and included both participating and non-participating ACs (PIM ACs and non-PIM ACs hereafter). In the second stage, I randomly selected households within each AC. A more detailed explanation of these two stages is provided in the following paragraphs.

In the first stage, as Hai Lang and Trieu Phong districts account for 97% of the area of the Nam Thach Han irrigation system, I only selected ACs from these two districts. Moreover, as nearly all PIM ACs are located along either first-level canals (N1, N3, N4, and N6) or in the middle and tail sections of the main canal, I limited the sample to these canals and sections. As a result, I randomly selected 3 ACs from the head, 4 ACs from the middle, and 4 ACs from the tail sections of these first canals. Five of the 11 ACs selected were included in the PIM project. Four of the selected ACs are in Hai Lang, and 7 are in Trieu Phong district, which is in proportion with the share of irrigated area in these districts.

Household surveys run with limited budgets commonly adopt a minimum sub-sample size of around thirty since this is generally large enough for the central limit theorem to hold, thus ensuring that the distribution of the sample means is approximately normally distributed. Therefore, in the second stage of sampling, an interview of 40 households for each sub-sample was planned, which after allowing for ‘wastage’, would give a minimum sample of 35 households in each AC. Every fifth household was selected from the AC register of members, however, some households were not willing to participate and some completed questionnaires were excluded due to doubts about the reliability of data. As a result, the actual eligible households included in our study ranged from 30 to 40 households in each AC.

Ideally, sampling would have been proportional to the number of ACs in the system and the number of households in each AC. However proportional sampling was not possible because of the skewed distribution of ACs in different parts of the system and the wide range in the number of households in each AC. There were also practical difficulties in achieving the planned sub-sample size in some ACs. In the analysis, I control for these issues using sample weights.

The number of total ACs, sampled ACs and sampled households by location are presented in Table 2.2. A total of 391 households were surveyed, of which 182 households were from PIM ACs, and 209 households were from non-PIM ACs.

Table 2. 2. Total number of ACs, sample ACs and sample households

Location	Non-PIM			PIM		
	Total ACs	Sampled AC	Sampled HHs	Total ACs	Sampled ACs	Sampled HHs
Head	20	2	64	21	1	34
Middle	12	2	76	16	2	71
Tail	14	2	69	15	2	77
TOTAL	**46**	**6**	**209**	**52**	**5**	**182**

2.2.2. Questionnaire design

Two separate questionnaires were designed: a structured household questionnaire and a semi-structured questionnaire for collecting information from sample ACs. In addition, a list of secondary data that would be collected from ACs and NTHIME was developed. The main contents of these questionnaires and the list of secondary data are reported in Table 2.3.

Table 2. 3. Data collected from different stakeholders

Households (Household questionnaire)	Agricultural cooperatives (AC questionnaire and secondary data)	NTHIME (Secondary data)
• Basic demography • Input and output of rice production & plot characteristics • Irrigation quality • Farmer participation • Farmer attitude toward ACs • Household income	• AC staff (number, experience and education) • Irrigation rules • Institution for participatory approach • Farmer participation • Plot locations • Irrigated area • Irrigation infrastructure • AC expenditure & revenue	• Irrigated area • Irrigation map of the NTH irrigation system • Details of irrigation infrastructure

The household questionnaire comprises five sections. The first section focuses on the characteristics of household members, housing and land. The second section covers information related to rice production, including the characteristics of rice plots, rice production inputs and outputs, contact with extension services, and irrigation quality. The third section concentrates on the involvement of farmers in irrigation management. Questions related to farmer perception of ACs are in the fourth section. The final section explores the sources of household income. The questionnaire is included in Appendix 1.

The AC questionnaire was used to collect general information about ACs and their staff as detailed in Table 2.3 (above) and to cross-check information collected from households. It includes questions on the number and qualification of staff, irrigation rules, rule compliance, institution for farmer participation, farmer participation and accountability mechanisms. The AC questionnaire is included in Appendix 2

Secondary data including AC parameters (eg. area, population and number of members), AC irrigated areas, AC irrigation infrastructure, AC expenditure and revenue were collected from sampled ACs while irrigated areas, irrigation infrastructure and maps of NTH irrigation systems were collected from NTHIME. Secondary data collected from NTHIME was used to supplement and cross-check the data collected from ACs.

2.2.3. Pretest and field visit

Draft questionnaires and details of the proposed sample selection procedure were reviewed by representatives of the Agricultural & Rural Development Department in Hai Lang and Trieu Phong districts and the Director of the Nam Thach Han Irrigation & Drainage Enterprise. They provided useful field-level insights into rice diseases, infestations and sufficiency of irrigation which enabled the questionnaire to be improved.

Eleven enumerators experienced in rice production and with a good knowledge of local communities were recruited and trained in data collection using the household questionnaire. Then, I did a pilot survey to pre-test the appropriateness of the household questionnaire. We chose three ACs located separately in the head, middle and tail section and two out of three ACs that were included in the PIM project. Four households in each ACs were interviewed.

Information provided by farmers included in the pre-test, about the locations of their plots and distances to water intake points in the pilot survey, proved to be inconsistent. So I decided to collect this information from the leaders of irrigation teams, who supervise water delivery to household plots. Some questions which used technical terms were modified to make them easier for respondents to understand. The order of sections was also changed slightly to improve the logical sequence of subjects covered in the interview.

2.2.4. Data collection

The household survey was conducted from January to March 2018 with the support of eleven enumerators. Over the survey period, I travelled the area to supervise the enumerators and also directly interviewed 5-10 households in each AC and so was able to gain a good understanding of conditions in each AC. I also interviewed the directors and leaders of irrigation teams in all selected ACs. I also contacted the Agricultural and Rural Development Departments and Statistics Offices in Hai Lang and Trieu Phong districts to collect secondary data on the socio-economic status of these districts. Secondary data, including irrigation maps, irrigated areas, infrastructure, and AC business and financial status, were collected from NTHIME and ACs.

2.2.5. Data processing and sample weights

Data processing

Data collected in the household survey was entered, cleaned and analysed using Stata 16. Frequency runs were used to detect data entry errors and missing values while graph means such as boxplots and histograms were used to detect outliers. Data entry errors were corrected by referring back to the questionnaires. Using the 1.5 interquartile range rule, I detected outliers and omitted them from analyses. Missing values were replaced by the mean value of other observations in the same cluster.

Sample weights

As noted in section 2.2.1. (above), the number of sample ACs and households is not proportional to population which may cause biased estimation. To mitigate this issue, the sample weight formulae proposed by Deaton (1997) was adopted in this thesis to estimate the weight of each household before data analysis. This approach is outlined below.

Suppose there are N clusters (the total number of ACs in each section in the NTH irrigation system) in the population and n clusters (sample ACs) have been selected. The number of sample households is denoted as m_c for cluster c.

π_c denotes the probability of selection for cluster c in the first stage, and π_{ic} for the probability of household i being selected in the second stage, given that c has been selected in the first stage. The unconditional probability that household i in cluster c is selected in a stratified two-stage sampling procedure is $\pi_c * \pi_{ic}$.

h_c is the number of population clusters represented by cluster c, and h_{ic} is the number of cluster c households represented by households i in cluster c. The overall inflation factor, which reports the number of households in the population represented by household i, is the product of h_c and h_{ic}.

$$w_i = h_c * h_{ic} = \frac{1}{(\pi_c * \pi_{ic} * m_c * n)} \qquad (1)$$

Where $\pi_c = \frac{1}{N}$ and $\pi_{ic} = \frac{1}{M_c}$

Then the normalised weight for household i is:

$$w_i^s = \frac{w_i}{\sum_{i=1}^{s} w_i} \qquad (2)$$

Where w_i^s denotes the normalised weighting of household i. The total normalised weightings of all sampled household are standardised to sum to unity.

2.3. Descriptive statistics of sampled households and agricultural cooperatives

This section provides some descriptive statistics of sampled households and ACs. National data are also integrated into the analysis in order to compare the study site with other rural areas in Vietnam. PIM and non-PIM households are also compared to explore differences and similarities between these groups.

2.3.1. Household endowments

Human resources

Table 2.4 shows some demographic characteristics of household members. Each sample household has 4.4 members on average. This is the same as the average household size in Quang Tri province in 2016 (ADB, 2020) but slightly higher than the average rural household size measured at the national level (4.2 members) in 2016 (Diem & Van Hoang, 2018).

Table 2. 4. Demographic characteristics of household members

	Sample		PIM		Non-PIM		P-value
Household size (#)	4.42	100%	4.48	100%	4.37	100%	0.43
Working-age (15-64 yr old)	3.40	77%	3.45	77%	3.37	77%	0.58
Children (<15 yrs old)	0.64	14%	0.66	15%	0.62	14%	0.61
Elder (> 64 yrs old)	0.38	9%	0.37	8%	0.38	9%	0.89
Years of education (age>18)	9.58		9.74		9.44		0.25
Main occupation (excluding migrants)							
Farming	1.32	52%	1.09	41%	1.52	63%	0.00***
Off-farm labour	0.11	4%	0.19	7%	0.04	2%	0.00***
Wage employment	0.30	12%	0.41	15%	0.22	9%	0.00***
Self-employed	0.38	15%	0.62	23%	0.18	8%	0.00***
Student or jobless	0.42	17%	0.38	14%	0.46	19%	0.26
Subtotal (excluding migrants)	2.54	100%	2.69	100%	2.42	100%	
Migrated [a]	0.84		0.74		0.93		0.04**

Note: P-values refer to the difference between PIM and non-PIM; *** $p<0.01$. ** $p<0.05$, * $p<0.1$
[a] People who are listed as belonging to the household and have migrated outside the area to work.

On average, 77% of household members are of working age. Children (under 15 years old) made up 14% and elders the remaining 9%. Working-age people who do not migrate account for 58% of the total population in the sample. Only 40% of survey households have any children while 27% of households have at least one elder.

Permanent and seasonal migrants (who live and work outside the local area) are included as household members if they are listed in household registration books. These migrants may provide remittances to support the household. In our sample, 53% of households have at least one member who has migrated. This proportion is much higher than the average national proportion (20%) in 2014 (Narciso, 2017). In a study by the General Statistics Office of Vietnam (2019), the Central Coast region is one of two regions with the lowest population growth rate. The out-migration flow is identified as the main cause of this situation.

Farming remains an important source of employment and income with 52% of total household effective labour[11] or 30% of total household members being engaged in this activity. At the national level, Liu et al. (2020) document the transformation of the rural labour force to the extent that in 2016, full-time farmers who work at least 35 hours per week account for only 9% of household members while those engaged in off-farm work account for 53% of household members. Data from the household survey demonstrates that households in the study site are more dependent on the agricultural sector than the national average.

Data from the survey also shows the extent to which farmers are involved in off-farm work. Of the respondents who reported their main job as farming, 37% also do off-farm jobs as hired labour (16%), waged labour (5%) or are self-employed (16%). Twenty-five percent of the main farmers[12] in each household consider farming to be their secondary occupation, 13% work as hired labourers, 7% run their own business, and 5% work as wage labourers.

Figure 2.3 shows the age groups of sample farmers and those whose main job is outside farming (non-farmers). On average, sample farmers are 50 years old, much older than non-

[11] Those who are in the working age bracket and who do not migrate.
[12] Those who spend more time on farming than other household members.

farmers (37 years old). These differences are very marked in the 18-30 age group and for those above 46. Only 3% of farmers are between 18 and 30, compared to 35% of non-farmers. At the other end of the age scale, 77% of farmers are between 46 and 64, compared to only 27% of non-farmers. This pattern is consistent with the general pattern of the ageing labour force in Vietnam. Specifically, Liu et al. (2020) show that at the national level, ageing in farm labour is more severe than in the overall labour force. The share of younger farmers (less than 50 years old) decreased by 15% (from 75% to 60%) in comparison with an 8% reduction (from 81% to 73%) for the total labour force from 2007 to 2016.

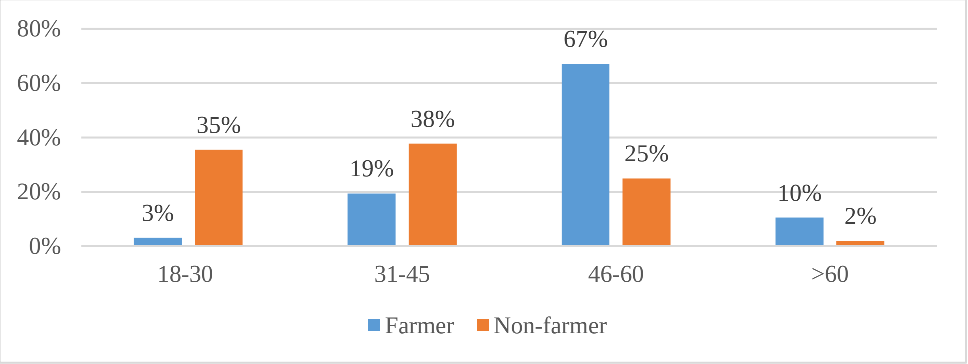


Figure 2. 3. Age distribution of farmers and non-farmers

Figure 2.4 compares the education of sample farmers, versus those engaged in other occupations (non-farmers) at different ages. Those whose main occupation is farming had received an average of 8.2 years of formal education versus 11.2 years for those working off-farm. Only 2% of those engaged in farming had a college or university education while 28% of those working off-farm had completed tertiary level education.

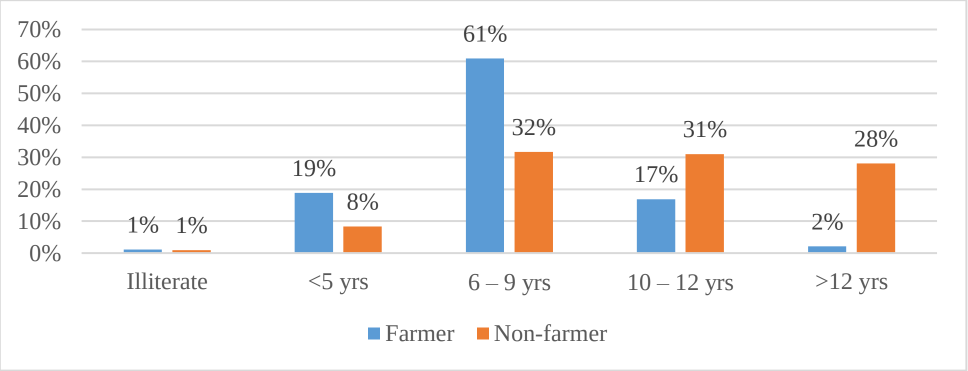


Figure 2. 4. Years of education of farmers and non-farmers

Statistical t-tests on the differences between mean values in PIM and non-PIM households (Table 2.4) suggest no significant difference for household size and age distribution but the labour force and migration variables are statistically different at the 5% level. The number of farmers is 40% higher in non-PIM households while the number of members that are self-employed is three times higher in PIM households. Non-PIM households also have a higher number of migrants. Moreover, the comparison between farmers and non-farmers indicates statistically significant differences between these groups in terms of age and education.

Natural capital

Land is a critical natural capital endowment for farming. Sample households own an average of 8.3 saos (0.42 ha). They rent out 0.4 saos and rent-in 3 saos, giving an average cultivated area of 10.9 saos (0.55 ha). Thirty-two percent of respondents rent and 8% rent land out as shown in Table 2.5. These figures are similar to the national average for area cultivated (0.6 ha) with 7% rented in and 11% rented out in 2016 (Ayerst, Brandt, & Restuccia, 2020). Nationally, the share of rural households involved in renting land in or out is reported to have increased from 28% in 2006 to 34% in 2014 (Markussen, 2017).

Table 2. 5. Area of land owned and rented per households

(Unit: Sao)

	Total	PIM	Non-PIM	P-value
Land ownership				
Owned	8.34	7.70	8.89	0.02**
Rented out	0.40	0.18	0.59	0.01***
Rented in	3.03	2.58	3.41	0.21
Land use				
Rice	9.43	8.32	10.40	0.01***
Number of rice plots	3.2	2.9	3.5	0.00***
Other crops	1.17	1.48	0.91	0.01***
Forestry	0.09	0.09	0.10	0.880
Aquaculture	0.26	0.22	0.29	0.710

Note: 1 sao = 500 m^2 = 0.05 ha; P-values refer to the difference between PIM and non-PIM; *** p<0.01. ** p<0.05, * p<0.1

In our sample, rice land accounts for 86% of the cultivated area. Sixty-five percent of households have between one and three plots, while 35% have between 4 and 9 plots, giving an average of 3.2 plots per household. The smallest plot recorded was only 150 m^2 while the largest plot was 12.5 saos (0.63 hectares). Nationally, rural households cultivated an average of 4.7 plots in 2010 (Markussen et al., 2016). Land consolidation has led to a reduction in the number of plots per household; from 5.8 in 2006 to 4.1 in 2014 (Markussen, 2017). Land consolidation has also been achieved in Quang Tri province, details are provided in Chapter 3.

A comparison of PIM and non-PIM households reveals that PIM households own less rice land and fewer plots, but they own more land cultivated with other crops.

Physical capital

Quality of housing is a useful indicator of household welfare. Several indicators of housing quality are summarised in Table 2.6. The average house size of sampled households is 94 m^2. The majority of households live in houses constructed using permanent materials (85% with concrete walls, 91% with concrete floors and 89% with either tile or concrete roofs). Twenty-two percent of households do all their cooking using gas or electricity, 41% of households have tap water piped to their houses and 87% of households have toilets with septic tanks (flush or squat toilets).

Table 2. 6. Housing and facilities of sampled households

	Total	PIM	Non-PIM	P-value
House size (m^2)	93.5	106.3	82.5	0.00***
House construction				0.67
Concrete walls (%)	85.4	84.6	86.1	
Concrete floor (%)	91.3	90.0	92.3	0.42
Tile or concrete roof (%)	88.5	87.3	89.5	0.50
Cooking energy				
Open fire, coal or kerosene (%)	5.9	8.2	3.8	0.06***
Gas or Electricity (%)	22.3	28.6	16.7	0.00***
Mixed (%)	71.4	62.6	78.9	0.00***
Water & Sanitation				
Piped water to house (%)	41.2	39.6	42.6	0.54
Toilet with septic tank (%)	87.4	84.1	90.4	0.06*
Poor households[13] (%)	5.6	3.8	8.1	0.02**

Note: P-values refer to the difference between PIM and non-PIM; *** p<0.01. ** p<0.05, * p<0.1

[13] Poor households are those whose income per capita is less than US$ 31 per month.

Statistical tests for the difference between PIM and non-PIM households indicate that PIM households have a larger average house size and a higher proportion of households cooking with gas or electricity. They also own more toilets with septic tanks. Overall, 6% of households are officially classified as being poor; 3% for PIM and 8% for non-PIM households.

Social capital

The size and quality of household social networks are reflected in their participation in local organisations and groups as well as by their network of friends. Social network indicators for PIM and non-PIM households are summarised in Table 2.7. Local groups can be categorised into three types: political groups, mass organisations and voluntary groups. Political groups include the Communist Party and the Fatherland Front while the main mass organisations are the Farmers Union, Women's Union, Youth Union, and the Veterans Union. Voluntary groups refer to all other groups in which members participate voluntarily. In our sample, 93% of households are members of at least one mass organisation, 30% participate in voluntary groups, and only 11% are members of any political group. P-values reveal no significant differences in these variables between PIM and non-PIM households. However, PIM households appear to have significantly more close friends and can approach more people to seek financial help.

Table 2. 7. Household memberships of local socio-economic groups and network

	Total	PIM	Non-PIM	P-value
Number of groups (#)	2.34	2.27	2.43	0.21
HHs joining political groups (%)	11	8	14	0.23
HHs joining mass organisations (%)	93	93	94	0.35
HHs joining voluntary groups (%)	30	30	31	0.46
Number of close friends (#)	8.12	9.75	7.13	0.00***
Number of contacts willing to lend money (#)	2.86	2.96	2.81	0.00***

Note: P-values refer to the difference between PIM and non-PIM; *** $p<0.01$. ** $p<0.05$, * $p<0.1$

Findings from the household survey are similar to those by Markussen (2017) for the Central Coast region in Vietnam in 2014. He found that 11% of households were Party members and that households joined an average of 1.4 mass organisations and 0.4 voluntary groups in 2014. Slightly over 90% of households had at least one contact being able to provide financial assistance in an emergency.

Solidarity and cooperation amongst households contribute to the social capital of communities and individual households. Table 2.8 summarises information from respondents on mutual assistance, conflict and participation. Three-quarters of farmers reported that they are very likely to support each other when an individual faces difficulties and only 3% did not agree with this statement. A quarter of households report occasional conflicts between households. They also report that farmers can usually resolve conflicts themselves or through the intervention of local groups. Three-quarters of households reported that they participated in at least one form of collective action. Communal authorities and groups encourage collective action to consolidate relationships amongst households and to strengthen the impact of these groups. Typically, collective action involves removing litter and vegetation along the sides of community roads, planting trees, controlling rats, or building houses for the poor.

Table 2. 8. Mutual assistance, conflict and participation

(% of households participating)

	Total	PIM	Non-PIM	P-value
Mutual assistance				0.76
Very unlikely	1	1	1	
Somewhat unlikely	2	2	3	
Somewhat likely	23	23	23	
Very likely	74	75	74	
Conflict frequency				0.97
Rare	51	50	51	
Never	24	24	24	
Sometimes	25	25	25	
Participation in community collective action	76	80	72	0.01***
Removing litter & vegetation along community roads	88	90	87	0.28
Planting trees in public places	37	54	23	0.00***
Rat control	73	74	72	0.76
Building houses for poor households	16	17	14	0.47

Note: P-values refer to the difference between PIM and non-PIM; *** $p<0.01$. ** $p<0.05$, * $p<0.1$

2.3.2. Household income

The sample household income[14] averaged USD 3,525, equivalent to USD 1,087 per capita (see Table 2.9). This is similar to the average for Quang Tri province in 2017 (ADB, 2020). Farming activities (including cropping, animal husbandry, aquaculture and forestry) account for 41% of the total income, with rice farming contributing around half of this. Off-farm activities including labouring, waged employment and self-employment contribute 50% of the total income, with the remaining 8% coming from pensions and remittances.

Table 2. 9. Total income and structure of income

	Total	PIM	Non-PIM	P-value
Household income (USD)	3,524.4	3,880.8	3,216.4	0.00***
Per capita income (USD)	1,086.8	1,126.4	1,051.6	0.28
Income sources				
Rice farming (%)	21.1	16.6	24.9	0.00***
All farming (%)	40.8	39.6	47.1	0.01***
Off-farm income (%)	50.1	52.4	44.3	0.01***
Pension and remittances (%)	8.3	8.0	8.6	0.72

Note: P-values refer to the difference between PIM and non-PIM; *** p<0.01. ** p<0.05, * p<0.1

PIM households have significantly higher household income than non-PIM households, however, there is no difference in mean per capita income between these two groups. Rice farming contributes a significantly higher proportion of non-PIM household income while off-farm income accounts for a significantly higher share of PIM household income. These differences may be linked to the larger area of land owned by non-PIM households (Table 2.5 above).

Liu et al. (2020) report on a marked decline in the share of agricultural income among rural households in Vietnam. They found that the median share of agricultural income fell from 46.5% in 2002 to 19.7% in 2016, while the median share of wage income increased dramatically from 7.6% to 34.5%. In comparison with national data, households in the study site seem to be more dependent on farming than rural households nationwide.

[14] This applies only to account members who have not migrated. Incomes earned by permanent migrants are not included in the total household income; only the remittance from these migrants are taken into account.

2.3.3. Agricultural cooperatives and their services

According to current Vietnam Cooperative law (2012), “a cooperative is defined as a collective economic organization with co-owners and legal entity status, established voluntarily by at least 7 members who cooperate with and assist one another in production, business or job creation activities to meet their common needs on the basis of autonomy, self-responsibility, equity and democracy in management of the cooperative” (Vietnam Law and Legal Forum, 2012, pp. 43-44)

Agricultural cooperatives (ACs) are autonomous and jointly-owned farmer organisations which are formed by the voluntary participation of farmers and which aim to meet their members’ common needs.

By 2018, Vietnam had around 11,000 ACs. Most ACs concentrate on the provision of inputs and services (as detailed below), while around 20% buy, process and sell agricultural products. There are also more than 65,000 farmer cooperation groups throughout Vietnam. These cooperation groups mainly focus on particular agricultural activities such as irrigation management, technology transfer and knowledge dissemination on specific crops or livestock (Tran & Le 2019).

In the Nam Thach Han irrigation system, the area covered by each AC is based on administrative rather than hydraulic boundaries. Ninety-five percent of ACs serve single villages, six ACs cover several villages, and one AC serves a whole commune. In our sampled ACs, one AC serves a commune, one covers two villages and the rest serve single villages. Five out of eleven sample ACs share hydraulic boundaries[15] with adjacent ACs.

Table 2.10 provides some key information for sample ACs. They have an average of around 290 members and serve an average population of around 1,400. ACs have the function of supporting or providing services for farm households and provide around 7 different services

[15] ACs share secondary-level canals with adjacent ACs.

on average. Most concentrate on the provision of basic services, including irrigation, plant protection, land preparation, veterinary service, agricultural input supply, and agricultural extension. Four ACs have expanded into other activities including rice milling, construction, provision of credit and agricultural product sales.

Table 2. 10. General information for sample agricultural cooperatives in 2017

	All ACs	PIM ACs	Non-PIM ACs
Size and services			
Member households	292.6	406.8	197.5
Population in AC area (people)	1,443.4	2,256.4	765.8
Services provided (#)	7.3	8.4	6.3
Cultivated and irrigated land			
Total agricultural area (ha)	210.8	287.2	147.1
Rice (%)	52.8	49.3	58.5
Total irrigated area (ha)	117.2	149.8	90.1
Irrigated rice area (%)	93.7	92.8	94.4
AC staff	8.3	9.2	7.4
Leader education (yrs in school)	11.3	11.8	10.8
Leader experience (yrs in post)	9.9	7.8	11.7
Number of water deliverers (#)	6.3	9.0	4.0
Water deliverer experience (yrs in post)	8.3	10.1	6.8
Financial status			
Total capital (USD)	108,196	167,948	58,388
Fixed assets (USD)	90,420	141,548	47,872
Current assets (USD)	17,776	26,400	10,516
Receivable from farmers (USD)	8,360	13,244	4,268
Total revenue (USD)	40,964	68,112	18,348
Irrigation service revenue (%)	33.6	26.5	40.5
Total profit (USD)	3,300	4,136	2,596
Irrigation service profit (%)	26.4	29.5	24.9

Sample ACs had an average of 211 hectares of agricultural land, including land for crops, aquaculture and forestry. Rice land accounts for nearly 53% of all agricultural land. The irrigation system provides water for an average of 117 ha of crops and aquaculture, with 94% of this land used for the cultivation of rice.

Of the 11 leaders of our sampled ACs, only one graduated from university, seven finished high school (up to year 12) and three completed secondary school (up to year 9). On average, they had been in their current position for 10 years. AC irrigation teams had an average of 6 staff with 8 years of experience.

The accounting value of total AC capital is USD 108,196 on average. Fixed assets take into account 83% of total capital but most are tied up in office building and irrigation infrastructure while current assets only contribute to 17% of total capital. It is noted that the average current assets include receivables from members (member debts). The mean of AC member debts is USD 8,360 which is more than twice the mean of AC total profit in 2017. A low share of current assets and a high level of farmer debt create financial difficulties for ACs in running business activities. Amongst the services provided by ACs, irrigation contributes to 34% of AC revenue and 26% of AC profit. For most ACs, irrigation service is the main source of income.

2.3.4. Summary of descriptive statistics

Farming, especially rice cultivation, is an important activity for households in the NTH irrigation system. Farming is the main occupation of 51% of the resident labour force and contributes 41% of the total household income. However, farmers are predominantly older and have less education compared to those who are mainly engaged in other occupations. The resident labour force is reduced by seasonal and permanent migration of household members. Half of all sample households have members who have migrated to other areas in search of work.

Our sample households mainly live in houses built using permanent materials, although 77% still use open fires, kerosene or coal for cooking to some extent. Fifty-nine percent do not have tap water piped into their houses, 13% do not have toilets with septic tanks, and 6% are categorised as being poor. Ninety percent of households are members of at least one local group; either a political group, a mass organisation, or a voluntary group, and 76% participate in community collective action.

There are no significant differences between PIM and non-PIM households in terms of household size, social capital and total income. However, PIM households have less land and allocate a lower share of their labour to farming.

ACs support farming by providing services to their members. Most ACs provide basic services like irrigation, input supply and technical consulting services. Provision and delivery of irrigation is an important service in most ACs, accounting for one-third of AC total revenue and a quarter of total profit, on average. AC operations are limited by their financial situation and often have a low share of current assets and high farmer debts.

Chapter 3 - Factors affecting farmer participation in irrigation management

3.1. Introduction

Governments around the world are struggling to shoulder the financial burden of operating and maintaining irrigation systems, leading to gradual deterioration of irrigation performance over time. As a response to this problem, there have been many attempts to increase farmer participation in irrigation system management. It is hoped that encouraging the involvement of farmers in managing irrigation systems will reduce government financial burdens, improve the quality of irrigation management, and in turn, enhance agricultural production.

These expected outcomes of increasing farmer participation in irrigation management may come about in different ways. First, farmers have some advantages over government agencies since they have a direct interest in the performance, cost efficiency, and sustainability of irrigation management (Vermillion, 1997). They also offer an on-the-ground presence, and they are knowledgeable about fellow irrigators (Groenfeldt & Sun, 1997). Second, the involvement of farmers in design, construction and maintenance processes may result in more useful designs, cost savings and construction knowledge for later operations and repairs. Third, and perhaps the most important benefit, is that farmer participation can help the government to offload some of the financial burden (Groenfeldt & Sun, 1997; Vermillion, 1997). Fourth, the establishment of Water User Organizations (WUOs) can help solve conflicts in water allocation and enhance the connection between government agency personnel and WUO leadership (Groenfeldt & Sun, 1997; Peter, 2004).

Different models of encouraging farmer participation have been adopted in different countries. The degree of farmer participation and devolution varies from encouraging users' joint involvement in management (e.g. Participatory Irrigation Management (PIM)) to those that assign full authority and management responsibility to users groups (e.g. Irrigation Management Transfer (IMT)). However, it cannot be assumed that when the state devolves management responsibilities, farmers will automatically be willing or able to take on the roles that they have been assigned. An international review of 230 examples of PIM/IMT by Senanayake et al. (2015) found negative or negligible impacts on farmer participation in half of all cases. Oxfam UK funded a survey across 15 provinces in Vietnam to assess the implementation of PIM. In most cases, irrigation management models established under PIM projects could not expand or be dropped after the project finished (Nguyen, 2008b). Some studies point out that farmers' involvement in irrigation management did not go beyond contributing labour and paying on-farm irrigation fees[16] (Department of Water Resource, 2008; Huynh & Tessier, 2019; Le et al., 2015; Pham, 2013). Therefore, identifying factors that create incentives for farmer participation is necessary to develop appropriate programs and effective implementation of PIM and IMT. This chapter describes research to address this issue with an empirical study of the Central Region Water Resource (CRWR) project in Quang Tri province of Vietnam.

This study contributes to the literature in three main ways. First, it provides an empirical study from Vietnam using econometric models of data from a household survey. Previous studies in Vietnam have mostly focused on institutional factors that shape the establishment of WUOs, the degree of WUO involvement in management processes and the interaction between WUOs and the other stakeholders in irrigation management (Benedikter & Waibel, 2013; Evers & Benedikter, 2009; Nguyen, 2008a, 2009; T. Pham, 2017; Pham, 2013; Tran, 2019). These studies place less emphasis on analysing the determinants of farmer participation in irrigation management within their own local WUOs. Qualitative and institutional analysis is the main

[16] Since 2008, when the circular regarding irrigation fee exemption (Decree 154/2007/NĐ-CP and then Decree 115/2008/ND-CP) was adopted nationally, farmers no longer have to pay irrigation fees for NTHIME but they still have to pay for irrigation services provided by ACs. This fee is called an on-farm irrigation fee.

approach adopted by scholars researching this issue. This study differs from other studies in Vietnam by using quantitative analysis to measure the intensity of farmer participation and econometric models to identify factors affecting their behaviour. Moreover, this study goes beyond institutional analysis and examines the other factors which drive the internal motivation for farmer participation, such as the attributes of water users and the condition of water resource.

Secondly, we use information on farmer participation in numerous irrigation management activities to generate participation indices using a modified version of principal component analysis. This contrasts with previous studies which mostly focus on selected activities. For example, Sharaunga and Mudhara (2018) and Nakano and Otsuka (2011) focus only on whether farmers choose to participate in irrigation infrastructure maintenance. Miao, Heijman, Zhu, and Lu (2015) and Araral (2009) measure farmer participation by whether they pay irrigation fees or whether they contribute labour to construct and maintain irrigation facilities. Although these studies offer valuable insights, participation should be understood as a process rather than a single choice or activity. Therefore, it should be measured by a number of activities related to different aspects and levels of participation. A few studies have tried to create participation indices based on several different activities, but there are some shortcomings in their methods. Specifically, Arun, Singh, Kumar, and Kumar (2012) used the subjective opinions of 15 specialists to assign weights for 20 individual activities which were then added together to generate a single participation index. A problem with this approach is that the index is subjective and more likely to be biased if the small group of specialists cannot represent the opinion of the whole population. Khalkheili and Zamani (2008) apply equal weights to generate a participation score from eight indicators which reflect farmer participation in irrigation management. However, it is widely recognised that participation activities are not of equal importance. To overcome these limitations, a handful of studies on forest management (Akamani & Hall, 2015; Coulibaly-Lingani, Savadogo, Tigabu, & Oden, 2011; Dolisca, Carter, McDaniel, Shannon, & Jolly, 2006; Lise, 2000) and one study on irrigation management (Muchara, Ortmann, Wale, & Mudhara, 2014) investigate resource user participation by using either factor analysis or principal component analysis. These methods can be used to estimate synthesised participation indices objectively from a number of activities since the weight of individual activities is estimated based on their contribution to explaining variance in the data. By using principal component analysis to estimate participation indices, this study not only fills a gap in empirical work to date but also proposes a modified way to use this method. Details of this modification will be described in section 3.4.2.

Thirdly, this study uses farmer perspectives of different aspects of the institution to explain variation in farmer participation. Some previous studies assess the institution for participatory irrigation management via the establishment of WUOs (Araral, 2009; Meinzen-Dick, Raju, & Gulati, 2002) or via the promulgation of a set of rules or a policy (Coulibaly-Lingani et al., 2011; McCarthy, Dutilly-Diané, & Drabo, 2004). These institutional changes are clear and easy to recognise. However, these indicators of institutional change may involve measurement errors if WUOs only exist on paper or if there is a lack of compliance with the rules. To circumvent such errors, this study uses farmer evaluations of institutional structures including democracy in decision making and information transparency. These indicators are somewhat subjective but we argue that farmers' assessments of their irrigation institutions should inform their behaviour more strongly than any other indicators of the situation.

The rest of this chapter proceeds as follows. Section 3.2 reviews the relevant literature and builds on this to set out a conceptual framework and research hypothesis in section 3.3. Section 3.4 describes the data and methods used to analyse the data. Analysis results and discussion are then presented in section 3.5 before section 3.6 offers some conclusions.

3.2. Literature review

Irrigation systems are a well-studied example of a common pool resource (CPR). They include an asset (physical infrastructure) that needs to be managed and they provide a stream of benefits (distribution of water) that require management. Restricting individuals' access to water is sometimes difficult (non-excludability), but the use of water by each person reduces the quantity of available water for others (rivalry). As such, individual users who access water have an incentive to free-ride and withdraw more than the optimal quantity. Therefore, irrigation systems often struggle with resources being overused and a shortage of contributions for operation and maintenance. This tragedy was explained by Hardin (1968) and is well known as the Prisoner's Dilemma.

Those outcomes of CPRs as a whole and irrigation systems, in particular, have posed a question around which management mechanisms are the most appropriate to address this dilemma. In an effort to find proper management for CPRs, four different approaches have been tried over the last half-century: IMT, PIM, water market and Public-Private Partnership (PPP). The combination of PIM/IMT has so far been the most commonly applied model.

The World Bank's descriptive term Participatory Irrigation Management (PIM) is well-known and has been widely used in the public irrigation sector. PIM represents the participation of water users in all aspects and at all governance levels of irrigation management. These aspects include planning, design, construction, financing, decision making, setting rules, operation and maintenance, monitoring and evaluation of the irrigation system. All levels include the full physical boundary of the irrigation system (from headwork to on-farm canal), up to the policy level (Groenfeldt & Svendsen, 2000).

The interrelated concept, Irrigation Management Transfer (IMT), is often used interchangeably with PIM but they are different. IMT refers to the process of passing irrigation management functions from a public agency or state government to the private sector or to local organisations (Garces-Restrepo, Vermillion, & Muoz, 2007; Groenfeldt & Svendsen, 2000). While IMT focuses on replacements of the government role in irrigation management by farmers, PIM serves to strengthen the linkage between farmers and government by enhancing farmer involvement in government management. These concepts refer to the co-management stage when farmers and the government share responsibilities before a final transfer of responsibility takes place (Garces-Restrepo et al., 2007). In general, the main theme of the IMT/PIM is the participation of water users in managing resources.

In parallel with the proliferation of participatory approaches in CPR management in general, and irrigation management in particular, numerous studies have investigated the question of which factors impact on the participation of resource users. Considerable debate exists amongst scholars on the factors that facilitate the involvement of people in managing irrigation systems. Dozens of factors have been discussed in the literature, commonly grouped into three categories: (i) condition of CPR; (ii) characteristics of resource users; and (ii) institution and governance structure. However, some disagreement exists on the direction, magnitude and significance of these factors.

(i) Condition of CPR

Scarcity of resources: It is widely agreed among scholars that water scarcity is one of the most important factors affecting farmer incentives to engage in irrigation management (Bardhan, 2000; Meinzen-Dick et al., 2002). The location (head/middle/tail) of households or WUOs in irrigation systems has commonly been used as a proxy indicator of water scarcity (Fujiie, Hayami, & Kikuchi, 2005; Meinzen-Dick et al., 2002; Nagrah, Chaudhry, & Giordano, 2016). Other studies employ irrigation intensity (Araral, 2009) or use the number of days that farmers cannot access irrigation water (Muchara et al., 2014) as indicators of water scarcity. An inverted U-shaped relationship between water scarcity and farmer participation has been frequently found. Fujiie et al. (2005), for example, found that in the Philippines, when water is uniformly abundant or varies greatly between the head and tail, farmers are less likely to join in collective actions to manage irrigation systems. Similarly, water users in upper sections of irrigation systems in India, with better access to water, are less likely to engage in meetings than those in middle and lower sections (Meinzen-Dick et al., 2002). On the other hand, Nagrah et al. (2016) found that watercourse communities in the tail reaches participated in maintenance and voting more frequently than those in the upstream reaches. Water shortages motivated these farmers to participate more in order to improve their access to the resource. Muchara et al. (2014) also showed that farmers with a high number of days without water access per week participated more in irrigation management. Araral (2009) pointed out that crop intensity (a proxy measure of water scarcity) had an inverted U-shaped relationship with the level of free-riding (a measure of participation on contribution).

Availability of alternative or/and supplementary resources: There are opposing arguments on the direction of the effect of alternative or supplementary water resource on participation. On one hand, Meinzen-Dick et al. (2002) and Nagrah et al. (2016) found that farmers with private access to groundwater tend to be uninvolved in collective actions. A reason for this may be that accessing groundwater enables farmers to be less dependent on surface irrigation, thus reducing the need to invest in collective action. On the other hand, Latif (2007) showed that private access to groundwater improved the incentive for collective action in managing irrigation systems.

(ii) Characteristics of resource users

Gender of household heads: Household heads have an important role in household decision making, thus many scholars have investigated whether the gender of the household heads explains farmer behaviour toward irrigation management. Researchers have found that women generally struggle to engage in collective action. Heavy housework commitments and social norms hinder the involvement of women in the collective action of communities (Nuggehalli & Prokopy, 2009). Dolisca et al. (2006) and Jana, Lise, and Ahmed (2014) found that female farmers tended to be more active in contributing labours and making decisions while males were more involved in sharing benefits from collecting non-timber products and managing the forest.

Age of household heads: According to Sharaunga and Mudhara (2018), older household heads are more likely to participate in agricultural projects because of the lower opportunity cost of their time compared to younger people. Dolisca et al. (2006) point out that different age groups are interested in different forms of collective action. Specifically, younger farmers in Haiti are willing to contribute their labour in forestry activities and participate in decision making while older farmers are more interested in collecting forest resources.

Education and training: Farmer adoption of new technology and management practices is generally associated with their knowledge and level of education. Dolisca et al. (2006) pointed out that higher literacy levels encourage farmers to take part in community action groups. Lestari, Kotani, and Kakinaka (2015) show that highly educated household heads had more inclined to participate at a higher level. When investigating the relationship between different household members, education and participation, Lise (2000) found that participation increases when the average education level of households decreases and the education of the respondent increases. Conversely, Khalkheili and Zamani (2008) found a negative correlation between educational background and farmer participation in collective action. A possible explanation for this is that low education levels may prevent households from obtaining off-farm jobs, thus they tend to concentrate on farm activities including irrigation.

Household livelihood: Farmers whose livelihoods mainly are reliant on irrigated agriculture would be expected to invest more heavily in activities to secure agricultural production than those less dependent on irrigated farming. An empirical study by Muchara et al. (2014) indicates that the level of income generated from irrigated farming motivates farmers to engage in irrigation activities. Dependence on natural-resource-based incomes is also associated with farmer participation in collective action outside the irrigation sector (Dietz, Ostrom, & Stern, 2003; Dolisca et al., 2006; Lise, 2000). Moreover, Mendoza (cited in Khalkheili & Zamani, 2008) determined that farmers are not likely to be interested in participation when they have a family-owned business and spend more time on off-farm work. An interesting study by Vandersypen et al. (2008) in Mali indicates that economic and institutional reforms compel farmers to be away from their plots to pursue non-agricultural employment and consider rice farming as a secondary occupation. Only half of these part-time farmers undertook water management while the remainder used waged labourers -- who have little incentive to engage in collective action -- to carry out irrigation.

Farm size and irrigated area: Arun et al. (2012) found that households with bigger farms are more likely to put more effort into ensuring reliable water supply to their farm. Muchara et al. (2014) also showed a positive relationship between household irrigated land area and collective participation in irrigation management.

(iii) Institutions and governance structure

Institutions and governance structure are identified as important factors affecting collective action in a well-known paper by Ostrom (1990). The impact of institutions and governance structure was explored through different aspects, including the control of farmers in organisations; the existence of governance policies or operational rules that provide a legal framework for participation; and the capacity of the leader or authority.

Reform of institutions or the governance structures for water management has been emphasised in many theoretical and empirical studies as a critical driver of farmer participation. Research by Araral (2009) finds that collective action is more likely to be undertaken in irrigation systems that are under the effective control of WUGs. Moreover, the existence of external impacts, such as government policies, create a good environment for cooperative behaviour. Fujiie et al. (2005) show that the provision of a special incentive from the National Irrigation Administration to Irrigation Associations in the Philippines led to a higher degree of cooperation in irrigation associations. Coulibaly-Lingani et al. (2011) indicate that the adequacy of government policy has a positive and significant impact on the involvement of farmers.

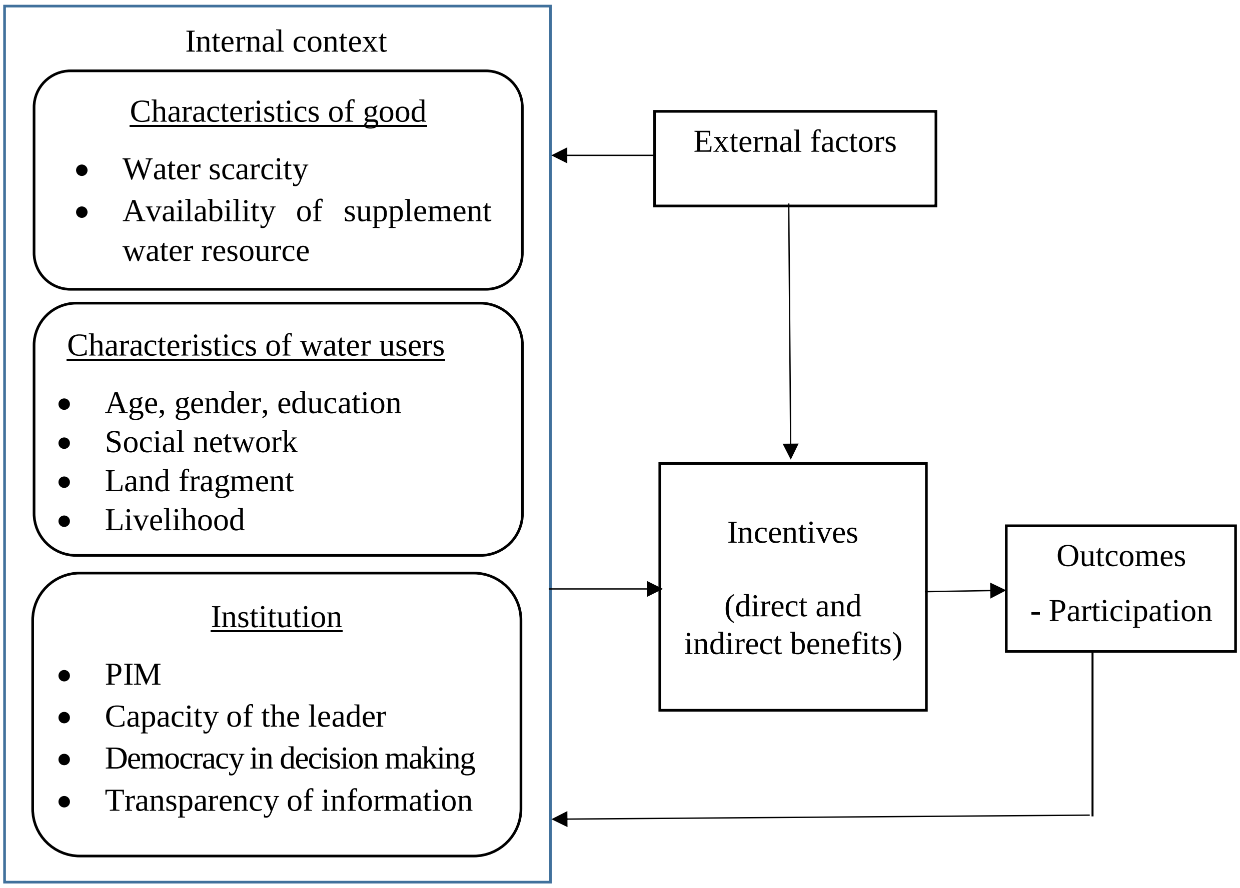
Several scholars have focused on the relationship between farmer perceptions of institutions/governance structures and their engagement with collective action. Khalkheili and Zamani (2008) found that farmer attitudes toward PIM and the personnel of water management and service-related organisations affected their participation decisions. Similarly, Muchara et al. (2014) found that farmers who perceive irrigation committees as effective are more likely to participate in irrigation management. Moreover, enforcement of working rules to solve conflicts between water users and the frequency of water management meetings had a positive effect on farmer participation.

The role of leaders in organising collective action to manage irrigation systems is evident. A study by Nagrah et al. (2016) found that the education level of leaders was positively associated with the proportion of farmers who pay water fees, vote in elections, and attend meetings. Fujiie et al. (2005) indicate that a higher quality of staff in local water management agencies accelerates cooperation in irrigation associations. However, although Meinzen-Dick et al. (2002) suggest that the capacity and influence of leaders do impact on the establishment of formal associations of water users, that alone is not significant in explaining farmer participation in maintenance and lobbying activities.

In general, considerable debate exists between scholars on the factors that facilitate the involvement of people in managing irrigation systems. Scholars disagree on the direction, magnitude and significance of these factors. The variety of results in the literature reflects the different contexts in which studies have been conducted and the different ways in which farmer participation and its determinants are measured. Some studies focus on separate activities such as labour contribution, fee payment, and making decisions, while others synthesise groups of activities to estimate participation. However, the importance of certain determinants of farmer participation -- the existence of institutions supporting the involvement of water users, the capability of leaders, the condition of the water resource, and the dependence on irrigated farming -- are beyond dispute.

3.3. Conceptual framework and research hypotheses

The preceding literature review suggests that collective actions in managing CPR are determined by three main factors: the condition of the CPR; the characteristics of resource users; and the institutional and governance structure. This fits with the relationship between "Context" and "Action arena" in Ostrom's well-known institutional analysis and development framework (Ostrom, 1990). Some scholars (Araral, 2009; Coulibaly-Lingani et al., 2011; Muchara et al., 2014) have adopted Ostrom and her coauthor's approach (1994) to build a conceptual framework of the factors that influence collective action outcomes in managing common-pool resources. We build on these approaches to develop a conceptual framework for analysing collective irrigation management in the Nam Thach Han irrigation scheme, presented in Figure 3.1.



Adapted from Ostrom et al. (1994) and Araral (2009)

Figure 3. 1. Conceptual framework to analyse the determinants of farmer participation

This framework suggests that farmer participation in irrigation management is driven by incentives which in turn are defined by the context that they face. Incentives refer to direct and indirect benefits that farmers or groups receive when taking part in collective action (eg. more timely water supply, better social networks and higher social prestige). The internal context that farmers face includes (i) the characteristics of the irrigation system, (ii) the attributes of farmers who use the irrigation system and (iii) institutional characteristics of local water management organisations. Both internal factors and farmer incentives are governed by external factors such as the legal framework and the market for crops. Reversely, internal factors combined with external factors create incentives for farmers to become involved in irrigation management.

All households in our study site are under a common legal framework or, in other words, the same external environment. Therefore, we concentrate on internal factors only and propose three sets of hypotheses related to the institutional factors of agricultural cooperatives, water resource characteristics, and water user characteristics.

(H1) Water user hypotheses

(H1a) Households with a higher level of land fragmentation participate more in irrigation management.

When households have plots scattered in different areas and which are distant from home, they are more inclined to spend more time to take care of their plots in comparison with others. Thus, they tend to be more active in irrigation management to secure irrigation water for their plots.

(H1b) Farmers with a higher level of "social networks" participate in irrigation management more than other farmers.

A farmer's social network is an aspect of social capital which is found to have a strong connection with participation in collective actions (Bisung, Elliott, Schuster-Wallace, Karanja, & Bernard, 2014; Miao et al., 2015). The social network is measured by the number of organisations that farmers are members of. Farmers with broader social networks tend to be more active in community activities because of their awareness of the ensuing benefits that come and their sense of responsibility toward collective actions. Therefore, we hypothesise that farmers with a broader social network are more likely to participate in irrigation management.

(H1c) Farmers who are more dependent on rice farming are more active in irrigation management.

Water is an important input for rice farming and strongly impacts on rice yield. Therefore, farmers more reliant on rice farming tend to be more concerned about water issues to secure their income. We expect that these farmers will be more active in irrigation management.

(H2) Institutional hypotheses:

(H2a) Farmers in Agricultural Cooperatives (ACs) included in the PIM project are more likely to participate in irrigation management than farmers in other ACs.

A PIM project may affect farmers' perceptions of, and behaviours toward, collective actions of irrigation management at large. Therefore, we predict that farmers living in PIM ACs will actively participate in irrigation management to a greater degree than other farmers.

(H2b) Farmers who have a positive perception of the AC institution for participation are more likely to participate than other farmers.

Farmer perceptions of the AC institution may explain their behaviour towards collective action. Two dimensions of AC institutions are used to investigate this relationship: information transparency and democracy in decision-making. Information transparency refers to the extent to which farmers can access information on irrigation schedules, maintenance schedules, financial contributions, AC funds and expenditure, and sanctions. Democracy in decision-making is measured by whether farmers believe they have a strong impact on AC decisions.

This hypothesis based on field-level observation that farmers are more likely to believe that they can strongly influence decision-making when they think that this process has not been captured by elites. As long as this is the case, they will believe that their participation may provide benefits, this in turn creates an incentive for their participation. We, therefore, test the hypothesis that when farmers believe that they have a strong impact on AC decisions, they are more likely to be involved in irrigation management activities.

Transparency is the core element of second-generation institutional reforms (Kaufmann & Bellver, 2008). De Stefano, Hernández-Mora, López-Gunn, Willaarts, and Zorrilla-Miras (2012) argue that information transparency can facilitate participation and collective action by stakeholders in water governance. They explain that transparency refers to stakeholders' accessibility to necessary information which allows them to make informed contributions to decision-making, the first step on the public participation ladder[17] (De Stefano et al., 2012). Therefore, we expect that information transparency within ACs also creates a good environment for farmer participation.

(H2c) Farmers with a positive perception of the capacity of AC leaders and irrigators are more likely to participate in irrigation management than other farmers.

The quality of leaders is evaluated by education level, while the quality of irrigators is measured by fairness in water allocation. When farmers think that the leader and irrigators have good capability and responsibility, they will have more trust in the effectiveness of collective actions and thus will participate more in irrigation management.

(H3) Water resource condition hypotheses:

(H3a) Farmers using supplementary water sources, such as pumps and/or boreholes, participate in irrigation management less than other farmers.

The existence of supplementary water sources, such as boreholes or pumps, means that farmers are not entirely reliant on the surface irrigation system. Therefore, we expect that farmers with supplementary water sources will be less committed to collective actions.

(H3b) Farmers in ACs located further from water sources are more likely to participate in irrigation management than farmers in ACs closer to water sources.

[17] The higher steps in the public participation ladder are consultation and active involvement.

The location of ACs along canals may impact water availability. Theoretically, water is normally plentiful in the head and scarce in the tail. Thus, we expect that farmers in the middle and the tail sections will be more involved in irrigation management than those in the head.

(H3c) Farmers in ACs sharing hydraulic boundaries with adjacent ACs are less likely to be involved in the activities of ACs.

One important principle for the success of WUGs is that they are organised within the hydraulic boundaries of irrigation schemes (World Bank, 2003). With this principle, members of WUGs are clearly defined. Therefore, it is easier for WUGs to call for engagement and coordination when members are clear about who they need to cooperate with. Such an arrangement helps to reduce disputes between ACs and farmers.

In Nam Thach Han irrigation system, most ACs are served exclusively by one or more second-level canal(s) while some ACs have to share second-level canals; we refer to this as 'shared hydraulic boundaries'. We contend that the sharing of hydraulic boundaries (sharing second-level canals) hinders collective action in irrigation management.

3.4. Data and methods

3.4.1. Data

This chapter makes use of data from the household survey. The household survey comprised seven sections, this chapter derives information from several of these sections. Specifically, Section 3, which focuses on the involvement of farmers in irrigation management, provides information to estimate farmer participation. Some information related to ACs is derived from Section 4 where farmers were asked to evaluate different aspects of these institutions. Information on household and farm characteristics are extracted from Section 1 and Section 5. The sample size for the data used in this chapter is 391 households of which 182 households were from ACs included in the PIM project and 209 households were located in non-PIM ACs. As detailed in Chapter 2, sample weights are used to reduce sampling bias.

3.4.2. Principal component analysis to derive farmer participation indices

This section will start by outlining the main arguments supporting the use of principal component analysis (PCA) and then describe the general procedure for generating composite indices. Finally, a modified procedure for computing farmer participation indices for this study will be presented.

Why use principal component analysis?

Farmers can participate in irrigation management in different ways. We recorded farmer participation using a list of twelve key activities. These vary from contributing labour and funds for operation and maintenance, attending meetings and getting involved in the decision-making process, to monitoring infrastructure, water delivery and maintenance. Farmers were asked about the frequency of their participation in the activities over the last five years since the PIM project finished. A four-point Likert scale from 1 to 4, corresponding with participation never, rarely, sometimes or always, was used to measure the frequency of farmer participation. We then developed indices of participation based on the frequency of participation in these activities. A simple summation of participation frequency, to report the total number of activities in which farmers participate, is not suitable since many activities are clustered or mutually correlated. For example, farmers who participate in meetings are more likely to engage in water-related discussion than those who do not attend meetings. Farmers who often monitor water delivery are more likely to report damages to irrigation infrastructure or illegal water withdrawal. Therefore, we needed to apply an appropriate technique to reduce the number of participation variables.

Theoretically, there are two methods to reduce a group of correlated variables to a smaller set of components that account for the variance of the original variables. They are Principal Component Analysis (PCA) and Factor Analysis (FA). PCA examines the variance in observed variables in terms of linear combinations of original data. It aims to find optimal ways of deriving a smaller number of components by combining variables. On the other hand, FA explores the structure underlying such variables and measures scores of latent factors. Given that the objective is to generate participation indices representing the variation of a large number of activities in which farmers participate, PCA is a more appropriate method for this study.

Generation of a composite index using PCA

The objective of PCA is to find a way to condense information about Q original variables x_1, x_2,… x_Q into M uncorrelated indices or principal components PC_1, PC_2,… PC_M (M<Q) with a minimum loss of information. PCA results are derived from using the correlation matrix, or its standardised form – the covariance matrix. In this study, the correlation matrix is used to avoid the undue influence of variables with large variance on the principal components (Saisana & Tarantola, 2002). The procedure of PCA can be illustrated as follows:

In the first step, Q principal components are generated as a combination of the original Q variables. Such situations could be represented as:

$$PC_1 = \beta_{11}x_1 + \beta_{12}x_2 + \cdots + \beta_{1Q}x_Q$$
$$PC_2 = \beta_{21}x_1 + \beta_{22}x_2 + \cdots + \beta_{2Q}x_Q$$
$$\vdots$$

$$PC_Q = \beta_{Q1}x_1 + \beta_{Q2}x_2 + \cdots + \beta_{QQ}x_Q$$

where PC_i is a set of Q principal components that are individually regressed against Q original variables x_j; and β_{ij} are weights/loadings for the i^{th} principal component and the j^{th} variable.

The loadings (β_{ij}) for each principal component are given by the eigenvectors of the correlation matrix of original variables. The variance (λ_i) for each principal component is given by the eigenvalue of the corresponding eigenvector.

In the second step, the first M principal components that preserve the majority of variance of original variables are selected. As a rule of thumb, principal components are chosen only if eigenvalues are greater than one, the contribution of each principal component to the explanation of overall variance is more than 10% (Joint Research Centre-European Commission, 2008). Applying this rule of thumb, we retain M components as follows:

$$PC_1 = \beta_{11}x_1 + \beta_{12}x_2 + \cdots + \beta_{1Q}x_Q$$
$$\vdots$$
$$PC_M = \beta_{M1}x_1 + \beta_{M2}x_2 + \cdots + \beta_{MQ}x_Q$$

Where $PC_1, \ldots, PC_M$ are retained, principal components with eigenvalues greater than 1, $M<Q$ and M can be as small as 1. In each retained principal component, a group of variables having higher loadings which reveal the underlying structure of the data set are called dominant variables. In other words, based on the magnitude and pattern of loadings in retained principal components, we can cluster variables into sub-sets, and the retained principal components are interpreted and named as different dimensions of the data set.

Finally, the PC score of each retained component is calculated as the sum of all Q original variables weighted by loadings in eigenvectors. Depending on the measurement unit of original variables, the value of PC score can range from $-\infty$ to $+\infty$. An observation with a higher value of a PC score means that it has a higher level of an index than other observations.

These PC scores can be normalised for the convenience of analysis and interpretation. This PC score will be referred to as a composite index in the following sections.

Procedure to compute Participation Index by PCA

First, we want to generate a composite index of overall participation to measure the overall level of farmer participation. Therefore, I use PCA to extract the first component from all original variables and denote the PC score from this component as the overall participation index.

Second, we want to estimate some sub-indices of farmer participation representing different forms of participation. PCA enables the detection of underlying structures of correlated variables which reflect different dimensions of farmer participation. Certain studies have developed several participation indices by using PCA to extract several first components (Coulibaly-Lingani et al., 2011; Miao et al., 2015). However, if we use PCA to directly extract indices from several first components, the PC scores will take into account the loadings of all original variables. As we do not want the overlap between the extracted indices, we apply two rounds of PCA.

In the first round, PCA is used to extract groups of original variables presenting different dimensions of farmer participation. In the second round, PCA is applied one more time on a sub-set of original variables. Only the first principal components explaining the largest proportion of variance is retained to generate a composite index of a particular dimension of farmer participation in irrigation management.

3.4.3. Regression analysis to determine factors affecting farmer participation

The retained participation indices from PCA for individual sampled households were used as dependent variables in OLS regression models to evaluate the associations between participation indicators and their determinants (including institutional factors, water resource factors and water user characteristics). The empirical model was developed as follows:

$$PI_{\mathrm{i}} = \alpha_0 + \sum_{l} \alpha_l \, watuser_{li} + \sum_{j} \alpha_{\mathrm{j}} inst_{\mathrm{ji}} + \sum_{k} \alpha_k watcond_{ki} + \varepsilon_i$$

where PI_i is the participation index of household ith, *watuser* is farmer and household-related variables, *inst* is the institutional-related variable, and *watcond* refers to variables related to water resource conditions. α_0, α_l, α_j , α_k are the parameters to estimate, and ε is the error term.

The first group of variables (*watuser)* include *main farmer's age*, *main farmer's education*, *average education of household members*, *number of rice plots*, *share of rice farming income*, and *social network*. In Asian countries where several generations live in one house, the oldest male person in a family is normally head of the household. However, their age and health may prevent them from being fully involved in farming activities and making decisions on farming activities. Therefore, this study uses information provided by 'main farmers' who are defined as the person who devotes the greatest time in farming activities in his or her family. We do not include the total area of rice cultivated in the model because this variable is strongly correlated with *number of rice plots*. Moreover, plots are normally located in different parts of the irrigation system. Therefore, *number of rice plots* both reflect farm size and the scatter of rice land. *Social network* is an index based on the number of local groups that household members join, the number of executive positions they hold, and the number of close friends they have.

The institutional variables (*inst*) include *PIM*, *information transparency*, *farmer influence in AC decisions*, *qualification of AC leader*, and *fairness of water deliverers*. PIM is a dummy variable to distinguish households in PIM ACs (PIM=1) and those in non-PIM ACs (PIM=0). *Information transparency* is an index measuring the accessibility of AC information. We use PCA to generate this index from farmer evaluations of the availability of irrigation service information, including the irrigation schedule, maintenance schedule, farmer contributions, AC revenue and expenditure, and fines for farmers who violated rules.

The third group of variables (*rescond)* consists of locations of ACs along canals, AC hydraulic boundary conditions, and household irrigation indicators. ACs located in the head and tail of first-level canals are coded as *First head* and *First tail* respectively while those in the middle of first-level canals are bases cases. Moreover, two variables, *Main middle & First head* and *Main tail & First tail,* distinguish ACs located in these extreme locations. The former indicates ACs located in the middle of the main canal and head of the first-level canals which is the most favourable location amongst sampled ACs. The latter represents the most disadvantaged location as it is at the tail of the main canal and the tail of the first-level canal. Two other dummy variables, namely *involvement in water dispute* and *using supplement irrigation water,* are indicators of household irrigation issues.

Sample weights and robust standard errors were adopted to obtain more precise results. Moreover, post estimation tests were done to test the model specification, including multicollinearity, normality of residuals, and residual heteroscedasticity.

3.5. Results and discussion

3.5.1. Selected descriptive statistics for sampled households

This section will provide some descriptive statistics for sample households, including a comparison between households included and not included in the PIM project. Table 3.1 shows that on average, main farmers are around 53 years old and have 8.3 years of formal education. No differences in age and education are identified between PIM and non-PIM main farmers. However, non-PIM households seem to be more dependent on rice farming with a higher contribution of rice farming in total household income (25% vs. 17%) and a higher number of rice plots (3.5 plots vs. 2.9 plots). Non-PIM households seem to have weaker social networks, having a markedly lower average social network index score (-0.21 vs. +0.24).

Table 3. 1. Descriptive statistics for sampled households

Variables	Total (n=391)	PIM (n=182)	Non-PIM (n=209)	Test for difference
Water user characteristics				
Main farmer's age (year)	53.4	53.8	53.1	0.49
Main farmer's education (yrs in school)	8.3	8.3	8.4	0.61
Average education of other members (yrs in school)	9.4	9.5	92.	0.28
Number of rice plots (plot)	3.2	2.9	3.5	0.00***
Share of rice farming income	0.21	0.17	0.25	0.00***
Institutional factors				
Information transparency in AC (index)	0.0	0.0	0.0	0.96
Farmer strongly influence on AC decisions (1=Yes; 0=No)	39.9	33.5	45.5	0.02**
Adequate qualification of AC leaders (1=Yes; 0=No)	60.6	64.8	56.9	0.11
Fairness of water deliverers (1=Yes; 0=No)	72.4	78.0	67.5	0.02**
Irrigation variables				
Using supplement irrigation water (1=Yes, 0=No)	0.52	0.68	0.39	0.00***
Involvement in water disputes (1=Yes, 0=No)	0.16	0.18	0.15	0.55
First head (1=Yes; 0=No)	0.25	0.19	0.31	0.01***
First tail (1=Yes; 0=No)	0.37	0.42	0.33	0.06**
Main middle & First head (1=Yes; 0=No)	0.09	0.00	0.16	0.00***
Main tail & First tail (1=Yes; 0=No)	0.19	0.22	0.16	0.15
Shared hydraulic boundary (1=Yes, 0=No)	0.43	0.38	0.47	0.07*

Note: *** p<0.01. ** p<0.05, * p<0.1

The majority of farmers have a positive impression of the quality of AC leaders and water deliverers. Moreover, more than one-third of respondents reported the strong influence of farmers on AC decisions. More than half of households reported that information related to the irrigation service is always available while less than 10% of households claimed this was difficult to access. A t-test and pair-wise test of the difference in farmer perception towards the AC institution and AC personnel shows significant differences between households inside and outside the PIM project, with PIM households less likely to believe that they can strongly influence AC decisions.

Five out of eleven ACs installed pump stations to supply water to areas that often suffer water shortages in the Summer-Autumn season or where NTHIME cannot provide irrigation. Moreover, some households have installed private pumps or boreholes. Therefore, more than half of the sample use supplementary water sources as well as gravity-based irrigation. 68% of households in PIM ACs are using supplementary water, while only 38% use these sources in non-PIM ACs. This reflects the difficulties in accessing gravity-based irrigation in PIM ACs. Sixteen percent of the interviewed households reported that they experienced water disputes during the last 12 months. This data on the incidence of water disputes provides additional information on water accessibility for sample households.

The sample does not include an equal number of PIM and non-PIM ACs at each location, so it is not surprising that the proportion of PIM/non-PIM households vary at different locations. PIM households are concentrated more in the tail end of canals than non-PIM households (42% vs. 33%) while non-PIM households account for a higher proportion in the head (31% vs. 19%). Moreover, the proportion of households under ACs with shared hydraulic boundary is 43%.

3.5.2. Frequency of farmer participation in irrigation management activities

The intensity of farmer involvement in 12 activities related to irrigation management was recorded using a 4-point Likert scale and is summarised in Table 3.2. The most commonly reported activity is attendance at meetings related to water management issues. The general meeting is the most important meeting and is held once a year; most farmers (78%) always attend, while 60% report that they participate regularly in other irrigation-related meetings during the rice-growing seasons. However, simply attending meetings does not necessarily mean that farmers can affect decision making. 28% of farmers reported that they often join in the discussion at meetings and 21% raised water-related issues in the meeting.

Fund contribution is another activity that attracts engagement from a considerable proportion of farmers. Over a quarter of farmers (29%) reported that they did not contribute money while 40% always contributed. Since the promulgation of Decree 115, which exempted farmers from water charges, farmers do not have to pay irrigation fees to Nam Thach Han IME but they still have to pay on-farm irrigation fees to ACs. However, the on-farm irrigation fee is relatively low and insufficient to cover the cost of regular maintenance and repairs. ACs cannot set on-farm irrigation fees higher than the ceiling level set by the Provincial People's Committee. Therefore, apart from on-farm irrigation fees, ACs sometimes call for extra monetary contributions for irregular operation and maintenance (O&M) costs. This may include costs for constructing or lining third-level canals, or for urgent circumstances, such as droughts or floods, when extra funds are needed to operate pump stations or to repair flood protection dykes.

Table 3.2. Frequency of farmer participation in activities related to irrigation management

No.	Variable	Level of participation (%)		
		Never & rarely	Sometimes	Always
1	Labour contribution for regular maintenance	77.0	14.1	8.9
2	Labour contribution for irregular maintenance	78.0	15.9	6.1
3	Fund contribution for irregular O&M cost	28.6	31.2	40.2
4	Attendance in General Meeting	4.9	17.7	77.5
5	Attendance in water-related meeting	7.4	33.0	59.6
6	Discussing irrigation-related issues in meetings	26.3	46.0	27.6
7	Raising irrigation-related issues in meetings	35.8	43.2	21.0
8	Enquiry about AC's expenditure and revenue	55.2	26.3	18.4
9	Reporting illegal water withdrawal	70.1	21.5	8.4
10	Reporting damage and leaking	66.2	17.1	16.6
11	Monitoring water delivery	73.4	12.0	14.6
12	Monitoring repair/maintenance	77.0	16.4	6.7

Reporting on-farm irrigation issues is a good way to help ACs recognise and solve irrigation problems on time and efficiently. Most farmers (98%) directly contacted representatives of the Executive Board's member of ACs or the irrigation team's members when they faced irrigation-related problems in their plots. However, a low ratio of farmers reported that they often informed ACs about illegal behaviour, such as illegal water withdrawal (8%). There are several possible explanations for these low percentages: the low incidence of these issues, the avoidance of potentially souring relationships with other farmers in the community, or a general lack of concern about these issues.

Labour contribution is a relatively uncommon participation activity. The low reward for contributing labour and the availability of more profitable work may explain why few farmers provide their labour for irrigation maintenance tasks. More than half of all farmers never participate and only 9% always provide labour for regular maintenance and 6% for irregular maintenance. Moreover, only two out of 11 ACs require compulsory labour contributions for canal dredging. Normally, there is at least one irrigation team that is paid and which specialises in delivering water and cleaning and repairing canals and other structures in the irrigation system. Moreover, ACs encourage participation of farmers and local socio-political groups (e.g. Women’s Union, Farmer’s Union, Youth’s Union) in dredging some canals via tenders. For unexpected situations, such as broken canal dykes, flood and droughts, ACs call for emergency voluntary labour contributions to protect irrigation systems or dredge irrigation and drainage canals.

In general, the level of participation in irrigation management is not homogenous amongst farmers. Attending meetings is the most common practice while labour contribution and monitoring-related activities are generally undertaken by only a minority of farmers. The information on farmer participation in the above twelve activities is used as an input in PCA to generate participation indices.

3.5.3. Participation indices with PCA

The composite index of overall participation is estimated by extracting the first component from twelve activities related to irrigation management by PCA. The first component explains 41% of the variance in the data set. The loading for individual activities of the first component is present in Table 3.3. It can be seen that activities related to monitoring have a higher loading which indicates the dominant role of these activities in explaining data variation. Some activities, such as attending the general meeting and enquiring about the AC's financial information, have the lowest loading.

The Bartlett Test of Sphericity shows that we can reject the null hypothesis that the original variables are uncorrelated at the 0.01 level of significance. Moreover, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy is 0.81 and the KMO value of all individual variables is greater than 0.6. The result of these tests suggests that the data is appropriate for PCA. The PC score generated from the first component of 12 variables is called the composite participation index.

Table 3. 3. PCA loading for composite participation index

Variable	Overall participation
Labour contribution for regular maintenance	0.24
Labour contribution for irregular maintenance	0.23
Fund contribution for irregular O&M cost	0.24
Attendance in General Meeting	0.20
Attendance in water-related meetings	0.27
Discussing irrigation-related issues in meetings	0.28
Raising irrigation-related issues in meetings	0.28
Enquiry about AC's expenditure and revenue	0.15
Reporting illegal water withdrawal	0.37
Reporting damage and leaking	0.37
Monitoring water delivery	0.36
Monitoring maintenance	0.37
Eigenvalue	4.70
Percentage of variance explained	39.20

Moreover, we are also interested in different dimensions of participation, thus we explore clusters of these activities. To examine whether twelve participation indicators (activities) are clustering into several groups, the first round of PCA with varimax rotation was conducted for all twelve participation indicators. Only components with eigenvalues greater than one and a percentage of variance over 10% were considered. As a result, we retain the three first principal components as shown in Table 3.4.

Table 3. 4. PCA loading for retained components

Variable	Component 1	Component 2	Component 3
Labour contribution for regular maintenance	0.07	0.03	**0.50**
Labour contribution for irregular maintenance	0.08	-0.04	**0.55**
Fund contribution for irregular O&M cost	0.06	0.12	**0.38**
Attendance in General Meeting	-0.12	**0.40**	0.20
Attendance in water-related meetings	-0.09	**0.49**	0.18
Discussing irrigation-related issues in meetings	0.04	**0.53**	-0.13
Raising irrigation-related issues in meetings	0.07	**0.50**	-0.14
Enquiry about AC’s expenditure and revenue	**0.26**	0.17	**-0.41**
Reporting illegal water withdrawal	**0.42**	0.09	-0.01
Reporting damage and leaking	**0.46**	-0.01	0.06
Monitoring water delivery	**0.48**	-0.06	0.07
Monitoring maintenance	**0.52**	-0.03	0.01
Eigenvalue	4.70	1.63	1.29
Percentage of variance explained	39.20	13.57	10.76

Table 3.4 shows loadings of original variables in each principal component, the eigenvalue, as well as the proportion of variance explained by each component. Any original variables with loadings greater than |0.2| are considered as dominating variables that explain most of the variance in the original variables, and which strongly correlate with other variables, contributing to a principal component. In component 1, five variables are dominant and all concentrate on monitoring activities. Component 2 reveals cross-correlation between variables associated with farmer involvement in making decisions while variables mainly focusing on input mobilisation for maintenance are dominant in component 3. Although *enquiry about AC's expenditure and revenue* has a high loading in both component 1 and 3, we decide to group it in component 1 due to the similarity of this activity with other dominant activities in component 1 and due to its positive sign as well.

PCA, then, is applied one more time for each cluster of original variables, namely *Participation in monitoring*, *Participation in decision making* and *Participation in input contribution*. The result of the second round of PCA is presented in Table 3.5.

Table 3. 5. PCA loading for activities in three dimensions of irrigation management

Variable	Par. in monitoring	Par. in decision making	Par. in input mobilization
Labour contribution for regular maintenance			0.63
Labour contribution for irregular maintenance			0.63
Fund contribution for irregular O&M cost			0.46
Attendance in General Meeting		0.38	
Attendance in water-related meetings		0.51	
Discussing irrigation-related issues in meetings		0.55	
Raising irrigation-related issues in meetings		0.54	
Enquiry about AC's expenditure and revenue	0.21		
Reporting illegal water withdrawal	0.47		
Reporting damage and leaking	0.49		
Participation in monitoring water delivery	0.49		
Participation in monitoring maintenance	0.51		
Eigenvalue	3.18	2.24	1.19
Percentage of variance explained	63.66	56.03	64.75

The Bartlett and KMO Test for individual clusters of variables all satisfied the assumptions that original variables are correlated and the sampling size is adequate, with p-values lower than 0.01 and KMO values equal or greater than 0.5. Thus, the adoption of PCA for clusters of variables is appropriate. The principal scores generated from the first components of three clusters of variables are called participation indices in monitoring, decision-making, and input contribution respectively.

3.5.4. Determinants of farmer participation

This section will analyse the results of the OLS regression of factors affecting farmer participation. The results of the multiple regressions are presented in Table 3.6 with a summary of findings relating to each hypothesis in Table 3.7. Moreover, the post estimation test indicates that the model specification is appropriate. The individual and overall VIF value of all independent variables are lower than 10. This means multi-collinearity does not exist between independent variables. The Kolmogorov-Smirnov test for normality on the residuals from the regression models shows that all models, except model 3 (factors affecting farmer participation in decision making), do not violate the normality assumption. However, with a sample size of over 200 households, the central limit theorem ensures that the residual distribution approximates normality. Heteroscedasticity in residuals is managed by the robust standard error.

Table 3. 6. Regression analysis to explain variation in farmer participation

Variable	Overall participation	Participation in monitoring	Participation in decision making	Participation in contribution
Main farmer's age	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)	0.02*** (0.01)
Main farmer's education	0.05*** (0.02)	0.04** (0.02)	0.04* (0.02)	0.03** (0.02)
Average education of HH's members	0.00 (0.01)	0.00 (0.01)	0.01 (0.01)	-0.01 (0.01)
Number of rice plots	0.10*** (0.04)	0.05 (0.04)	0.15*** (0.04)	0.06 (0.05)
Share of rice farming income	0.26 (0.32)	0.49 (0.32)	0.12 (0.39)	-0.28 (0.31)
Social networks	0.07 (0.06)	0.06 (0.06)	0.06 (0.06)	0.04 (0.06)
PIM	0.32* (0.15)	0.11 (0.16)	0.40*** (0.15)	0.39*** (0.14)
Information transparency in AC	0.12* (0.06)	0.15** (0.07)	0.10 (0.07)	-0.01 (0.06)
Farmer influence on AC decisions	0.23* (0.13)	0.01 (0.14)	0.47*** (0.12)	0.18 (0.15)
Adequate qualification of AC leader	0.44*** (0.14)	0.47*** (0.16)	0.28** (0.11)	0.22* (0.13)
Fairness of water deliverers	-0.11 (0.13)	-0.28* (0.15)	0.07 (0.14)	0.15 (0.13)
Using supplementary irrigation water	-0.20 (0.13)	-0.13 (0.14)	-0.12 (0.12)	-0.29** (0.13)
Involved in water disputes	0.22 (0.14)	0.12 (0.14)	0.20 (0.12)	0.28* (0.15)
First head	1.39*** (0.16)	1.35*** (0.17)	1.29*** (0.18)	0.38** (0.17)
First tail	1.77*** (0.15)	1.81*** (0.14)	0.83*** (0.15)	1.26*** (0.17)
Main middle & First head	0.37* (0.20)	0.02 (0.21)	0.11 (0.22)	1.19*** (0.19)
Main tail & First tail	-0.70*** (0.17)	-0.79*** (0.18)	-0.12 (0.17)	-0.70*** (0.19)
Sharing hydraulic boundary	-0.67*** (0.13)	-0.46*** (0.15)	-0.70*** (0.15)	-0.58*** (0.12)
Intercept	-3.01*** (0.47)	-2.38*** (0.48)	-2.75*** (0.51)	-2.02*** (0.44)
R^2_{adj}	0.46	0.41	0.27	0.44

Notes: * p<0.10, ** p<0.05, *** p<0.01; standard errors in parentheses

Table 3. 7. Summary of findings for each hypothesis

	Expected impact	Finding			
		Overall	Monitoring	Decision	Contribution
H1a. Land fragment	+	+	+	+	NS
H1b. Social network	+	NS	NS	NS	NS
H1c. Dependence on rice farming	+	NS	NS	NS	NS
H2a. PIM	+	+	NS	+	+
H2b. Positive perception of AC institution for participation	+	+	+	+	NS
H2c. Positive perception of AC personnel	+	+	+/-	+	+
H3a. Supplementary water sources	-	NS	NS	NS	-
H3b. Distance from water sources	+	U	U	U	U
H3c. Sharing a hydraulic boundary	-	-	-	-	-

Note: + (-) means significantly positive (negative) effects, NS means not significant, U means a U-shape relationship

We found that water resource conditions at AC level have strong effects on farmer participation. Notably, the location of ACs along canals is significantly associated with differences in the level of farmer participation. Contrary to hypothesis H3b, farmers located in the head of first level canals had significantly higher participation indices than farmers in the middle section. A similar situation was reported by Reddy and Reddy (2005) who found that farmers in the head participated more in contribution than those in the middle and tail reaches. However, in line with hypothesis H3b, we also find that farmers in the tail of first-level canals are more likely to engage in all forms of collective action in comparison with households in the middle section. Specifically, farmers in the tail section have mean participation index scores that are 1.8, 1.8, 0.8 and 1.3 standard deviations higher for overall participation, monitoring, decision-making and input contribution respectively, compared to farmers in the middle section. Inequality in water allocation, namely water abundance in the middle section alongside shortages in the tail-end section, could be considered as a driver for farmer behaviour. This result is consistent with the finding in Sharaunga and Mudhara (2018) that farmers who have plots located in the tail of canals are more likely to participate in irrigation maintenance than those located in the middle. These results indicate that farmer participation in the middle section is worse than in the head and tail sections.

For the two *extreme* locations, we observed opposite behaviours. Households located closest to the headwork (*Main middle & First head*) are more likely to have higher indices in terms of overall participation and input contribution. Compulsory labour requirements applied in the AC to which these households belong may explain this difference. In contrast, farmers belonging to ACs located farthest from the headwork (*Main tail & First tail*) are significantly less likely to take part in all forms of participation. This result is consistent with the empirical findings of Bardhan (1993), Uphoff, Wickramasinghe, and Wijayaratna (1990) and Araral (2009). These authors indicate that *extreme* scarcity of water resources do not create incentives for cooperation between water users. Overall, the relationship between AC location and participation appears to take a U shape distribution, with farmers at the head and tail participating more than farmers in the middle. In addition, we note that farmers closest to the headwork participate more and farmers at the extreme tail participate less.

Sharing hydraulic boundaries seem to be an obstacle for cooperation amongst farmers. Farmers in ACs with shared second-level canals are less likely to participate in all forms of irrigation management activities. Leaders of these ACs reported that their ACs have to share responsibilities for cleaning shared second-level canals with adjacent ACs. While ACs in the tail of second-level canals put more effort into maintaining canals and monitoring water delivery along shared canals, ACs in the head are less likely to devote resources to these activities. Some households withdraw water illegally without fear of being punished by adjacent ACs due to sharing of second-level canals. All of these factors may reduce farmer incentives to join in irrigation management in these ACs.

While water resource issues at AC level explain variation in farmer participation in nearly all dimensions, at the household level, availability of supplementary water tends to reduce input contributions while involvement in water disputes is associated with higher input contribution. In the study site, supplementary water sources include water from AC pump stations or private mobile pumps and boreholes. These water sources are generally closer to farm plots and more reliable than gravity-based water provided jointly by NTHIME and ACs. Therefore, it is understandable that farmers with access to these sources tend to have less incentive to devote time and money to help manage AC irrigation canals. Our results are in line with those reported by Meinzen-Dick et al. (2002) and Nagrah et al. (2016).

Farmers reported that water-related disputes mainly originate from sharing the same water intake point and drainage outlet. These plots are irrigated by water flowing from neighbouring plots and drained by flowing onto low altitude plots and so have to use the same irrigation schedule. However, sometimes farmers do not follow the crop calendar recommended by ACs, as they may be planting different rice varieties or simply busy with other work. Thus, their plots need a different irrigation schedule. Moreover, a small plot size prevents the development of separate irrigation and drainage canals for every plot. As a result, farmers may withdraw water from upstream neighbouring plots and drain water to downstream neighbouring plots in a way which is harmful to adjacent plots.

Nearly all AC institutional factors have a positive impact on the overall participation of farmers while particular institutional aspects are strongly associated with specific forms of participation. Specifically, farmers in PIM ACs have participation indices in decision-making and input contribution that are 0.4 and 0.39 standard deviation higher than those from non-PIM ACs. In other words, they are more likely to be involved in decision-making and input contribution. Farmers in PIM ACs had a chance to learn about the concept of PIM and were encouraged to engage in project activities, especially in decision making, including discussions about irrigation issues such as operational rules, construction, and canal rehabilitation. Moreover, AC staff and some representatives of the Women's Union, and the Farmer's Union in PIM AC participated in several training courses related to the PIM model and operation and maintenance of the irrigation system. These factors may explain the positive impact of the PIM project on farmer participation.

The impact of farmer perceptions of ACs in terms of institutions and personnel significantly correlate with farmer participation. Farmers with a higher evaluation of AC information transparency are more likely to engage in monitoring activities and farmers who believe that farmers have a strong influence on AC decisions are more likely to be actively involved in decision making. Moreover, when farmers think that the AC leaders have adequate qualifications, they are more likely to join in all forms of collective action. In contrast, farmers who believe that water deliverers are fair are less likely to monitor the irrigation service. Water deliverers directly operate the irrigation facility and deliver and allocate water to individual plots. Therefore, it is understandable that farmers pay less attention to monitoring the water delivery service if they trust the fairness of water deliverers.

The regression models show that households with more cultivated plots are significantly more likely to engage in irrigation management, especially monitoring and decision making. By 2015, the number of plots in Quang Tri province fell by 70% (Dinh, 2015) after the promulgation of official dispatch number 1176/UBND by the People's Committee of Quang Tri province about land consolidation on 7th July 2003. The People's Committee selected one AC to do a land consolidation pilot. After the success of that model, the land consolidation campaign was replicated in many ACs. In several ACs, land consolidation has allowed ACs to undertake large field models in which all plots in that field cultivate only one variety of rice, apply one crop calendar, and keep to standardised cultivation practices. However, due to the varied and difficult characteristics of rice plots, some ACs have not completed the land consolidation process. Currently, each household still has approximately three plots in three different locations on average.

Some other household characteristics, including the age and education of the main farmers, are significantly associated with variations in farmer participation. Specifically, different participation indices significantly increase 0.02 to 0.05 standard deviation for each year increase in the age and education of the main farmers. Our Spearman tests showed a significant positive relationship between the main farmers' age and total days spent on rice farming and a significant negative relationship between age and total days spent on off-farm jobs. Younger farmers seem to be busier with off-farm jobs while older farmers spend more time on rice farming. Therefore, older farmers can devote more time than younger farmers to irrigation management.

Overall, most of the independent variables included in the model have contributed to an improved understanding of the variance in farmer participation. The variables explain 46% of the variation in overall farmer participation, 41% for participation in monitoring, 27% for participation in decision making, and 44% for participation in input contribution.

3.6. Conclusions

PIM approaches have been implemented in Vietnam to improve the management of surface irrigation systems and reduce dependence on the government budget. For this approach to be a success, we need to thoroughly understand the factors that accelerate as well as constrain farmer participation in managing local irrigation systems.

Our study of the Nam Thach Han irrigation system shows that attending meetings is the most common form of participation with 78% of farmers always attending the annual general meeting while 60% attend other irrigation-related meetings. 74% report that they always (28%) or sometimes (46%) join in the discussions at these meetings. 40% of farmers always contribute money for irregular maintenance and construction work while 31% sometimes contribute. The proportion of farmers who contribute their time for maintenance work (sometimes/always) is less than 25% of which only 9% of farmers always engage in this activity. Between 7% and 17% of farmers always actively take part in the different monitoring activities while 60% to 77% rarely, if ever, participate.

The descriptive statistics for farmer participation show a similar trend in the variance of farmer participation in different groups of activities (contribution, decision making and monitoring). That result is confirmed by the result of the PCA which divides participation activities into three clusters and which generates participation indices reflecting the level of participation in these three dimensions.

Experience with the PIM project seems to have a positive impact on farmer participation in general and in decision-making and input contribution in particular. A higher farmer evaluation of information transparency and democratic decision-making tends to increase their involvement in monitoring and decision making. Moreover, if they believe their leaders are sufficiently qualified they are more likely to participate in different forms of combined action.

Farmers in ACs located at the tail of first level canals, which normally faces insufficient water, have an incentive for collective action. However, farmers located furthest from the headworks participate less. These farmers may face extreme water scarcity and may feel that they have nothing to gain from participation in irrigation management. We also found that when several ACs share second level canals and supplementary water resources are available, farmer participation in irrigation management is significantly reduced.

Although internal household characteristics such as age, education level of main farmers and the number of plots positively correlate with participation intensity, the magnitude of these effects is relatively small.

These findings suggest that the integration of PIM in irrigation projects can be a good way to accelerate farmer engagement in irrigation management. The quality of AC staff, especially leaders, needs to be emphasised in terms of its importance in affecting farmer participation. The education and knowledge of leaders can be built up through training courses. Along with these courses, finding and developing capacity for the next generation of leaders is another useful strategy to increase the sustainability of ACs. The results also suggest that reform in the governance of ACs toward transparency in information and democracy in decision-making can create fertile ground for the involvement of farmers in AC activities and irrigation management. Improving cooperation between ACs or re-establishing ACs based on hydraulic boundaries may also facilitate participation and improve irrigation management.

The analysis and results described in this chapter contribute to the literature by providing a case study based on survey data from Vietnam; generating composite participation indices for different groups of activities; and using farmer evaluations to measure specific institutional aspects of WUGs (Agricultural Cooperatives in the context of the study site). However, this study also has some limitations mainly due to lack of accurate measurements of the volume of water distributed to individual households.

Chapter 4 - The impact of collective action on the sufficiency and timeliness of irrigation

4.1. Introduction

According to the institutional analysis framework developed by Tang (1992), farmer interaction to solve collective action problems is an important determinant of irrigation performance in community and government-managed systems. These patterns of interaction are affected by the incentives faced by farmers, which in turn are defined by institutional arrangements, irrigation system physical factors, and the socio-economic characteristics of farmers. Institutional arrangements refer to three different levels of rules including constitutional rules, collective choice rules, and operational rules (Ostrom et al., 1994; Tang, 1992). These rules guide the actions taken by farmers, which include constitutional actions, collective choice actions, and operational actions, all of which Ostrom et al. (1994) subsumed under the general heading of collective action. Based on this framework, scholars have investigated the determinants of collective action as well as the relationship between institutional arrangement and irrigation performance.

The literature in this field mainly focusses on the relationship between the *existence* of water user organisations or sets of irrigation management rules and irrigation performance (Abdelhadi, Adam, Hassan, & Hata, 2004; Bastakoti, Shivakoti, & Lebel, 2010; Bhatta, Ishida, Taniguchi, & Sharma, 2006; Huang, 2014; Samad, 2002; Wang et al., 2007). But while collective action carried out by the members of these organisations has a direct impact on irrigation performance, only a few studies focus on the impact of these actions on irrigation management (Mushtaq, Dawe, Lin, & Moya, 2007; Vandersypen, Verbist, Keita, Raes, & Jamin, 2009). Given that the irrigation rules set up under the PIM project are no longer used, it is particularly important to assess whether a higher intensity of collective action can lead to improved irrigation performance.

This chapter seeks to assess whether a higher intensity of collective action in irrigation management increases the probability that farmers will receive sufficient and timely irrigation for rice farming. To answer this research question, we use survey data collected from 355 households and 777 plots receiving gravity-based irrigation in the Nam Thach Han irrigation scheme. The sufficiency and timeliness of irrigation, referred to here as *'irrigation quality'* is assessed at the plot level while collective actions are measured at AC level. A logit model is used to estimate the impact of collective action on the sufficiency and timeliness of irrigation.

The rest of this chapter is structured as follows. The literature review and research hypotheses are presented in section 4.2. Then, in section 4.3, we briefly describe the data and explain the economic models, measurement of variables, and descriptive statistics. An analysis of our results and discussion are presented in section 4.4, followed by conclusions in section 4.5.

4.2. Literature review

4.2.1. Irrigation performance including farmer perspectives

Irrigation performance has been defined variously in journal articles over the last forty years. Lenton (1986) referred to the level of attaining designed objectives, while Abernethy (1989) added further detail to the definition by stating that objectives are measured using several indicators for the achievement of system goals. Small and Svendsen (1990) broadened the concept by including both operational aspects (input acquisition and transformation from inputs to outcomes) and impact (the effects of operational activities on the irrigation system and external environment). Murray-Rust and Snellen (1993) suggested that operational and strategic performance should be included based on the business assessment approach of Ansoff (1979, as cited in Murray-Rust & Snellen, 1993). Accordingly, they use operational performance to refer to the degree of fulfilment of targets while strategic performance is the procedure by which resources are utilised to produce outputs. Additionally, they also emphasised changes in performance expectations over time. Gorantiwar and Smout (2005, p. 3) also identified temporal aspects of irrigation performance as they claimed that irrigation performance is “the extent to which land and water resources in the irrigation schemes planned for allocation to different users and their spatial and temporal distribution in [*sic*] planning and operation stage follow the objectives of the irrigation scheme”. Generally, the differences in these definitions originate from two drivers: the scope of ‘the system’, and target audiences who may be concerned with different aspects of performance.

For the scope of ‘the system’, Small & Svendsen (1992) illustrate the irrigation system as a subsystem nested within a broader set of agroeconomic and socioeconomic systems. Specifically, the irrigation system is the core system, which is nested within the irrigated agriculture system, the agricultural economic system, the rural economic system, and finally, the socio-economic system. The final output from a smaller system serves as an input into a broader system.

Generally, the definitions proposed by Lenton (1986) and Abernethy (1989) are general and can apply to any system, while the definition by Small and Svendsen (1990) emphasises internal irrigation system performance and its linkage to other systems. In contrast, the definition by Gorantiwar and Smout (2005) mainly concentrates on the irrigation system itself.

Chambers (1988, cited in Bos, Burton, & Molden, 2005) attempts to link different audiences with their respective interests. While farmers are interested in adequate, convenient, timely water supply, irrigation engineers are concerned with water delivery efficiency from headworks to tertiary outlets. Agricultural economists focus on high and stable farm production and incomes, whereas political economists emphasise equitability of benefit distribution. The irrigation performance definitions by Small and Svendsen (1990) and by Murray-Rust and Snellen (1993) also highlight different aspects of irrigation performance to satisfy different audiences.

These differences in approach to defining irrigation performance lead to differences in selection of irrigation performance indicators in the literature. Indicators initially focused merely on water utilisation efficiency, including conveyance efficiency, distribution efficiency, and field application efficiency (Bos & Nugteren, 1990) as they focus only on the irrigation system itself. Some authors (Malhotra, Raheja, & Seckler, 1984; Seckler, Sampath, & Raheja, 1988) even suggest a single key indicator in order to easily assess the irrigation system. The shortlist of indicators reported in earlier works has gradually evolved into a comprehensive list of indicators, covering water delivery and utilisation, agricultural production, economics, socio-economics, human welfare, and the environment (Bos et al., 2005; Gorantiwar & Smout, 2005; Small & Svendsen, 1990).

Although researchers have different approaches to defining irrigation performance and have developed different groups of performance indicators, most agree that the assessment of irrigation performance needs to include two main domains: water delivery and agricultural productivity. The former domain commonly refers to the adequacy, equity, timeliness and reliability of water delivery, while the latter domain is frequently associated with crop yields, cropping intensities and water productivity.

In this thesis, we choose to use the definition by Small & Svendsen (1990, 1992) as the core definition of irrigation performance. Accordingly, indicators of irrigation performance are categorized into three types – internal process, system outcomes and system impacts. Process indicators present the transformation of inputs into intermediate outputs, whereas output indicators refer to the final outputs of the system. Impact indicators of irrigation performance include the effects that irrigation has on the broader systems such as the irrigation agriculture system and the rural economic system. Chapter 4 will focus on output indicators relating to water delivery, specifically sufficiency and timeliness. These indicators are direct outputs of the irrigation system and farmers are interested in these indicators. These two indicators are referred to as irrigation quality in this thesis since they represent the quality of irrigation service provided to farmers. In chapter 5, we will focus on the impact indicators, specifically the technical efficiency of rice farming, delving into the connection between the irrigation system and the irrigated agricultural system.

In research by Bos, Murray-Rust, Merrey, Johnson, and Snellen (1994), the sufficiency of irrigation is defined as the ratio of the actual volume of water allocated to an area unit, over the volume of water demanded by that area, during an irrigation rotation or a crop season. The timeliness of irrigation refers to the predictability of the length of the rotation and the length of the interval between rotations. However, it is not feasible to estimate these two indicators in many Asian developing countries because of the lack of water measurement structures to measure water flow, duration, and timing at plot level. The main alternatives adopted in many previous studies are to directly assess the opinion of farmers on the sufficiency and timeliness of irrigation. For example, Sam‐Amoah and Gowing (2001) and Ghosh, Singh, and Kundu (2005) used fuzzy set theory to analyse the linguistic responses of farmers regarding tractability, timing, convenience and predictability of irrigation service. Aheeyar and Smith (1999) and Gunchinmaa and Yakubov (2010) used proxy flow data reported by farmers to create delivery performance indicators. Pasaribu and Routray (2005) and Vandersypen et al. (2009) used Likert scales to investigate farmer opinions on adequacy, timeliness, flexibility, equity and ease of irrigation.

Building on the existing literature, this study will use information provided by farmers on the sufficiency and timeliness of irrigation, to measure irrigation performance in the study area. Although data based on farmer perceptions have some shortcomings for the assessment of irrigation performance, it synthesises various types of information, including objective data and subjective observation (Saleth & Dinar, 2004). Importantly, the absence of water measurement structures at agricultural cooperatives (ACs) and plot level, does not allow us to use volumetric measurements of water delivery. Therefore using data reported by farmers is reasonable and the only feasible approach in this study.

4.2.2. Determinants of irrigation performance

There has been a wealth of theoretical and empirical studies dedicated to irrigation performance assessment as well as its determinants. According to the institutional analysis framework developed by Tang (1992), there are three groups of factors that may impact on collective action. They are (i) institutional arrangements, (ii) irrigation system physical factors, and (iii) the socio-economic characteristics of farmers. Similarly, Subramanian, Jagannathan, and Meinzen-Dick (1997) developed a conceptual framework of factors impacting irrigation performance. They placed water user groups and water user associations at the centre of their framework and hypothesised that these groups directly impact irrigation performance. Other factors including (i) physical and technical aspects of irrigation; (ii) the social and economic context; and (iii) government and irrigation agencies both regulate water user groups and irrigation systems. Building on these conceptual frameworks, we categorize the literature into three groups of factors as follows.

Institutions and governance factors

Many studies of the relationship between institutions and irrigation performance emphasise the establishment of farmer entities, such as water user groups (WUGs) or water user associations (WUAs) and the adoption of irrigation management transfer (IMT) or participatory irrigation management (PIM). Some authors have compared irrigation performance before and after institutional reform (Samad, 2002; Samad & Vermillion, 1999) while others have compared the irrigation performance of schemes under farmer organisation against those under government control (Bastakoti et al., 2010; Bhatta et al., 2006; Huang, 2014; Wang et al., 2007). Other researchers have compared the irrigation services that members and non-members of water user associations receive. Some positive associations between institution and irrigation performance have been reported. Specifically, the establishment of water user groups has been found to increase the effectiveness and equity of irrigation delivery (Gunchinmaa & Yakubov, 2010), and members of water user associations have been found to receive more reliable water supplies than non-members (Arun et al., 2012). Farmer-managed irrigation systems out-perform state-managed irrigation systems in some aspects (Bhatta et al., 2006; Lam, 1998), and have better performance than irrigation systems managed by private providers (Huang, 2014).

However, not all institutional reforms lead to better outcomes. Samad and Vermillion (1999) found that management transfer only brings about significant effects on agricultural productivity when accompanied by irrigation system rehabilitation. Wang et al. (2007) claimed that institutional reform policies do not significantly increase water use efficiency unless they include specific incentives to save water. Furthermore, a review by Samad (2002) revealed no discernible evidence of the impact of water user associations on irrigation services and agricultural production in Indonesia, India, Nepal and Sri Lanka.

A few studies pay attention to the impact of particular forms of participation on irrigation performance. Vandersypen et al. (2009) showed that coordination in water allocation increased irrigation efficiency and reduced irrigation problems. A study by Miruri and Wanjohi (2017) in Kenya pointed out that community participation in project development is associated with better irrigation performance. In contrast, Mushtaq et al. (2007) showed that a higher frequency of collective action to maintain small reservoirs is not significantly associated with better irrigation during periods of water shortage.

Irrigation system physical factors

Despite the important role of institutions in mediating irrigation performance, it has been recently suggested that the persistent focus on institutional aspects has overshadowed the important role of technical aspects and the socio-economic context in producing irrigation outcomes (Anderies, Janssen, & Schlager, 2016; Epstein, Vogt, Mincey, Cox, & Fischer, 2013; Vogt, Epstein, Mincey, Fischer, & McCord, 2015). Interconnections among technological, environmental, social, economic, and institutional processes are important in any irrigation systems. Irrigation system physical factors can be divided into those related to the biophysical environment and the built infrastructure. The former refers to the hydrological patterns and topographical features of the irrigated area while the latter relates to the irrigation infrastructure, such as reservoirs, weirs, and canals. The role of physical factors was underlined in a study by McCord, Dell'Angelo, Gower, Caylor, and Evans (2017). Their analysis revealed that heterogeneity of water delivery outcomes was strongly connected with physical and biophysical factors but not with institutional factors. Distance to water sources, elevation gradients between water sources and intakes, and the number of distribution lines were significantly associated with irrigation outcomes. The association between physical, technical factors and variability in irrigation supply and drainage in irrigation schemes was also revealed in a study by Borgia, García-Bolaños, and Mateos (2012). Farmers located in the head reaches of schemes had an advantage which impacted the adequacy of their water supply (Bruns, 2007; Sharaunga & Mudhara, 2016). Powered irrigation methods, such as electric and diesel pumps, are more likely to be associated with irrigation adequacy than conventional gravity irrigation (Sinyolo, Mudhara, & Wale, 2014). Although physical factors are salient determinants of irrigation performance, focusing on infrastructure development alone leads to failure in irrigation intervention. Infrastructure development and strong institutions should work hand-in-hand to secure the sustainable development of irrigation that provides water security (Cook & Bakker, 2012; Grey & Sadoff, 2007).

Farmer and farming factors

Farmer attributes may also affect irrigation performance to some extent. Knowledge of water management practices and agricultural cultivation techniques can help farmers to enhance water use efficiency and subsequently improve irrigation adequacy (Allouche, 2016; van Koppen, Tapela, & Mapedza, 2018). In contrast, water disputes between farmers have been found to have a negative influence on irrigation adequacy (Dirwai, Senzanje, & Mudhara, 2019). Degree of dependency on common water resources may also be an important determinant of the effectiveness of common property management. Users tend to have a stronger commitment to resource management if it is important for their survival. Mushtaq et al. (2007) showed that the dependency of households on the irrigation system to secure their livelihood has a positive connection with irrigation frequency and the quality of maintenance tasks.

4.2.3. Research hypotheses

Based on the literature review and conditions at the study site, we test two hypotheses:

(H1) Farmer participation in collective action related to irrigation management leads to improvements in irrigation quality (the sufficiency and timeliness of irrigation)

'Collective action' refers to actions taken by a group to attain members' shared interests. When a small proportion of members engage in collective action, their interests may represent a small part of all members' interests, thus the outcome of their collective action may satisfy only a small proportion of members. But when a large proportion of members participate in collective action, the outcome of their actions is more likely to satisfy the majority of members. Previous empirical studies show that farmers are mainly concerned with the adequacy and timeliness of irrigation. Therefore, we assess the hypothesis that when more farmers participate in collective action, the probability that plots receive sufficient and timely water supply is increased.

(H2) Irrigation quality in ACs included in the PIM project is better than Irrigation quality in ACs not included in the project

The research detailed in this chapter is also designed to allow an assessment of the impact of the PIM project. The PIM project was intended to improve the performance of ACs through the following activities:

1. forming and strengthening WUGs with written institutions and irrigation rules;

2. establishing WUAs, to coordinate irrigation delivery between WUGs sharing hydraulic boundaries;
3. training to improve the capacity of irrigators and executive board members in business plan development and irrigation operation and maintenance;
4. training for farmers to enhance awareness of PIM; and
5. improving irrigation delivery by partly lining some third-level canals.

These interventions were intended to encourage more participative irrigation management thus improving operation and maintenance and contributing to the project target of increasing agricultural production and reducing poverty. Accordingly, ACs included in the project were expected to have better irrigation quality (sufficient and timely irrigation in particular) compared to non-project ACs.

However, in 2017 when the data for this study was collected, WUAs had ceased to exist and the irrigation rules developed under the PIM project were no longer used. After the end of the PIM project, funding for WUAs ceased and coordination of water delivery between ACs was left to informal arrangements between ACs. Leaders of PIM ACs also explained that after the promulgation of the Agricultural Cooperative Law in 2012, each AC generated its own charter and rules in line with the new law, but they did not include the specific rules covering irrigation that had been developed under the PIM project.

Nevertheless, some other outcomes of the project remain such as rehabilitated irrigation infrastructure and AC staff trained in irrigation planning, irrigation operation and maintenance, financial management (Kolkma & Takahashi, 2017), and improved farmer awareness of participative irrigation management. Therefore, we may still find a positive impact of the project on water irrigation quality.

4.3. Data and econometric methods

4.3.1. Data

The main dataset for this chapter comes from a randomly selected sample of 355 households, farming 777 plots irrigated by gravity irrigation in 11 sampled ACs. As 70% of the irrigated area in the Nam Thach Han irrigation system receive gravity-based irrigation from the headwork, we decided to focus on the performance of gravity-based irrigation alone. This allowed us to avoid some of the heterogeneity in irrigation performance caused by different water sources and irrigation methods.

While a wide range of information was collected through the household questionnaire, for this chapter, we use data from Section 3 (irrigation service), and Section 4 (participatory irrigation management), to measure irrigation performance and collective action. Some information related to household characteristics and plot characteristics is gathered from other sections of the questionnaire. In addition, information at the AC level relating to AC personnel, the area irrigated, and irrigation infrastructure, were collected from ACs. Information about plot locations along canals was collected from AC irrigation team leaders.

4.3.2. Indicators of irrigation performance and collective actions

Irrigation performance

As explained in section 4.2.1, we use information reported by farmers about the adequacy and timeliness of irrigation to their plots to measure irrigation performance. To reduce measurement error caused by self-reporting, we focused on performance in the irrigation-rotation period and used a benchmark suggested by NTHIME staff and AC water deliverers to measure performance. We will describe the allocation of water by rotation in the Nam Thach Han irrigation system in the following paragraph to justify our choice of indicators.

In the study site, there are two rice crops annually; the Winter-Summer season lasts from the beginning of January to the middle of May and the Summer-Autumn season from the end of May to the middle of September. Water is released daily to all first and second-level canals in the first 40 to 60 days of each crop season. After this period, water is supplied by rotation. Each rotation lasts for eight to ten days and each first-level canal receives water for 4 to 5 consecutive days. In total, there are five to six irrigation rotations during a rice crop season.

In the period of continuous irrigation, farmers rarely suffer water-related problems due to the abundance of water in the system and lower water demand in the early development of the rice plant. Therefore, we use irrigation rotations as reference points to ensure comparability between farmers' self-reported information. Moreover, it is reported by NTHIME staff as well as by AC water deliverers that ideally, they have to deliver water to plots until water depth reaches around 7 to 10 cm in each rotation. Therefore, a rotation with sufficient irrigation is defined as the water level in a plot reaching at least 7 cm depth, while timely irrigation means that the plot receives water on planned dates. Farmers were asked to separately report the number of rotations with inadequate water and the number of rotations with untimely water during each crop season.

Two dummy variables are used to measure irrigation performance at the plot level in the Summer-Autumn season since water shortage is not a common problem in the Winter-Summer season (rainy season). The first one is sufficient irrigation and the second one is timely irrigation. Plots that did not suffer water shortage or delay in any rotation in the Summer-Autumn season are categorised as having sufficient irrigation or timely irrigation, respectively.

Collective action

Since Mancur Olson (1965) published "The Logic of Collective Action", the definitional core of the term 'collective action' has been identified as a common or shared interest amongst a group of people. It is thus more than 'an action taken by a group of people'.

Collective action is generally defined as "action taken by a group or organization in pursuit of members' perceived shared interests" (Scott, 2014, p. 92).

Based on this concept, we focus in this chapter on five specific activities that require cooperation amongst farmers to either construct, operate, or maintain irrigation systems in pursuit of better irrigation quality. These are labour contribution for maintenance, money contribution for irregular operation and maintenance costs, meeting attendance, participation in discussions at meetings, and water delivery monitoring. We measure collective action by aggregating information at the household level to estimate the proportion of farmers who participated in these actions in each AC in 2017.

4.3.3. Economic models to assess determinants of irrigation performance

Since our dependent variables (sufficient irrigation and timely irrigation) are dummy variables, we can use logit, probit, or linear probability models. In comparison with logit and probit models, linear probability models have several problems, including non-normality, the heteroscedastic variance of the disturbances, and nonfulfillment of the requirement that the estimated probability lies between 0 and 1 (Gujarati, 2009). Therefore, logit and probit models are generally preferable to linear probability. Chambers and Cox (1967) and Cakmakyapan and Goktas (2013) point out the similarities of the logit and the probit model and show that the logit model is better than the probit model for a large sample size (i.e. n=500). Moreover, existing studies mostly use logit. Therefore, we choose to use the logit model to make it easier to compare our results with previous studies.

The logit model is described as follows:

$$P_i = E[Y = 1|X_i] = \frac{1}{1+e^{-(\beta_1+\beta_2 X_i)}} \quad (1)$$

where P_i stands for the probability of the ith plot receiving sufficient or timely water; Y is water delivery performance at the plot level (sufficiency and timeliness), and X_i is explanatory variables. Equation (1) can be transformed as:

$$P_i = \frac{1}{1+e^{-Z_i}} = \frac{e^{Z_i}}{1+e^{Z_i}} \quad (2)$$

where $Z_i = \beta_1 + \beta_2 X_i$. Equation (2) represents what is known as the logistic distribution function. When Z_i ranges from -∞ to +∞, P_i ranges between 0 and 1.

From equation (2), the probability that a plot receives sufficient or timely irrigation is given by $(1 - P_i)$ in equation (3), which can be written as:

$$(1 - P_i) = \frac{1}{1+e^{Z_i}} \quad (3)$$

Therefore, the odds ratio $(P_i/(1-P_i))$ – the ratio of the probability that a plot receives sufficient or timely irrigation to the probability that it receives insufficient or untimely irrigation -- is given by equation (4):

$$\left[\frac{P_i}{1-P_i}\right] = \frac{1+e^{Z_i}}{1+e^{-Z_i}} = e^{Z_i} \quad (4)$$

If we take the natural logarithm of equation (4), we obtain the following result:

$$L_i = ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \beta_1 + \beta_2 X_i \quad (5)$$

L is called the logit, and equation (5) is a logit model. When P_i ranges between 0 and 1, the logit L_i goes from -∞ to +∞. L_i is linear in X_i but the probability P_i is nonlinear in X_i.

We use the maximum-likelihood (ML) method to estimate the parameters. The slope coefficients estimated by the ML method measure the change in the estimated logit in responding to a unit change in the value of the regressors. The antilog of these coefficients presents the change in odds-ratio for a unit change in the value of regressors. Both these ways of interpreting coefficients are less practical and tangible. Therefore, we estimate the marginal effect of individual regressors to provide a more intuitive meaning.

Based on the institutional analysis framework developed by Tang (1992), literature review and the context of the study site, we develop the empirical model used in this chapter as follows:

$$I_i = \beta_0 + \beta_{ji} colact + \beta_{ki} PIM + \beta_{mi} control + \varepsilon_i \quad (6)$$

where I_i is irrigation quality (either the sufficiency of irrigation or timeliness of irrigation) for the ith plot, *colact* denotes a vector of collective action variables, *PIM* distinguishes ACs under the PIM project from other ACs, *control* stands for control variables, β is a vector of parameter estimates, and ε is the error term.

We include control variables representing different aspects (institution & governance, irrigation system physical factors and farming factors) which are measured at different levels (AC, household and plot levels) to take into account other drivers of irrigation quality, apart from collective action. These are the capacity of managers and staff (education and, for AC leaders, years in their post), infrastructure (irrigated area managed per water deliverer, irrigated area per kilometre of third-level canal), household farming practices and their social network, and physical and biophysical characteristics of farm plots (location, elevation, water retention capacity and plot size).

4.3.4. Descriptive statistics

Summary statistics for the variables included in equation (6) are presented in Table 4.1. It can be seen that 38% of plots ‘always’ received sufficient water and 68% of plots ‘always’ received water on time in the 2017 Summer-Autumn season. This implies that a considerable number of sampled plots faced water shortages and untimely irrigation, with 62% of plots experiencing at least one irrigation rotation with insufficient water and 32% experiencing delays. It is worth noting that nearly 18% of plots suffered water shortages and 6% suffered delays in three or more of the six rotations in the Summer-Autumn season.

Table 4. 1. Summary statistics of response and explanatory variables

Variables	Mean	Std.	Min	Max
1. Response variables (plot level, n=777)				
Sufficient irrigation	0.38	0.48	0.0	1.0
Timely irrigation	0.68	0.47	0.0	1.0
2. Explanatory variables				
AC level (n=11)				
Collective labour contribution (%)	22.4	29.6	0.0	81.1
Collective money contribution (%)	39.6	28.2	10.0	86.5
Collective meeting attendance (%)	77.5	19.2	39.5	100.0
Collective meeting discussion (%)	27.0	15.4	10.8	60.0
Collective water delivery monitoring (%)	14.5	22.5	0.0	78.4
PIM (1=Yes; 0=No)	0.4	0.5	0.0	1.0
Leader years in position	9.9	6.8	1.0	26.0
Leader education level (years in school)	11.3	1.8	8.0	14.0
Area per water deliverer (ha/person)	19.1	5.9	11.5	31.3
Area per km third-level canal (hectare/km)	18.9	10.9	5.4	36.8
Household level (n=355)				
Number of water conservation practices	2.1	1.0	0.0	4.0
HH person-days for rice farming (day/sao)	5.6	1.7	2.0	11.0
HH social network (index)	0.0	1.0	-1.6	4.8
Plot level (n=777)				
Distance from plot to second-level canal (100 m)	2.9	3.3	0.0	15.0
Distance from second to first-level canal (100 m)	8.5	7.4	0.0	26.0
Distance from first to main canal (100 m)	55.6	33.5	0.0	110.0
Low-lying plot (1 = Yes, 0 = No)	0.3	0.4	0.0	1.0
High-lying plot (1 = Yes, 0 = No)	0.2	0.4	0.0	1.0
Plot area (sao)	2.9	2.1	0.3	15.0
Level of water retention (1=Low, 2=Medium; 3=High)	2.1	0.6	1.0	3.0

Note: 1 *sao* = 500 m^2

The proportion of farmers contributing labour for regular and irregular irrigation maintenance is 22% on average. However, this proportion varies widely from zero to 81% across ACs since only two ACs require compulsory labour contribution for canal dredging while others use money collected from farmers to pay for dredging to be carried out, based on tenders submitted by local farmers. For unexpected situations, such as broken canals, broken dykes and droughts, ACs call for emergency voluntary labour contribution to protect irrigation systems or dredge canals. Nearly 40% of farmers contributed money, in addition to the on-farm irrigation fee, to line third-level canals, or to repair irrigation canals or operate pumps in urgent situations, such as floods or droughts. As annual general meetings require a quorum as laid down in the rules of the AC, the proportion of farmers attending these meetings is high

(78%). On average, 27% of farmers reported that they join in water-related discussions in these meetings. Although water is delivered along third-level canals by water deliverers and ACs do not organise collective monitoring of water delivery, around 15% of farmers monitor this process themselves to try and ensure water supply for their plots. If they discover any problems, they can inform the water deliverer or the AC Management Board.

According to the general rules of ACs, leaders are elected for a 5-year term. Over 60% of leaders have been in their posts for more than two terms and one leader has been in his post for six terms. On average, AC leaders have been in their posts for nearly 10 years and have 11.3 years of formal education, higher than the average education level of farmers in the study site (7.7 years in school).

Area per water deliverer indicates the workload of water deliverers. It is the ratio of the total irrigated area over the number of water deliverers in an AC. In our sample, this indicator varies widely from 11.5 to 31.3 hectares per water deliverer. Moreover, *area per kilometre of third-level canal* is the ratio between the total irrigated area and the total length of third-level canals. It is a reverse ratio of the intensity of on-farm irrigation canals. When third level canals supply water to a large area, the probability that plots receive enough water or timely water may be reduced.

Water conservation practices measure the number of practices that farmers use to reduce water loss. The International Rice Research Institute (IRRI) recommends four main practices to improve plot water retention: 1) constructing field canals to and from plots; 2) preparing land and creating a hardpan; 3) levelling the plot and 4) constructing bunds and repairing any cracks or holes. On average, sample households applied two practices with land preparation being the most common.

HH person-days for rice farming refers to the number of days that farmers spend preparing land, planting, weeding, fertilising, spraying pesticides, visiting plots, and harvesting. The average time that farmers spend on rice farming is around 5.6 person-days per *sao*. The distribution of this variable is symmetric with 60% of households spending from 4 to 7 person-days per *sao*, 20% using less than 4 person-days and 20% using more than 7 person-days. This variable does not include ploughing and harvesting, which are generally carried out by paid contractors.

Household social network is an index generated using principal component analysis, thus its mean approximates zero and its standard deviation is close to one[18]. The index value is based on the number of local groups that household members join, the number of executive positions they hold, and the number of close friends they have. Farmers reported that when they have water-related problems, they seek help from leaders, water deliverers, and their friends. Therefore, households with stronger social networks may be able to gain support more easily, thus, leading to receiving a better irrigation quality.

Three variables describe the distance of plots from the water source – *Distance from plot to second-level canal, Distance from second to first-level canal, and Distance from first to main canal*. Measurement of these distances is illustrated in Figure 4.1, for example, distance from a plot to a second-level canal is given by a + b. Plots which are further from canals are less likely to receive sufficient and timely irrigation.

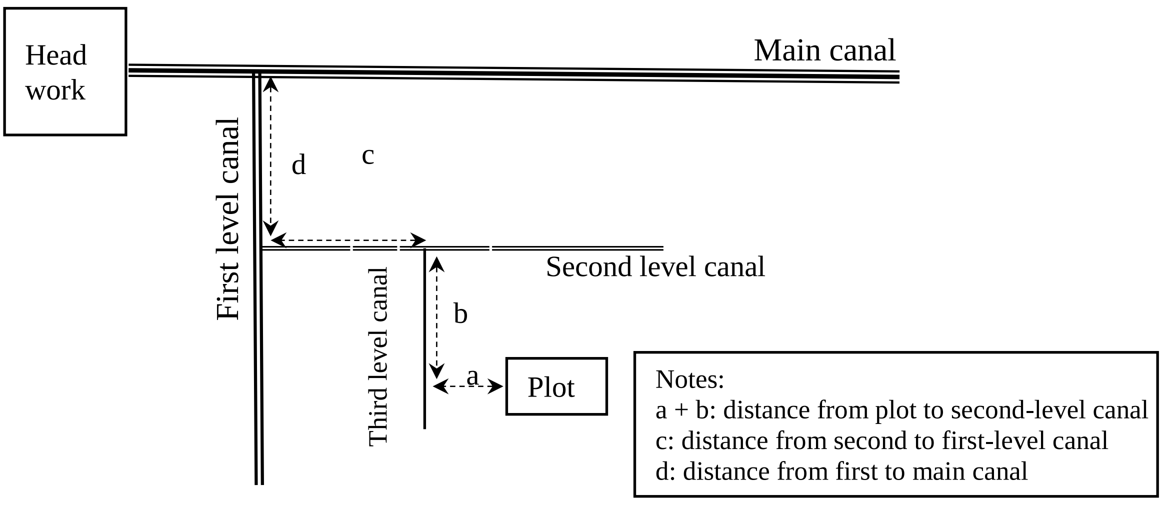


Figure 4. 1. Diagram of canals and the distance from plots to intake points

[18] Standard deviation for the full sample is one, but households without gravity irrigated plots were excluded.

In all ACs, plots are categorised into three groups in terms of their elevation; described as high, medium or low. Farmers prefer medium elevation plots because they are less likely to face as many water shortages as high-lying plots and they are less likely than low-lying plots to suffer waterlogging. In our sample, 27% of plots are 'low' and 16% are 'high'. Moreover, farmers rank the water retention capacity of their plot into three levels – low, medium and high. Plots with high water retention capacity suffer lower levels of water loss and so are more likely to receive sufficient irrigation.

4.4. Result and discussion

4.4.1. Irrigation performance within and across agricultural cooperatives

In this section, we aim to assess whether there are any obvious patterns in the timeliness and sufficiency of irrigation within and across ACs, corresponding to relative plot locations along AC canals (head, middle and tail). Figure 4.2 shows the proportion of plots receiving sufficient irrigation while Figure 4.3 shows the proportion of plots receiving timely irrigation. The average proportion of plots receiving sufficient irrigation varies widely (from 9% in Xuan Duong to 78% in An Luu). The share of plots receiving timely irrigation falls within a smaller range; from 44% (Tram Ly) to 97% (Ba Du). The share of plots with sufficient irrigation seems to vary considerably between the head, middle and tail in most ACs while the share with timely irrigation seems to be more similar. However, the results of chi-square and Fisher's exact tests suggest that the correlation between irrigation performance and plot location is statistically significant in only four ACs for irrigation adequacy and in three ACs for irrigation timeliness. In these ACs, irrigation performance is likely to be better in the head and worse in the tail section.

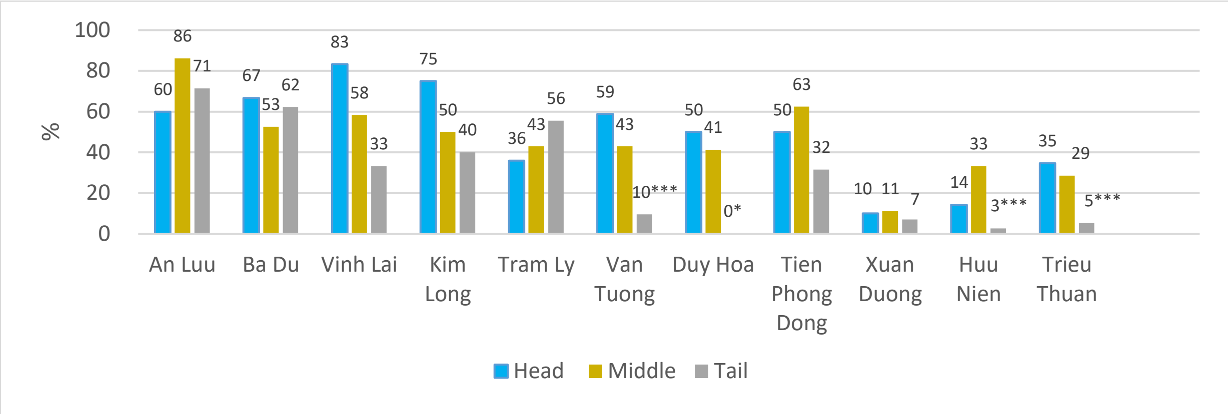


Figure 4. 2. ***Proportion of plots receiving sufficient irrigation by plot location and by AC***

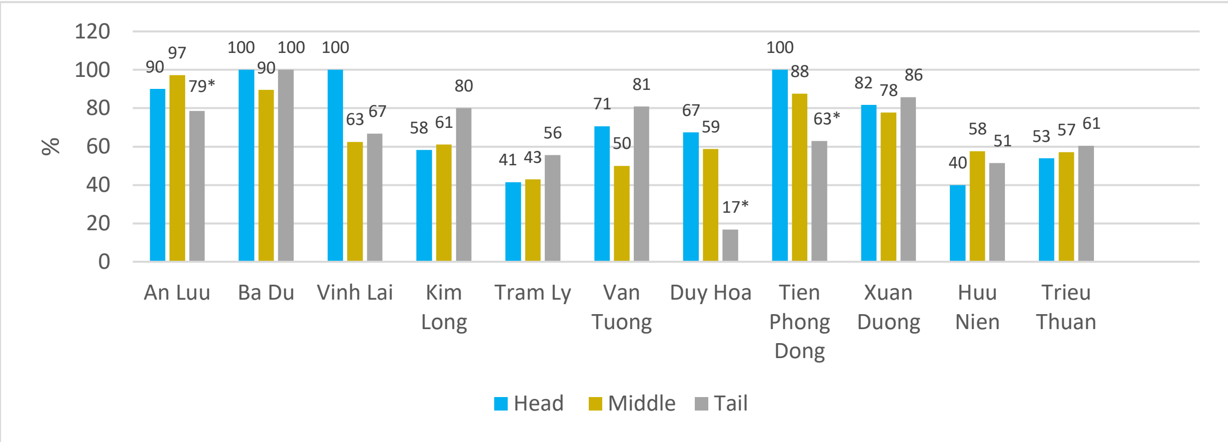


Figure 4. 3. ***Proportion of plots receiving timely irrigation by plot location and by AC***

Comparison amongst ACs shows that An Luu, Vinh Lai, Kim Long and Ba Du have a high percentage of plots with sufficient and timely irrigation. Location advantage (at the head of a first-level canal) and flatter fields may explain the high level of irrigation sufficiency in An Luu. Other possible factors include high frequency of contribution of labour and money (Ba Du and Kim Long) and young, active, more qualified leaders (Kim Long and Vinh Lai).

Noticeably, a very small percentage of plots in the tail section of Van Tuong and Duy Hoa receive enough water. Unlined third-level canals and a higher level of unpaid fees are some challenges for these ACs. Only 9 - 18% of sampled plots in Xuan Duong, Huu Nien A and Trieu Thuan received enough water. These plots share second-level canals with adjacent ACs and are located far from intakes.

Generally, irrigation quality varies within ACs as well as between ACs, and clear patterns are hard to discern. Differences in the physical condition of rice plots, irrigation canals, AC management factors, and the degree of farmer engagement in irrigation management may explain some of these variations. Therefore, to evaluate irrigation performance at plot level, we need to take into account all of these factors. In the next section, we will use econometric models to identify the determinants of the sufficiency and timeliness of irrigation, focusing on the impact of collective action.

4.4.2. The impact of collective action on the sufficiency and timeliness of irrigation

Results from a logit regression to estimate the impact of collective action on the sufficiency and timeliness of irrigation are detailed in Table 4.2. Restricted models (column 1 and 3) are used to test the impact of collective action and the PIM project on irrigation adequacy and timeliness, while full models (column 2 and 4) include control variables at AC, household, and plot level. The full models have higher chi-square values and higher proportions of correctly classified cases than the restricted models. Moreover, the likelihood ratio tests comparing the restricted and full models are significant, which suggests that the full models are a significant improvement on the restricted model. Results from the Hosmer–Lemeshow test also confirm that the restricted models have less good fit.

Table 4. 2. Logit estimation results for factors influencing sufficient and timely irrigation

VARIABLES	Sufficient irrigation (MEM)		Timely irrigation (MEM)	
	(1)	(2)	(3)	(4)
Collective labour contribution	0.01**	0.03*	0.01	0.06***
	(0.00)	(0.02)	(0.01)	(0.02)
Collective money contribution	0.03***	0.08***	-0.03***	0.04*
	(0.01)	(0.02)	(0.01)	(0.02)
Collective meeting attendance	0.01**	0.02	0.02***	0.04***
	(0.00)	(0.01)	(0.01)	(0.01)
Collective meeting discussion	-0.00	0.09	0.05***	0.07
	(0.01)	(0.08)	(0.01)	(0.07)
Collective water delivery monitoring	-0.06***	-0.05	0.03**	-0.04
	(0.01)	(0.05)	(0.01)	(0.05)
PIM	0.28	-0.31	-0.96***	-0.97**
	(0.21)	(0.50)	(0.21)	(0.49)
Leader years in post		-0.25***		-0.35***
		(0.05)		(0.05)
Leader education level		1.29***		1.10***
		(0.42)		(0.37)
Area per water deliverer		-0.18***		-0.13***
		(0.03)		(0.03)
Area per km of third-level canal		-0.25**		-0.22**
		(0.11)		(0.10)
HH social network		0.13		-0.08
		(0.10)		(0.11)
Water conservation practices		-0.11		0.04
		(0.11)		(0.11)
HH person-days for rice farming		0.10		0.04
		(0.07)		(0.06)
Distance from plot to 2nd-level canal		-0.07**		-0.01
		(0.04)		(0.03)
Distance from 2nd to 1st-level canal		-0.02		-0.00
		(0.03)		(0.02)
Distance from 1st to main canal		-0.07***		-0.06**
		(0.02)		(0.02)
Low-lying plot		-0.00		0.38*
		(0.24)		(0.23)
High-lying plot		-0.61**		0.21
		(0.28)		(0.26)
Plot area		0.03		-0.01
		(0.05)		(0.05)
Level of water retention		0.36		
(Medium vs. Low)		(0.28)		
Level of water retention		0.74**		
(High vs. Low)		(0.34)		
Constant	-1.86***	-7.22*	-0.68*	-4.77
	(0.36)	(3.88)	(0.37)	(3.30)
Pseudo R-squared	0.07	0.18	0.06	0.13
Log likelihood	-481.4	-420.9	-460.8	-427.6
Chi square test	66.78	187.9	55.99	122.5
Correctly classified (%)	65.77	72.72	65.89	70.53
Hosmer–Lemeshow test (Pro > chi2)	0.00	0.17	0.00	0.48

Notes: MEM - Marginal effects at the means; Standard errors in parentheses; *** p<0.01. ** p<0.05, * p<0.1

When looking at the restricted models (1 & 3), most collective action in irrigation management is significantly correlated with irrigation sufficiency and timeliness. However, the direction of correlation is not constant among the different forms of collective action. While labour contribution, monetary contribution, and meeting attendance increase the probability of sufficient irrigation, the proportion of farmers engaging in monitoring water delivery have a negative association with irrigation adequacy. Similarly, an increase in input contribution is associated with a lower probability of timely irrigation while the intensity of farmer involvement in discussion and monitoring water delivery is positively correlated with the incidence of irrigation timeliness. The PIM project is not significantly correlated with irrigation adequacy but is negatively associated with irrigation timeliness.

A possible reason for the inconsistent impact direction of collective action in restricted models may be omitted variables. McCord et al. (2017) suggest that all other factors that could correlate with irrigation performance should be included to avoid spurious correlation, which might happen if we only focus on collective action and overlook other factors. Therefore, we develop full models (2 and 4) to control for other related factors and compare the restricted and full models.

We can see the change in impact direction and magnitude of impact between collective action and irrigation quality when comparing models 1 and 3 with models 2 and 4. Model 2 shows that water delivery monitoring is not significantly correlated with sufficient irrigation while increasing the proportion of farmers contributing labour and money significantly improves irrigation sufficiency. In model 4, a higher proportion of farmers contributing labour and money increases the probability of irrigation timeliness, while a higher proportion of farmers engaging in meeting discussions and water delivery monitoring is no longer significantly associated with timely irrigation.

We also find that the magnitude of impact is higher in the full models. In model 2, a 1% increase in the number of farmers contributing money is associated with an 8% increase in the probability that plots receive enough water, while a one-unit increase in labour contribution leads to a 3% increase in irrigation sufficiency. In model 1, these figures are only 2% and 1% respectively. Similarly, a 1% increase in the proportion of farmers contributing labour or money or attending meetings enhances the probability that plots receive water in a timely manner by 6%, 4%, and 4% respectively in model 4, and by 1%, 3% and 2% in model 3. Based on these findings, it appears that the restricted model under-estimates the impact of collective action on irrigation adequacy and irrigation timeliness.

Overall, these results suggest that input mobilisation in the form of labour and monetary contributions are associated with improved irrigation adequacy and timeliness. However, according to AC leaders, farmers are increasingly busy with off-farm jobs and less dependent on farming so ACs have been finding it difficult to mobilise labour and monetary contributions. Our survey data shows that 25% of main farmers considered farming to be their secondary job. Farmers, on average, devoted 24% of their working hours to non-farm employment and 35% of farmers engaged in off-farm jobs.

Moreover, the level of the on-farm irrigation fee in ACs is quite low, from 22 to 66 USD/ha/season and is only enough for ACs to pay for basic operation and maintenance tasks. They cannot increase these fees because farmers are not willing to pay more. According to our survey data, 76% of interviewed farmers were not willing to pay more for irrigation, 20% were willing to pay an extra 2.2 to 8.8 USD/ha/season, and less than 4% of farmers were willing to pay an extra 13.2 to 22 USD/ha/season. Currently, the majority of sampled ACs do not put money aside to cover infrastructure depreciation, so they do not have funds for major repairs or upgrades. When ACs need to undertake major repairs or line third level canals, they have to call for farmer contributions or wait for a government grant.

Although the PIM project was finished 5 years ago, the project was expected to result in a continuing positive impact on irrigation performance. However, we did not find a significant positive correlation between PIM and the adequacy of irrigation to household plots.

Notably, we found that plots in ACs included in the project had less timely irrigation. We note that this could be related to the fact that ACs with water-related problems were more likely to be selected for inclusion in the PIM project.

Some control variables, such as the characteristics of AC personnel and on-farm canal and plot characteristics, are correlated with the quality of irrigation service. Number of years in post and the education level of AC leaders have a significant effect on irrigation adequacy and timeliness, but these two factors have opposite effects. While an increase in the educational level of leaders significantly increases the probability of irrigation adequacy and timeliness, the number of years that leaders stay in their position has a negative impact. This may reflect the fact that leaders who stay in their position for many years may be less dynamic in managing irrigation than the younger generation of leaders who normally have a higher education level.

We find that an increase in the area served by each water deliverer or per kilometre of third-level canals is associated with a lower probability of sufficient and timely irrigation. These larger areas may indicate a shortage of labour in irrigation teams and the low density of third level canals, which again originates from budget constraints faced by most ACs.

Plot characteristics including location, elevation, and water retention capacity are significantly correlated with irrigation performance. More specifically, plots which are further from the second-level canals and the main canal are less likely to receive sufficient and timely irrigation. Water loss due to seepage is a common problem in surface irrigation systems. Water losses increase when it is delivered over a long distance and this may also lead to delays in irrigation. The construction and condition of canals may be also relevant as 87% of third-level canals in the Nam Thach Han irrigation system are earth lined. We also find that high-lying plots are 61% less likely to receive sufficient irrigation compared to medium-lying plots, while low-lying plots are 38% more likely to get water on time. Farmers are 75% more likely to report that plots with high water retention capacity receive enough water, compared to plots with low water retention capacity.

4.5. Conclusions

Surface irrigation schemes are complex systems and their ability to supply sufficient and timely irrigation relies on a wide range of factors. This study emphasises the relationship between collective action and irrigation quality while taking into account the impact of physical and management factors at AC, household, and plot level.

We find that irrigation problems commonly occur in the Summer-Autumn season when only one-third of plots received enough water and two-thirds received water on time in all irrigation rotations. When we compare the proportion of plots receiving sufficient and timely irrigation by plot location, we find heterogeneity in irrigation quality within and across ACs.

The results of the full logit models suggest a significant correlation between collective action and irrigation. A higher percentage of farmers contributing labour or money is associated with a higher probability of plots receiving sufficient and timely irrigation. In addition, higher levels of farmer attendance at meetings is positively associated with more timely irrigation. However, plots located in PIM ACs are not likely to receive more timely irrigation than those in non-PIM ACs, perhaps because the ACs selected for inclusion in the PIM project were more likely to suffer from water shortages. Analysis of restricted models suggests that failing to control for managerial and physical factors may lead to underestimation of the impact of collective actions on irrigation quality.

The full models also suggest a correlation between some managerial and physical factors and irrigation quality. Specifically, more educated leaders are associated with a higher probability of attaining sufficient and timely irrigation while AC leaders who have been in their posts for longer are associated with a lower probability. An increase in the irrigated area managed by each water deliverer or which is served by third-level canals reduces the probability that plots receive sufficient and timely irrigation. The incidence of sufficient and timely irrigation is likely to decrease as plots are further away from intake points. In comparison with medium-lying plots, high-lying plots are less likely to receive adequate irrigation while low-lying plots are more likely to be irrigated on schedule.

Some policy implications can be drawn from these findings. It is suggested that ACs should continue their efforts to involve farmers in irrigation management and contribution of labour and money to enhance their capacity to satisfy water demand. Fostering knowledge and capacity for leaders as well as other management staff and encouraging the involvement of young and knowledgeable persons in management positions in ACs are some solutions that need to be considered.

This study provides important empirical results on the linkage between collective action and irrigation performance. However, it also has some limitations mainly due to constraints around data collection and the lack of quantitative data on irrigation performance. First, it uses farmers self-reported information rather than physical measures of irrigation performance. Second, it has not been possible to control for possible reverse causality between collective action and irrigation performance as described by Agrawal (2001) and Anderies et al. (2016). Third, the robustness of the relationship between collective action at AC level and irrigation quality at the plot level was limited by the relatively small number of ACs that could be included in our study.

Chapter 5 - The impact of irrigation on rice farming technical efficiency controlling for plot-specific environmental conditions

5.1. Introduction

In Vietnam, rice production plays a critical role in providing food security as well as rural employment. It accounts for 90% of national grain output and 88% of the area cultivated with grains (GSO, 2018). The total value of rice produced was around 12.5 billion U.S dollars in 2018, equivalent to one-third of the total value of agricultural production and 5.1% of the GDP[19]. The national Socio-Economic Development Strategy for the period 2011–2020 targets agricultural modernisation as a means of improving agricultural productivity, farm incomes and national food security. However, there is limited room for increasing production by increasing cultivated areas or through labour inputs. The government capped the total area of rice at 3.8 million ha in the 2020 Agricultural Master Plan (Jakob & Khemka, 2017). From 2001 to 2010, over one million hectares of farmland were converted to non-agricultural uses (Alcaide Garrido et al., 2011). A steady diversification of rural households away from agricultural activities (Kinghan & Newman, 2017) and increasing migration from rural to urban areas (Amare & Hohfeld, 2016; Narciso, 2017) have led to a shortage of farm labour. Moreover, technology adoption in rice production in Vietnam seems to be low, as is often the case for farmers in developing countries (D'Souza & Mishra, 2018). An expansion of production scale or an outward shift of production frontiers would be very difficult because of the scarcity of land and labour, and low technology adoption. As a result, production growth in the rice sector relies on increasing efficiency, particularly maximising output with a given level of input. Given the current situation, an examination of the technical efficiency (TE

[19] Calculation from FAO data (http://www.fao.org/faostat/en/#home) and World Bank Vietnam data (https://data.worldbank.org/country/vietnam?locale=vi)

hereafter) of rice farming and its determinants in Vietnam should increase our understanding of this vital sector and assist with the development of appropriate policies to increase the TE of rice farming.

Irrigation has been treated as either a rice production input (Varghese, Veettil, Speelman, Buysse, & Van Huylenbroeck, 2013; Watto & Mugera, 2014b) or an environmental factor impacting on rice output (Fuwa, Edmonds, & Banik, 2007; Sherlund, Barrett, & Adesina, 2002; Van Hoang & Yabe, 2012) or as an off-farm factor impacting on rice farming TE (Alam et al., 2012; Gebregziabher, Namara, & Holden, 2012; Gedara, Wilson, Pascoe, & Robinson, 2012; Mekonnen, Siddiqi, & Ringler, 2016; Pedroso et al., 2018; Sharma, Pradhan, & Leung, 2001; Yao & Shively, 2007). In developing countries like Vietnam, directly investigating the impact of irrigation on rice output at plot or household level is infeasible as plot and household water usage data is often unavailable. Moreover, it is not useful to consider irrigation simply as an environmental factor to distinguish irrigated versus rain-fed rice farming in Vietnam since 96% of rice is irrigated (World Bank, 2019). However, in Vietnam, the quality of irrigation management is thought to be a limiting factor. The government aims to improve irrigation management by devolving power and responsibility to farmer organisations (World Bank, 2019). As such, an evaluation of the impact of irrigation *quality*, specifically the sufficiency and timeliness of irrigation as a result of changes in irrigation management on rice farming TE is essential.

Rice production in Vietnam is also impacted by a range of environmental factors. Chen et al. (2012) predict that Vietnam will be one of the rice-producing nations most severely affected by climate change. Rice farmers suffer from salinity intrusion and frequent floods and droughts (Nguyen, Renaud, Sebesvari, & Nguyen, 2019; Toan, 2014; Yuen et al., 2020). Moreover, fragmentation and small plot size are considered to be critical constraints for Vietnam rice farming (Markussen et al., 2016; Van Hung et al., 2007). Therefore, plot-specific environmental factors should be taken into account and analysing TE at plot level may provide more insight than farm-level analysis.

This study contributes to the literature in several ways. Previous studies have suggested various impacts of irrigation-related factors on TE. Some authors have indirectly evaluated the impact of irrigation quality on farming TE through farm location and quality of irrigation infrastructure (e.g.Alam et al., 2012; Gedara et al., 2012; Mekonnen et al., 2016; Yao & Shively, 2007). Others have investigated related institutions such as the existence of water user associations (Gragasin, Maruyama, Marciano, Fujiie, & Kikuchi, 2005; Sharma et al., 2001) or farmer participation and cooperation in these associations (Arun et al., 2012; Gedara et al., 2012; Li & Li, 2011). However, none of these studies directly examine the influence of irrigation quality -- specifically, sufficient and timely irrigation -- on TE. Moreover, they do not control for plot-specific environmental factors when evaluating the impact of irrigation. This could cause estimation bias as indicated by Sherlund, Barrett, and Adesina (2002) and Fuwa, Edmonds, and Banik (2007). This study is an effort to fill these gaps by examining the extent to which irrigation quality is associated with TE in rice farming when environmental factors are controlled. In particular, to what extent is rice production likely to be more technically efficient when water is supplied in sufficient quantity and on time? As far as we know, no other studies compare plot-level TE and farm-level TE when controlling for environmental factors.

To answer this research question, we sequentially investigate several sub-questions.

Question 1: Is there a significant correlation between irrigation quality and TE in rice farming?

Question 2: Is the impact of irrigation quality on technical inefficiency under-estimated when we fail to control for environmental factors?

Question 3: Does aggregate household-level data give the same estimates of TE as unaggregated plot-level data if we control for environmental factors?

The outline of this chapter is as follows. Section 5.2 provides a review of the literature on technical efficiency, estimation approaches, and empirical studies of rice farming efficiency. This is followed by a discussion of the data and methodology in section 5.3. Summary statistics, analysis results and a discussion are presented in section 5.4. The final section summarises the findings and discusses policy implications, before outlining the limitations of this study and offering suggestions for future research.

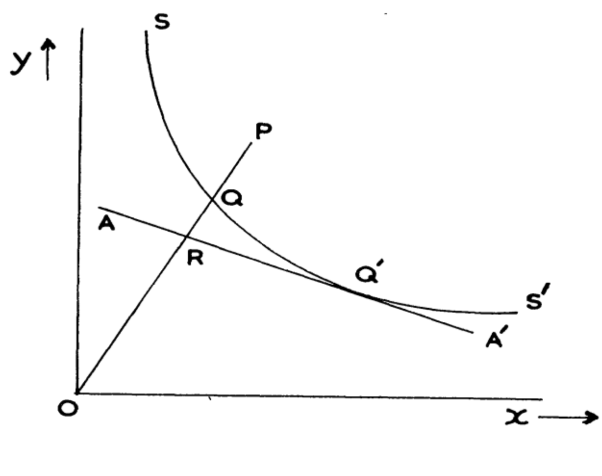
5.2. Literature review

5.2.1. Technical efficiency and approaches to estimate technical efficiency

In this section, we provide a brief conceptual framework of technical efficiency and a review of the measurement methods used in relation to it. We also point out the pros and cons of these approaches to justify the methodology that we use in the study described in this chapter.

Concept and measurement of technical efficiency

Modern concepts of efficiency and their computation were advanced in the seminal paper by Farrell (1957). In this paper, Farell identifies three types of efficiency: technical efficiency, price efficiency (allocation efficiency) and overall efficiency (economic efficiency). The basic idea underlying Farrell's approach to measuring efficiency is illustrated in Figure 5.1.



Source: Farrell (1957)

Figure 5. 1. The measurement of technical and allocative efficiency

Suppose there is a firm (A) that uses two inputs (x and y) to produce one output (m) under constant returns to scale. With these assumptions, we can draw the production function by a simple isoquant SS'. The isoquant illustrates the various combinations of the two inputs that are used to efficiently produce unit output. Point P represents the combination of two inputs that firm A uses to produce one unit of output. Point Q represents an efficient firm (B) using two inputs in the same ratio as at point P. Firm B produces the same output as firm A but it uses only a fraction OQ/OP as much of each input. In other words, Firm B produces OP/OQ times as much output from the same inputs. Therefore, the fraction OQ/OP is defined as the *technical efficiency* of firm A.

Given the price of inputs, we can draw isocost line AA' to measure allocative efficiency. The slope of the isocost line is equal to the ratio of the prices of the two inputs. The isocost AA' is tangential to isoquant SS' at Q'. Both Q and Q' are at optimal technical efficiency but the cost of production at Q' is a fraction OR/OQ of the cost at Q. The fraction OR/OQ is defined as the allocative efficiency of observed firm A. The firm producing at Q' is at both optimal technical efficiency and optimal allocative efficiency. Its costs at Q' is a fraction OR/OP of the cost at P. This ratio (OR/OP) is defined as the economic efficiency of firm A.

From the example above, technical efficiency can be defined as the ability of a decision-making unit to produce the maximum output from a given set of inputs and technology (output-oriented), or as the ability to use a minimum amount of input to generate a given amount of output (input-oriented). Stated differently, technical inefficiency refers to the failure to obtain the maximum possible output with a given amount of input (or failure to use minimum input to create a certain level of output).

Allocative efficiency is associated with a firm's ability to use inputs in optimal proportion with respect to input prices and marginal productivity. Economic efficiency is a combination of technical efficiency and allocative efficiency. It refers to the capacity to produce a given level of output at minimum cost with a given level of technology. The estimation of these efficiency measures is useful. It provides indicators to compare across similar economic units, and further analysis of factors causing the variance of efficiencies generates meaningful policy implications for the enhancement of efficiencies.

This study will focus on technical efficiency because, as argued by Schmidt and Lovell (1980) and Kalirajan and Shand (1992), technical efficiency and allocative efficiency are positively correlated and technical efficiency influences allocative efficiency but not vice versa. In other words, improving *technical* efficiency is generally a better way of enhancing *allocative efficiency* which results in improvements in *economic* efficiency. Moreover, Barrett (1997) comments that for smallholder agriculture where most decisions on the allocation of land, labour and livestock are not associated with market transactions, estimating allocative and economic efficiency with observed market prices could lead to incorrect estimates on the extent to which farmers misallocate inputs.

Techniques for estimating technical efficiency

Since Farrell's paper, many production frontier models have been developed which can be classified into two approaches: parametric and non-parametric. Parametric frontiers can be separated into deterministic frontier and stochastic production frontier (SPF) approaches. The deterministic frontier method assumes that any deviation from the frontier is caused by inefficiency. In other words, all of the measurement error or other sources of stochastic variation in the dependent variable are embedded in the inefficiency estimate. As a result, inefficiency estimates may be biased due to the existence of outliers. On the other hand, SPF, which was initially proposed by Aigner, Lovell, and Schmidt (1977) and Meeusen and van Den Broeck (1977), treats deviation from the production frontier as a combination of noise and inefficiency. It incorporates a two-sided error term and a one-sided component representing inefficiency, simultaneously. The two-sided error term captures measurement error as well as statistical noise, thus solving the noise problem that deterministic frontiers face. Moreover, in SPF, standard errors can be estimated and hypotheses tested. These tasks are problematic with deterministic frontier methods due to violation of maximum likelihood regularity conditions (Schmidt, 1976). Both deterministic frontier and stochastic frontier methods require a specific functional form and distribution for the inefficiency term. Moreover, they are only appropriate for single output technologies (Bogetoft & Otto, 2010; Hillier & Price, 2011).

Data Envelopment Analysis (DEA), initially proposed by Charnes, Cooper, and Rhodes (1978), is the most commonly used non-parametric approach. It does not rely on a particular functional form and can be used to analyse production involving multiple outputs. However, the flexibility of DEA is accompanied by the major drawback that all deviations from the frontier are assumed to be caused by inefficiency with any noise due to measurement and sampling errors being ignored. This results in DEA being highly impacted by outliers (Bogetoft & Otto, 2010).

The stochastic production frontier approach is adopted for this investigation for two main reasons. First, SPF solves the problem of measurement error and noise in estimate rice farming technical efficiency. This is important since rice yield data tends to include outliers caused by environmental factors such as weather and diseases and household survey data is always susceptible to measurement errors in data collection. Second, SPF is appropriate for the estimation of technical efficiency for the production of a single output using multiple inputs as is the case with rice farming.

Apart from estimating TE, it is also important to identify the exogenous factors that drive variation in TE. These exogenous factors are neither production inputs nor outputs but can affect the efficiency of production. Previous researchers have often adopted a two-step approach to estimating sources of efficiency variation. In the first step, technical inefficiency scores are derived from an estimated stochastic production frontier without controlling for exogenous factors. Then, in the second step, the technical inefficiency scores are regressed on exogenous factors. However, the two-step approach has been criticised because it leads to biased parameter estimates (Battese & Coelli, 1995; Kumbhakar, Ghosh, & McGuckin, 1991). Specifically, exogenous factors may be correlated with input choice, thus leading to inconsistent parameter estimates and inefficiency scores. In addition, the OLS regression in the second stage may not be appropriate since the inefficiency score is a one-sided error. As a result, Kumbhakar et al. (1991) and Battese and Coelli (1995) proposed a single-step approach in which exogenous factors are incorporated directly into the inefficiency error term. In this approach, either the mean or the variance of the inefficiency error term is assumed to be a function of exogenous factors. The parameters of the stochastic frontier and the inefficiency model are then estimated simultaneously. Because of the widely acknowledged advantages of this method, the one-step approach is used in this study.

5.2.2. Technical efficiency of rice farming and its determinants

Stochastic production frontier (SPF) approaches have been used in numerous studies to investigate rice farming TE and its determinant in developing countries such as India (Coelli & Battese, 1996; Kalirajan & Shand, 1999); the Philippines (Kalirajan & Flinn, 1983), Sri Lanka (Gedara et al., 2012), Nepal (Sharma et al., 2001), Bangladesh (Asadullah & Rahman, 2009; Bäckman, Islam, & Sumelius, 2011; Rahman, 2011; Sharif & Dar, 1996), Thailand (Srisompun & Isvilanonda, 2012), China (Chang & Wen, 2011; Tan, Heerink, Kuyvenhoven, & Qu, 2010; Yao & Liu, 1998) and Vietnam (Dam, Amjath-Babu, Zander, & Müller, 2019; Khai & Yabe, 2011; Pedroso et al., 2018; Tu & Trang, 2016; Van Long & Yabe, 2011; Vu, 2007). Results obtained by these authors indicate that the TE of rice production varies considerably between ~50% and ~90%, suggesting that there are often opportunities to attain additional outputs or reduce the level of inputs with existing technology and resource endowments.

The inputs that most authors use to develop production frontiers include seed, labour, capital, fertiliser, and pesticides. Sherlund et al. (2002) indicate that input usage is partly conditional on environmental production conditions (eg. irrigation, weather, plant diseases, pest and weed infestation, and heterogeneity of land topography). Given the heterogeneous environmental factors across farmer plots, Sherlund et al. (2002) suggested the use of plot-level data and the addition of environmental factors in the production frontier. This would make parameter estimates of production frontier and technical inefficiency function unbiased. Since Sherlund et al. (2002), a handful of studies (Chang & Wen, 2011; Fuwa et al., 2007; Rahman & Hasan, 2008; Van Hoang & Yabe, 2012) have managed to control for environmental factors while investigating farm production efficiency.

Researchers have taken different approaches to analyse the effect of irrigation on technical efficiency. Irrigation has been treated as either a production input or an environmental factor or as an off-farm factor impacting on farming TE. Ideally, the quantity of irrigation water applied (or used) should be considered as a production input and included in crop production frontiers, especially for water-intensive crops like rice. However, measuring water usage is often challenging in developing countries. Only a few studies manage to include used water volumes in production frontiers for some crops such as vegetables (Karagiannis, Tzouvelekas, & Xepapadeas, 2003), rice (Varghese, Veettil, Speelman, Buysse, & Van Huylenbroeck, 2013; Watto & Mugera, 2014b), wheat (Mekonnen et al., 2016; Tang, Folmer, van der Vlist, & Xue, 2014), and cotton (Watto & Mugera, 2014a). Generally, it appears that crop output is significantly responsive to an additional volume of irrigation water. These studies mainly examine groundwater irrigation where measurement of water volumes is generally easier. In the case of surface irrigation systems, data on the quantity of water used is generally not available, so proxy variables such as the number of irrigations applied, irrigation duration or simply irrigation availability have been used (Abedullah & Mushtaq, 2007; Gedara et al., 2012; Sharma et al., 2001). These studies indicate a significant positive role of irrigation in explaining variation in rice output. Nonetheless, Sharma et al. (2001) acknowledge that TE estimates would be improved by including input data on water quantity.

Sherlund et al. (2002), Fuwa et al. (2007) and Van Hoang and Yabe (2012) categorised irrigation as an environmental factor and used it to distinguish irrigated versus rain-fed rice farming. The linkage between weather and the quantity of water in irrigation canals may be their rationale for categorising irrigation as an environmental factor. However, it should be pointed out that the existence of irrigation infrastructure and its performance is mainly a ‘human-made’ factor, not an environmental factor. Other researchers have considered irrigation to be an off-farm factor since it is a service provided in government or farmer-managed irrigation systems. They have investigated the impact of irrigation accessibility, irrigation methods, irrigation infrastructures and irrigation management on farming TE.

The impact of irrigation accessibility, represented by farm location along canals, has been investigated by several authors. Yao and Shively (2007) found that large distances between a farm and the main canal and the presence of siltation in canals reduce the TE of rice farming. Similarly, Gedara et al. (2012) observed that farms located along the middle section of canals are more likely to attain higher TE than those at the tail. In contrast, Alam et al. (2012) found that farms at a further distance from the main canal have higher TE.

Irrigation infrastructure may also explain the variation in TE. Alam et al. (2012) showed that farmers on the rehabilitated concrete irrigation scheme have a significantly higher TE than those relying on traditional canals made from mud and stones. Mekonnen et al. (2016) added empirical evidence on the impact of irrigation method on TE. They found that farmers who rely solely on surface water achieved higher TE than those using groundwater. Moreover, the conjunctive use of ground and surface water leads to higher TE than the use of groundwater alone for farmers located in the middle section of canals.

Irrigation management is another factor associated with production efficiency. Gragasin et al. (2005) found that the water user association did not succeed in increasing agricultural productivity and equity in water distribution. However, the mean and variance of farm TE in irrigation systems with water user associations were higher and more consistent than those without associations. Sharma et al. (2001) also found that the TE of farmers using farmer-managed irrigation services was higher and more consistent than that of farmers under a government irrigation system.

None of the studies reviewed above directly examine the impact of irrigation quality, specifically the adequacy and timeliness of irrigation, on TE. Moreover, Sherlund et al. (2002) and Fuwa et al. (2007) note that omission of environmental factors can result in under-estimation of parameter values in production frontiers and technical inefficiency functions. However, no studies have controlled for the impact of exogenous environmental factors when examining the impact of irrigation on TE.

In this study, we aim to fill some of the gaps in the literature. We categorise irrigation as an off-farm factor since our focus is on the quality of irrigation services provided by farmer organisations. We integrate environmental factors into the stochastic production frontier and estimate technical efficiency and its determinants at both plot and household level. Estimates with and without environmental factors and at plot level and household level are compared.

Various other factors, not directly related to irrigation, also drive variations in TE. These factors have been divided into three groups, namely agent factors, on-farm factors, and off-farm factors.

(i) Agent factors

Agent factors refer to household demographics such as the age and educational attainment of those who cultivate rice. Many of these factors have been found to significantly impact TE although there is little consensus on the direction of impact.

Some authors (Asadullah & Rahman, 2009; Li & Li, 2011; Sharif & Dar, 1996) find that educational attainment has a positive impact on TE while others find that education reduces TE or has no significant impact (Bäckman et al., 2011; Coelli & Battese, 1996; Yao & Shively, 2007). It has been suggested that farmers with a higher level of education have more opportunities to do off-farm jobs, and so tend to devote less time and effort to rice farming, leading to lower TE. Moreover, Gedara et al. (2012) argue that measures of formal educational attainment are not good indicators of farming knowledge since education in school is not likely to cover farming of rice and other crops.

Bäckman et al. (2011) and Coelli and Battese (1996) suggest that farmer age is negatively correlated with efficiency since younger farmers are more likely to be willing to adopt new practices. On the other hand, farmers can improve their proficiency through 'learning by doing', thus their experience may increase TE. Kalirajan and Flinn (1983) and Li and Li (2011) found a positive relationship between experience and TE.

Yao and Shively (2007) reported a positive relationship between the number of members of the household who are engaged in farming and TE. In the context of urbanisation and modernisation, the agricultural labour force may be reduced as workers move to urban areas and/or switch to off-farm jobs. In the absence of surplus labour, availability of farming labour has become more important for agricultural production. However other researchers (Chang & Wen, 2011; Yang et al., 2016) did not find a significant negative impact of off-farm work and/or migration on farming TE. Chang and Wen even found that households engaged in off-farm work use inputs more efficiently than those without off-farm work.

Participation of farmers in collective action is another source of TE variation. Arun et al. (2012) showed that the TE of farmers participating in water user organisations is 6% higher than that of non-participating farmers. Gedara et al. (2012) and Li and Li (2011) also found that a higher level of farmer involvement in water user organisations is positively associated with TE.

(ii) On-farm factors:

On-farm factors refer to rice farming practices and paddy field characteristics. Tan et al. (2010) found that larger distance between homesteads and plots was associated with lower TE in rice production while scholars such as Kompas, Che, Nguyen, and Nguyen (2012), Bäckman et al. (2011), Wadud (2003), Coelli and Battese (1996) identified negative impacts on TE from land fragmentation.

Technology adoption also contributes to differences in the level of efficiency between farmers. Using hybrid varieties (Fuwa et al., 2007), owning tractors (Yao & Shively, 2007) or applying integrated pest management (IPM) are some examples of technology adoption which increase TE. However, a counter-intuitive relationship between technology adoption and TE is also reported by some researchers. Kalirajan (1982) found that an increase in the proportion of modern varieties resulted in a reduction in TE. He suggested that this may have been caused by insufficient experience in dealing with these new varieties. Gedara et al. (2012) found that herbicides have a positive impact on TE but usage of insecticides is associated with a decline in TE.

(iii) Off-farm factors:

Off-farm factors refer to services that farmers receive or managerial factors beyond the household level. For example, access to microfinance may enable farmers to adopt improved technologies such as high yielding variables which may enhance TE. This is particularly true for marginal farmers in developing countries such as Bangladesh (Bäckman et al., 2011), Cameroon (Binam, Tonye, Nyambi, & Akoa, 2004), and Ethiopia (Gebregziabher et al., 2012). These farmers are often stuck in a loop of financial hardship. Access to credit can reduce financial difficulties and allow them to purchase and use inputs properly to increase TE.

Interaction with technical support organisations such as extension agents can also contribute to variation in TE amongst farms. More frequent contact (Kalirajan & Flinn, 1983) or closer distance to extension services (Gebregziabher et al., 2012) are often correlated with higher TE.

It seems self-evident that longer distances to markets will be associated with lower opportunities to access farming services and information on new technologies, and will be related to higher transaction costs to obtain inputs. That is the reason why the study by Fuwa et al. (2007) found that distance to market hurts farming efficiency. Contrastly, Gebregziabher et al. (2012) found that farmers who are distancing from the road, an indicator of farmer capacity to access the market, are more likely to attain higher TE.

The technical efficiency of rice farming and its determinants has been an important topic attracting the attention of numerous scholars worldwide. Different methods have been adopted to estimate TE. Choosing between the SFA and DEA depends upon the objective of the research, the type of industry, and the availability of data. The value of TE varies across countries and over time, which reveals the potential to increase outputs by using inputs more efficiently. The education and experience of the household head, plot size, farm fragmentation, access to extension services, technologies and access to credit are common determinants of TE.

Although irrigation is less commonly investigated, it is positively associated with TE in most of the literature. However, research conducted to date does not control for plot specific environmental factors. The investigation detailed in this chapter fills this important gap and contributes to a more thorough understanding of the relationship between irrigation and farming TE.

5.3. Data and econometric methods

5.3.1. Data

The assessment of TE and its determinants in this chapter is based on a sample of 337 households and 977 plots. Some households were excluded because of a lack of plot-level data, while rain-fed plots were also excluded. The household survey covered a wide range of topics including household demographics, rice farming inputs and outputs, irrigation services, participation in irrigation management and household income. This paper uses information related to rice farming inputs and outputs, household socio-economic characteristics, and plot characteristics. While input, output and plot-specific environmental conditions were collected at the plot level, most other information was collected at the household level.

5.3.2. Methods and empirical models

The technical efficiency of rice farming and its determinants is estimated using the SPF single-step approach. Production frontiers are estimated at both plot and household level while controlling for environmental factors. Stochastic production functions take the general form:

$$ln(Y_i) = f(X_i, Z_i; \beta) + e_i = f(X_i, Z_i; \beta) + v_i - u_i, \quad i=1,..,N \quad (1)$$

where Y_i is the total rice output of observation i (either plot-level or household level); *f(.)* defines the production frontier, X_i is a vector of inputs including land, seed, fertiliser and labour. Z_i is a vector of environmental factors including waterlogging, pest and disease infection, rat damage, plot elevation and soil quality. β is a vector of estimated parameters. e_i is a composed error term comprised of v_i and u_i. v_i is a stochastic error term, including model misspecification, measurement error and random shocks. v_i is assumed to have a normal distribution $N(0,\sigma_v^2)$ and be independent of u_i. u_i is a one-side error term ($u_i \geq 0$) representing the technical inefficiency of the ith observation and its variance denoted as σ^2_u. If u_i=0, observation i will have the maximum level of output, which means that the observation is exactly on the production frontier. If u_i>0, the actual output of observation i is lower than its attainable maximum output. In other words, observation i lies inside the production frontier.

Model (1) can be rewritten in the Cobb-Douglas or Translog functional form. The Cobb-Douglas model is widely used in the estimation of efficiency since it is fairly straight forward to implement and estimate (Xu & Jeffrey, 1998), and does not impact the measurement of empirical efficiency (Kopp & Smith, 1980). However, it has some restrictive properties including constant input elasticities, constant returns to scales for all production units, and a unitary elasticity of substitution. On the other hand, the Translog form does not impose restrictions on returns to scale or substitution possibilities. This study initially estimates equation (1) using the Translog specification taking the form:

$$lnY_i = \beta_0 + \sum_{j=1}^{J} \beta_j\, lnX_{ji} + {}^1/_2 \sum_{k=1}^{J}\sum_{j=1}^{J} \beta_{kj} lnX_{ji}\, lnX_{ki} + \sum_{m=1}^{M} \beta_m Z_{mi} + v_i - u_i \quad (2)$$

where $\beta_{kj}=\beta_{jk}$ (j, k =1,…,J).

The likelihood ratio test is used to test model specifications. If we fail to reject the null hypothesis, we re-estimate the production frontier using the Cobb-Douglas functional form.

For inefficiency term (u_i), scholars have proposed various distributional form such as the truncated-normal, half-normal, exponential and gamma distributions (Aigner et al., 1977; Meeusen & van Den Broeck, 1977; Stevenson, 1980). Up till now, there is no clear prior justification for the selection of a particular inefficiency distribution form. In this study, we investigated different distributional assumptions and found that models with a truncated normal distribution were difficult to identify. The LR test suggested that the half-normal distribution was better than the exponential distribution. Therefore, we decide to use the half-normal distribution for u_i.

We can present u_i as:

$$u_i = \delta_0 + \sum_{h=1}^{H} \delta_h W_{hi} + \epsilon \quad (3)$$

where δ_0 is the intercept, W_i is a vector consists of agent factors, on-farm and off-farm factors that might affect technical inefficiency, δ_h are associated inefficiency parameter coefficients, and ϵ is error term. The main inefficiency parameters of interest are irrigation-related variables. Details of variables in equation (2) and (3) are presented in the next section.

Subsequently, we predict TE using the estimator developed by Battese and Coelli (1988). TE is the ratio of actual outputs over the maximum attainable output. Its value ranges from 0 to 1. TE of a specific observation i is expressed as:

$$TE_i = \frac{E(Y_i|u_i > 0, X_i, Z_i)}{E(Y_i|u_i = 0, X_i, Z_i)} = \exp(-\widehat{u_i}) \quad (4)$$

where $\widehat{u_i}$ is the mean $E(u_i|\varepsilon)$.

To justify the appropriateness of our models, we need to test some hypotheses before presenting the results.

- Hypothesis 1: The frontier model specification for the data is the Cobb-Douglas production function. That is H_0: $\beta_{kj}=0$ in equation (2) versus H_1: $\beta_{kj}\neq 0$.
- Hypothesis 2: Environmental factors do not have a significant effect. That is H_0: $\beta_m=0$ versus H_1: $\beta_m\neq 0$.
- Hypothesis 3: There is no inefficiency effect. That is H_0: $\sigma^2_u=0$ versus H_1: $\sigma^2_u>0$.
- Hypothesis 4: Inefficiency effects are not a linear function of each inefficiency factor. That is H_0: $\delta_h=0$ in equation (3) versus H_1:$\delta_h\neq 0$.

A generalized log-likelihood ratio (LR) test can be used to test these hypotheses. These tests require estimation of the model under the null hypotheses and alternate hypotheses as well. The test statistic is calculated as:

$$LR = -2[ln\{L(H_0)\} - ln\{L(H_1)\}]$$

where $L(H_0)$ and $L(H_1)$ are the values of likelihood functions under the null hypothesis (H_0) and the alternative hypothesis (H_1) respectively. It is assumed that the test statistic has approximately a chi-square (χ^2) distribution or mixed χ^2 distribution with degrees of freedom equal to the number of restriction involved. The hypothesis will be rejected if LR is greater than the critical value.

We initially estimate parameters for plot-level models, and then for the household-level model. For plot-level models, information on inputs, output, and environmental factors were originally collected for individual plots while household-level models are generated by aggregating information for all rice plots cultivated by each household. Simultaneously, environmental variables are added to control for the effect of environmental factors.

5.4. Results, analysis and discussion

5.4.1. Descriptive statistics for rice farming at the study site

Table 5.1 reports summary statistics for all production-related variables including rice production output & inputs, environmental factors and all determinants of TE at both plot and household level. The first three groups of variables are used for production frontier models while the last group of variables are for technical inefficiency models.

Table 5. 1. Descriptive statistics for input, output and other production-related factors

Variables	Plot-level data			Household-level data		
	Mean	SD	SK	Mean	SD	SK
Production (kg)	660.4	435.9	1.63	1914.6	1328.9	1.69
Land area (*sao*)	2.92	2.02	1.81	8.46	5.96	1.55
Seed (kg)	13.04	8.38	1.70	37.82	26.03	1.49
Fertiliser (kg of active N, P, K)	95.10	62.94	1.59	275.69	191.8	1.40
Labour (person-days)	15.26	10.16	1.82	44.23	29.61	1.63
Waterlogged[a]	0.17	0.38	NA	0.16	0.32	1.83
Rat damage[a b]	0.53	0.50	NA	0.53	0.48	-0.09
Pest &disease infestation[a b]	0.64	0.48	NA	0.65	0.43	-0.63
Poor soil[a]	0.21	0.41	NA	0.10	0.25	2.62
High-lying plots[a]	0.33	0.47	NA	0.30	0.35	0.78
Irrigation sufficiency[a]	0.56	0.50	NA	0.53	0.43	-0.15
Irrigation timeliness[a]	0.72	0.45	NA	0.70	0.41	-0.88
Irrigated by pump[a]	0.30	0.45	NA	0.28	0.34	0.87
Main farmer with above average education[c] (dummy)	0.22	0.42	NA	0.22	0.42	NA
Composite participation index	-0.01	0.96	0.08	-0.01	0.96	0.08
Training attendance (dummy)	0.44	0.50	NA	0.44	0.50	NA
Proportion of rice farming income (%)	0.21	0.19	1.37	0.21	0.19	1.37
Row seeding (dummy)	0.12	0.33	NA	0.12	0.33	NA
Ploughing with medium tractors (dummy)	0.18	0.39	NA	0.18	0.39	NA
PIM (dummy)	0.47	0.50	NA	0.47	0.50	NA
Hai Lang district (dummy)	0.39	0.49	NA	0.39	0.49	NA

Note: 1 *sao* = 0.05 hectare; [a] Coded as dummy variable at plot level and as % of household cultivated area at household level; [b] Plots are coded as suffering rat damage or pest and disease infestation if more than 20% of plot area affected by these factors; [c] main farmers with more than 9 years in school.

Land holdings and plot size. Rice production in NTH irrigation system is still characterised by small-scale production. Around 72% of farmers cultivate 0.5 ha or less, and only 6% cultivate more than 1 ha. Plot sizes vary greatly (from 0.3 *saos* to 12.5 *saos*), and this distribution is skewed to the right with a small number of large plots. Given the land area is dramatically skewed to the right, it is not surprising that input quantities per plot and household also have right-skewed distribution.

Seed and Fertiliser. Although the Provincial extension centre recommends that farmers use a seed rate of 3.5 to 4.5 kg/*sao*, the majority of farmers (56%) still apply more than the recommended amount. They explain that they take rodent damage into account and hope to avoid spending additional labour replanting. Only 8% of households still use cattle manure together with chemical fertilisers while the rest apply 100% chemical fertilisers[20].

Rice production. On average, farmers harvested 660kg/plot and 1.9 tonnes/household in the 2017 Summer-Autumn (SA) season. These figures are equivalent to 4.6 tonnes per hectare which is quite low compared to the average district yields in the previous SA season (5.3 tonnes/ha in Trieu Phong district and 6.1 tonnes/ha in Hai Lang district). The fourth storm in the 2017 SA season was accompanied by heavy rains causing long-lasting waterlogging (over 6 days) and yield reduction for around 2,450 ha of rice land in Quang Tri province (Van Hai, 2017). In our sample, 17% of plots and 16% of the household cultivated area suffered long-lasting waterlogging. Moreover, half of the plots and 53% of the household cultivated area was damaged by rats while 64% of plots and 65% of the household area suffered pest and disease infestation.

Irrigation. 56% of plots received sufficient irrigation and 72% received this irrigation on time. These figures at the household level are 53% and 70% of the household cultivated area respectively. Pumps provide water for 30% of plots (28% of the cultivated area), and the remainder is irrigated from canals using furrow irrigation.

Farming practices. 12% of households adopt row seeding with drum seeders to reduce seed usage and enhance yield while the rest use broadcast seeding. The higher labour

[20] Farmers use both single fertilisers (urea, phosphate, potassium) and intergrated fertilisers (NPK with different ratios). We converted intergrated NPK into single fertilisers and sum up to measure total fertiliser usage.

requirement for land preparation and seeding constrains a potentially greater uptake of drum seeders, even though farmers can obtain a 50% subsidy to buy drum seeders and some ACs own drum seeders for the use of their members.

With the application of machinery in some labour-intensive tasks such as land ploughing and harvesting, farmers have reduced the amount of labour input for rice farming. Only six sampled farmers still used buffalo to plough land, with the majority hiring small tractors for tillage, of which 18% hired medium tractors.

It may be suggested that our environmental variables are not truly exogenous as farmers can influence them to some extent. For example, farmers can use more labour and more pesticide to control pests, diseases and rats. However, the correlation matrix between environmental factors and input usage in Table 5.2 shows that there is no strong correlation between input variables and environmental variables. Therefore, we can consider these environmental variables as "partially" exogenous variables.

Table 5. 2. Correlation matrix between environmental variables and input variables

Variable	Land	Seed	Fertiliser	Labour
Plot-level data				
Waterlogging	0.054*	0.075**	0.028	0.008
Rat damage	-0.055*	0.003	-0.081***	-0.011
Pest and disease infestation	0.041	0.057*	0.013	0.091***
Poor soil	-0.071**	-0.069**	-0.055*	-0.023
High-lying plots	0.061**	0.045	0.059*	0.041
Household-level data				
Waterlogging	0.136***	0.152***	0.099***	0.061**
Rat damage	-0.036	0.025	-0.062**	0.012
Pest and disease infestation	0.014	0.031	-0.016	0.074**
Poor soil	-0.049	-0.069**	-0.057*	-0.017
High-lying plots	0.189***	0.164***	0.18****	0.178***

Note: Inputs are in the log form; *** p<0.01, ** p<0.05, * p<0.1

5.4.2. Production frontier parameters and technical efficiency scores

Parameter estimates for plot-level and household-level production frontiers without environmental factors (restricted models) and with environmental factors (full models) are reported in Table 5.3. The likelihood ratio (LR) test indicates that the Cobb-Douglas functional form (H_0: β_{kj}=0) is rejected in both the plot and household-level models at the 1% and 5% levels of significance. Therefore, we use the translog form for all production function models. Moreover, the value of lambda (λ), which represents the ratio of technical inefficiency (u) over stochastic error (v), is always greater than 1. This implies that there is significant technical inefficiency amongst sampled plots and households. Therefore, application of the stochastic production frontier approach is appropriate for our data set.

Table 5. 3. Stochastic production frontier estimates

VARIABLES	Plot level		Household level	
	Restricted model	Full model	Restricted model	Full model
Land	-5.26***	-5.45***	-4.85**	-3.74
	(1.57)	(1.60)	(2.36)	(2.32)
Seed	3.63***	3.59***	4.00**	3.36**
	(1.21)	(1.20)	(1.67)	(1.64)
Fertiliser	2.23***	2.75***	0.99	1.12
	(0.71)	(0.76)	(1.04)	(1.00)
Labour	1.06***	0.99***	1.52***	1.09*
	(0.35)	(0.37)	(0.53)	(0.56)
Land x Seed	1.32**	1.25**	2.16***	1.69**
	(0.59)	(0.58)	(0.81)	(0.79)
Land x Labour	0.47***	0.38***	0.70***	0.42*
	(0.14)	(0.14)	(0.21)	(0.22)
Land x Fertiliser	0.90***	1.00***	0.26	0.22
	(0.29)	(0.30)	(0.44)	(0.43)
Seed x Labour	-0.10	-0.04	-0.17	-0.00
	(0.13)	(0.13)	(0.17)	(0.17)
Seed x Fertiliser	-0.75***	-0.69***	-0.21	-0.16
	(0.27)	(0.26)	(0.38)	(0.36)
Fertiliser x Labour	-0.18**	-0.14	-0.23*	-0.12
	(0.08)	(0.09)	(0.14)	(0.13)
½ $Land^2$	-2.48***	-2.33***	-2.90***	-2.02**
	(0.70)	(0.69)	(1.04)	(1.03)
½ $Seed^2$	-0.54	-0.69	-1.88**	-1.67**
	(0.62)	(0.61)	(0.81)	(0.79)
½ $Fertiliser^2$	-0.16	-0.35*	0.03	-0.09
	(0.19)	(0.20)	(0.26)	(0.25)
½ $Labour^2$	-0.16**	-0.22***	-0.27**	-0.33***
	(0.07)	(0.07)	(0.11)	(0.11)
Waterlogged		-0.22***		-0.21***
		(0.02)		(0.03)
Rat damage		-0.04***		-0.05***
		(0.01)		(0.02)
Pest and disease infection		-0.03**		-0.02
		(0.01)		(0.02)
Poor soil		-0.01		-0.02
		(0.01)		(0.03)
High-lying plots		0.02		0.04**
		(0.01)		(0.02)
Constant	-2.29	-3.17	-1.10	-0.64
	(1.87)	(1.94)	(2.85)	(2.75)
Observations	977	977	337	337
Log likelihood	286.2	377.3	152.5	186.2
df_m	14	19	14	19
chi2	18595	16592	10332	9722
Lambda ($\lambda=\sigma_u/\sigma_v$)	5.20	2.58	5.37	3.11
Specification tests	Test statistics	Test statistics	Test statistics	Test statistics
H_0: Cobb-Douglas functional form	37.88***	36.34***	52.87***	19.00**
H_0: No environmental factor	NA	182.20***	NA	67.39***

Note: Standard error in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The result from Table 5.3 shows the impact of rice inputs on output. Rice output is significantly correlated with all inputs in the models, with the exception of fertiliser input in the household-level models. Moreover, environmental factors clearly affect output. Plot outputs decrease significantly under unfavourable environmental conditions such as waterlogging, pest or disease infestation, and rat damage. Notably, waterlogging is associated with an average drop in plot output of around 22% and household output of 21%. However, poor soil do not lead to a statistically significant change in plot and household rice output.

The LR test for the joint significance of environmental factors (H_0: β_m=0) demonstrates the superiority of the full model. The null hypothesis is rejected at the 1% level of significance for both plot and household-level models. Accordingly, full models which control for environmental factors are better than the restricted models.

When we omit plot-specific environmental factors, estimates of input-related parameters are biased. This pattern is more apparent when we look at Table 5.4 which reports the output elasticity at mean input levels. These estimates are generally downward biased in the plot-level model and upward biased in the household model. This trend reflects two drivers. First, plot rice output in the SA season is strongly impacted by environmental factors. Thus, when we omit environmental factors associated with yield loss caused by bad weather and pest, rat and disease infestations, we underestimate the influence of input on output. Second, because information on environmental factors is collected at plot level, the effect of controlling these factors on parameter estimates is consistent at the plot-level model. For the household-level model, the difference in the plot-specific characteristics between households may be ambiguous since each household normally has several plots with different geographic conditions.

Table 5. 4. Output elasticity at mean input levels

Production input	Plot level		Household-level	
	Restricted model	Full model	Restricted model	Full model
Land	0.856***	0.869***	0.957***	0.957***
	(0.049)	(0.052)	(0.082)	(0.080)
Seed	-0.020	-0.049	-0.082	-0.059
	(0.044)	(0.047)	(0.069)	(0.069)
Fertiliser	0.085***	0.080**	0.036	0.031
	(0.031)	(0.033)	(0.047)	(0.048)
Labour	0.056***	0.073***	0.074***	0.065**
	(0.017)	(0.018)	(0.026)	(0.028)
Return to scale	0.977	0.973	0.985	0.994

Note: Standard error in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Once we include environmental factors, the gap in output elasticity between the plot and household-level models narrows. Accordingly, this comparison provides initial evidence of the similarity of parameter estimates from aggregate household-level data with those deriving from plot-level data once environmental factors are controlled.

Output is most responsive to land area in all models. If other inputs remain constant, output increases between 0.86-0.96% if farmers add 1% of land area. A 1% increase in the use of fertiliser or labour leads to an increase in output of less than 0.1%. Seeds seem to be overused with negative output elasticity but these estimates are not significant in all models. The level of output elasticity with respect to inputs is similar to the results of Fuwa et al. (2007) in India, and Chang and Wen (2011) in Taiwan. Fuwa et al. (2007) found that rice output is most responsive to land at the ratio of 0.62% increase in output for 1% increase in land. Moreover, the impact of seed, fertiliser and labour range between 0.07% to 0.14% in a study by Chang and Wen (2011) and between 0.03% and 0.33% in a study by Fuwa et al. (2007).

The estimated returns-to-scale computed as the sum of output elasticities of all inputs varies slightly from 0.973 to 0.994 across the models. These estimates suggest that rice farming in the study site does not exhibit diseconomies of scale.

We also find that omitted environmental factors lead to biased TE scores. Table 5.5 presents the summary statistics of TE while Figure 5.2 illustrates the cumulative distribution functions of TE. In both plot and household-level models, the two-sample t-test shows that there is a statistically significant increase in TE once environmental factors are included in the models. Figures 5.2a and 5.2b support this result as the cumulative distribution functions for the full models lie completely to the right of the line for the restricted models. This result is consistent with the finding of Sherlund et al. (2002).

Table 5. 5. Technical efficiency summary statistics

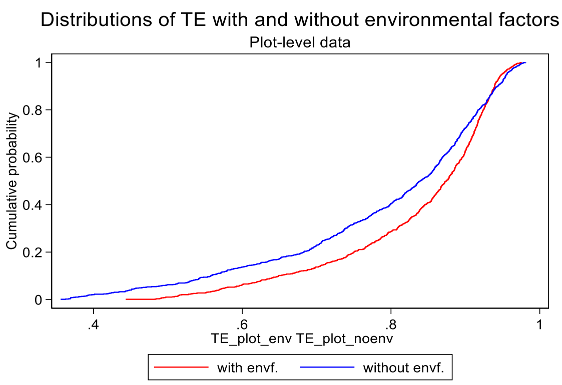
Data level	Model specification	Mean	Std.Dev./Std.Err.	Min	Max	Obs
Plot level	Restricted model	0.793	0.149[a]	0.356	0.981	977
	Full model	0.835	0.113[a]	0.443	0.976	977
	Difference	-0.042***	0.002[b]			
Household level	Restricted model	0.814	0.141[a]	0.369	0.983	337
	Full model	0.847	0.114[a]	0.458	0.978	337
	Difference	-0.033***	0.003[b]			
Difference bw. plot full model and HH restricted model		0.021**	0.009[b]			
Difference bw. plot full model and HH full model		-0.012*	0.007[b]			

Note: *** p<0.01, ** p<0.05, * p<0.1; Envf. Environmental factors; [a]Standard deviation; [b]Standard error

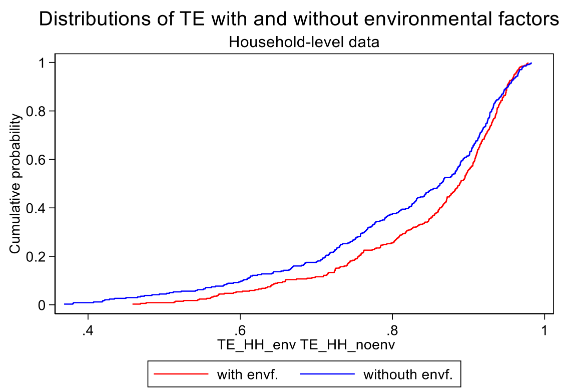
When we compare TE scores between the plot and household models using the Welche t-test, the mean difference is also statistically significant. This means that the TE achieved from the household-level restricted model is downwardly biased compared with the TE estimate for the plot-level full model. Figure 5.2c visually illustrates this bias. This result is consistent with the argument by Fuwa et al. (2007) that TE at plot level is higher than farm-specific TE because aggregated household-level estimates do not take plot-specific environmental conditions into account.

It is interesting to note that the magnitude of difference and confidence level, at which the statistical test is significant, narrow down when we control for environmental factors. Specifically, when we test for the difference between the plot-level full model TE and the household-level full model TE, we still reject the hypothesis that they are equivalent, although only at the 10% level of significance. Figure 5.2d clearly shows the partial overlap of the TE cumulative distributions of the plot and household-level full models. This suggests that differences in TE are relatively small when environmental factors are included in the model. Fuwa et al. (2007) also compared TE at the household level with TE at disaggregated plot level separately for different rice varieties and land types. This comparison was not as robust as the analysis detailed above since Fuwa et al. use a subset of plot-level data to estimate TE and compare it with pooled household-level data. Moreover, they did not statistically test the difference in TE.

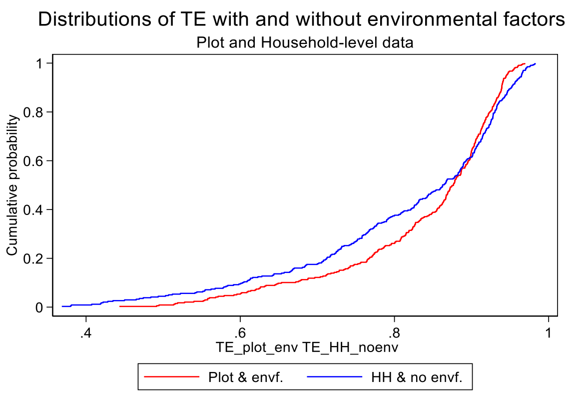
Our results suggest that it may be acceptable to use aggregate household-level data for total efficiency estimation provided these factors are properly controlled for environmental factors. This is a new result that has yet to be reported in the literature and it has strong practical implications for situations where plot-specific data is unavailable. Our findings will be very useful for future studies which aim to examine rice farming TE at regional or national levels.



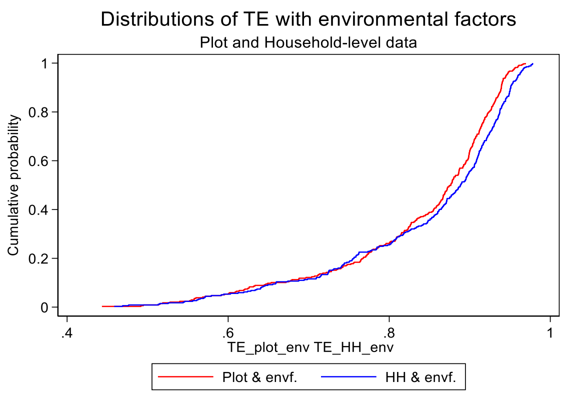
(a)



(b)



(c)



(d)

Figure 5. 2. Distribution of TE for different models

5.4.3. Technical inefficiency estimates

In this section, we consider the determinants of technical inefficiency and the way in which technical inefficiency estimates, especially irrigation, can be biased when we fail to control for environmental factors. Table 5.6 reports the parameter estimates of the technical inefficiency functions. Because they are technical *inefficiency* functions, negative signs on the coefficients mean that these parameters have a *positive* impact on TE.

Table 5. 6. Technical inefficiency function estimates

	Plot level		Household level	
VARIABLES	Restricted model	Full model	Restricted model	Full model
	(1)	(2)	(3)	(4)
Sufficient irrigation	-0.44***	-0.58***	-0.38*	-0.53**
	(0.11)	(0.13)	(0.22)	(0.24)
Timely irrigation	0.06	-0.08	0.22	0.05
	(0.11)	(0.13)	(0.22)	(0.24)
Irrigated by pump	-0.22*	-0.21	-0.29	-0.13
	(0.12)	(0.13)	(0.29)	(0.33)
Participation index	0.05	0.03	-0.04	-0.04
	(0.06)	(0.07)	(0.11)	(0.12)
Main farmer with above average education	-0.41***	-0.61***	-0.28	-0.47*
	(0.12)	(0.16)	(0.22)	(0.25)
Training course attendance	0.03	0.01	-0.04	0.03
	(0.11)	(0.12)	(0.18)	(0.20)
Share of rice farming income	1.06***	0.65*	1.27**	1.06*
	(0.30)	(0.34)	(0.53)	(0.56)
Row seeding	0.15	0.12	0.12	0.13
	(0.16)	(0.18)	(0.29)	(0.31)
Ploughing with medium tractor	-1.43***	-1.42***	-1.79***	-1.78***
	(0.16)	(0.20)	(0.29)	(0.35)
PIM	0.35***	0.37**	0.10	0.20
	(0.13)	(0.15)	(0.23)	(0.25)
Hai Lang District	-0.87***	-1.06***	-1.12***	-1.38***
	(0.12)	(0.14)	(0.21)	(0.24)
Constant	-1.85***	-2.07***	-2.05***	-2.29***
	(0.15)	(0.18)	(0.28)	(0.31)
Specification test	Test statistics	Test statistics	Test statistics	Test statistics
H0: No inefficiency	257.76***	51.91***	101.16***	35.62**
H0: No explanatory	190.27***	163.94***	92.35***	80.76***

Note: Standard error in parentheses; *** p<0.01, ** p<0.05, * p<0.1

We find that irrigation adequacy is significantly associated with higher TE (low technical inefficiency) while timeliness of irrigation, pump-based irrigation and farmer participation in irrigation management do not significantly explain the variation in inefficiency. Main farmers who have above average levels of education (more than 9 years in formal education) are associated with higher TE than farmers with less formal education.

A higher proportion of farmer income from rice farming is associated with lower TE. This result is broadly consistent with findings by Chang and Wen (2011) in Taiwan but is opposite to what Yao and Shively (2007) found in the Philippines. An improved farming practice, such as ploughing with medium tractors, has a significant positive impact on TE while row seeding does not significantly explain variation in TE.

At the plot level, inclusion in the PIM project is correlated with lower TE at the 5% significance level, but any correlation is statistically insignificant in household-level models. Both plots and farmers in Hai Lang district are consistently more likely to achieve higher TE than those from Trieu Phong district.

The results of LR tests support our argument that variation in technical inefficiency is significantly explained by explanatory variables. Specifically, at the 1% and 5% significance levels, we reject both the null hypothesis that the standard deviation of technical inefficiency is equal to zero (H_0: σ_u=0) and the null hypothesis that all coefficients of explanatory variables in the technical inefficiency models are zero (H_0: δ_h=0).

A comparison between the different models shows that failure to control for environmental factors leads to downwardly biased estimates. Figure 5.3 and Figure 5.4 support this argument since the gaps between the TE distribution functions for irrigation adequacy are wider for full models than for restricted models at both plot (Figure 5.3a vs 5.3b) and household level (Figure 5.4a vs 5.4b).

All of these results indicate that including environmental factors in the production frontier helps to reveal the true influence of quality of irrigation on technical inefficiency.

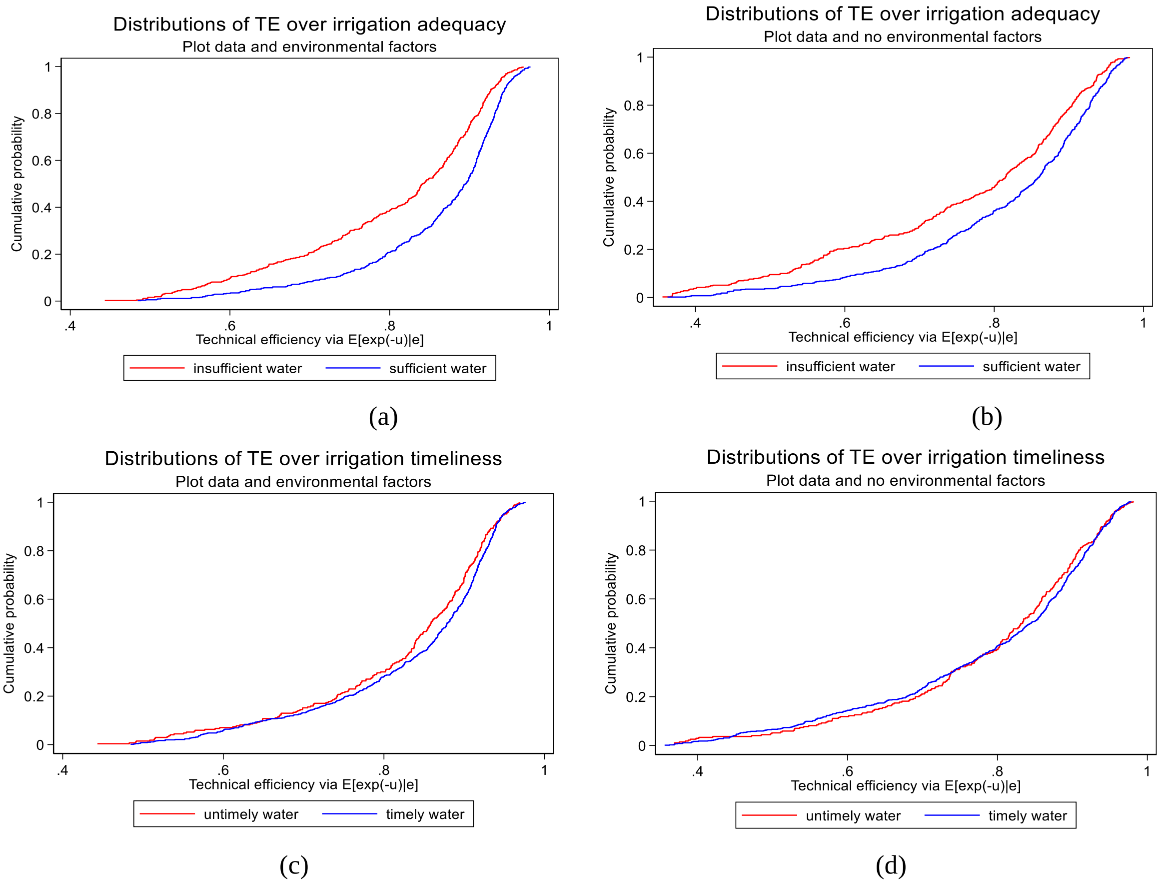


Figure 5. 3. Distribution of plot TE by the quality of irrigation service

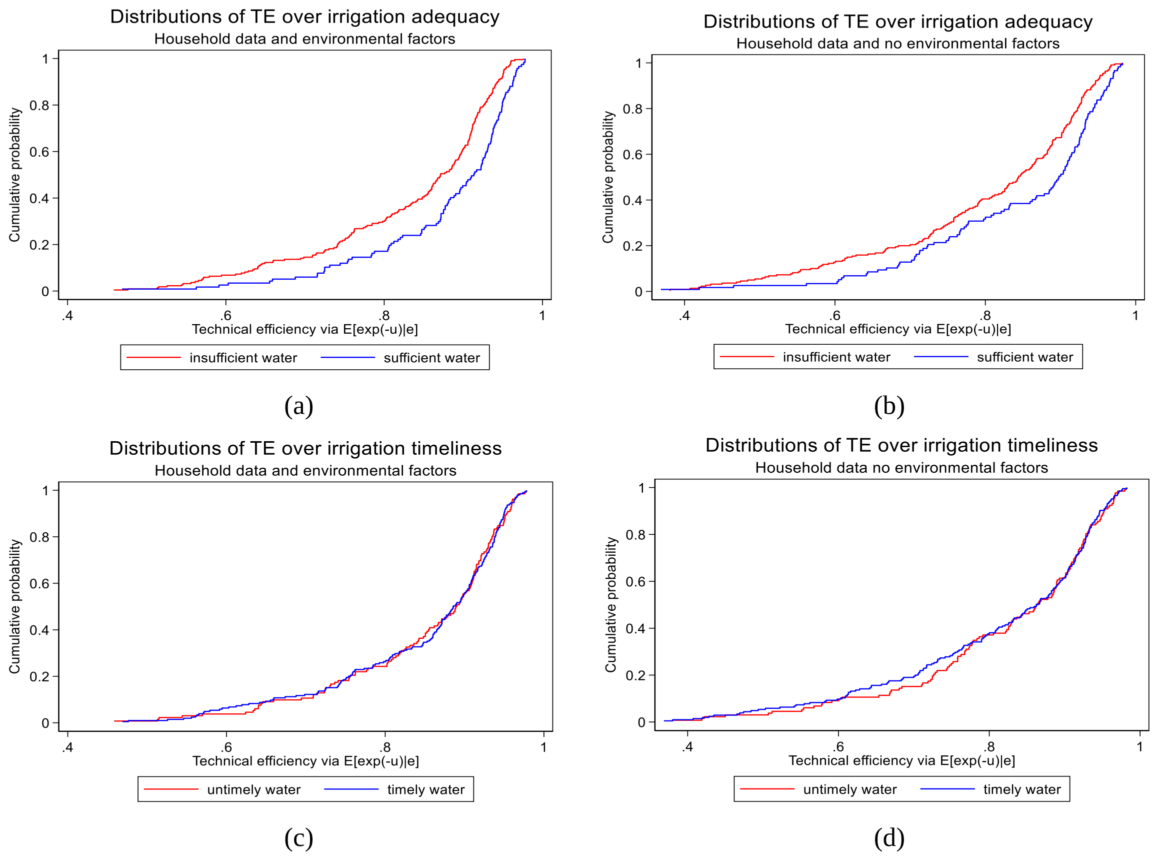


Figure 5. 4. Distribution of household TE by the quality of irrigation service

5.5. Conclusions

Over the last few decades, several authors have provided useful insights into the impact of irrigation-related factors on rice farming TE using stochastic production frontier approaches and household-level data sets. Some have criticised the use of household-level data because of the diversity of household plots and have noted that environmental conditions are latent drivers in determining variation in input usage and production output. This study is distinct from previous work in assessing TE and the impact of irrigation on TE at plot and household level while controlling for environmental conditions.

We find that irrigation sufficiency has a significant positive impact on TE while irrigation method and farmer participation in irrigation management are not significantly associated with TE. Farmer education, ploughing with medium tractors, and district are other important drivers of variation in TE. Using plot-level data, we find that input use is more efficient than we would have thought based on the more conventional household-level approach.

The impact of irrigation and other determinants may be underestimated if environmental factors are not controlled for. Omitted environmental factors may lead to biased estimates of TE score and biased inferences for determinants of technical inefficiency. Interestingly, once environmental factors are taken into account, the difference in the TE score generated from the plot-level model and the score for the household-level model is relatively small. In other words, if we manage to control for aggregate environmental factors, using aggregate household data still gives approximately unbiased estimates as with using plot-specific data.

Some policy implications can be drawn from our findings. First, irrigation sufficiency is expected to increase the TE of rice production. This is important given that there is little room left for the expansion of irrigated rice areas. Moreover, TE may be increased, by enhancing the education level of farmers and supporting the use of medium tractors that enable improved land preparation. Second, variation in plot-specific environmental conditions should be controlled for, in order to correctly explain differences in inter-plot output and TE between farmers. Third, studies using aggregate household-level data should pay attention to collecting data on aggregate environmental factors to reduce estimation bias.

Although our study yields some interesting findings, we recognise its limitations. For a start, this study uses cross-sectional data and investigates a small study site with limited diversity in terrain and climate conditions. This limits our capacity to investigate more deeply into the impact of irrigation and environmental conditions on TE and also prevents us from drawing broader inferences. In addition to this, the data on the quality of irrigation was reported by farmers, rather than being directly measured, meaning that it will be associated with some degree of measurement error. More convincing variables or more accurate measurements would be needed for more definitive results although this might be challenging in the context of Vietnamese irrigation schemes.

Chapter 6 - Conclusions

6.1. Overview

Irrigation plays an important role in supporting agricultural production and ensuring food security but it is also one of the greatest sources of pressure on global water resources. Moreover, governments across the world have been struggling to maintain deteriorating irrigation systems. Participatory irrigation management (PIM) has been promoted as a panacea for the poor performance and high cost of many public schemes. However, no clear consensus has been reached on the impacts of PIM and the factors associated with its success and failure (Araral, 2010; Meinzen-Dick, 1997; Senanayake et al., 2015).

In Vietnam, many researchers have studied PIM since it was first introduced in the 1990s. Low levels of farmer participation and the limited life of water user organisations (WUOs) established under the project have been commonly reported (Department of Water Resource, 2008; Huynh & Tessier, 2019; Le et al., 2015; Nguyen, 2008b). Researchers seeking to explain the success or failure of PIM have mainly focused on institutional and qualitative approaches to analyse the establishment of WUOs, their involvement in management, and their interaction with other stakeholders (Benedikter & Waibel, 2013; Evers & Benedikter, 2009; Fontenelle, 2001; Nguyen, 2008a, 2009; T. Pham, 2017; Pham, 2013; Tran, 2019). However, the involvement of farmers in operation and maintenance activities within WUOs, and the impact of their collective participation on irrigation performance, was little studied before the research detailed in this thesis.

Building on gaps in the literature with a focus on the Vietnamese context, this thesis examines (i) patterns of farmer participation and the factors that influence farmer participation in irrigation management within agricultural cooperatives, (ii) the impact of collective action on the quality (sufficiency and timeliness) of irrigation that farmers receive, and (iii) the impact of irrigation quality on rice farming technical efficiency, while controlling for environmental factors.

6.2. Main findings

Factors affecting farmer participation (Chapter 3)

Farmer perceptions of AC governance and leadership are one of the main drivers of participation. Farmers with a higher evaluation of AC information transparency and democracy in decision making are more likely to engage in monitoring activities and decision making. Similarly, farmers who believe that AC leaders have adequate qualifications are more likely to join in all forms of collective action. Sharing of second-level canals seems to be an obstacle to cooperation amongst farmers since farmers in ACs with shared canals are less likely to participate in all forms of irrigation management activities.

The relationship between collective action and irrigation quality (Chapter 4)

Observation of farmer participation in certain major activities in Chapter 3 led to an examination of the relationship between collective action and irrigation quality in the Summer-Autumn season. A higher percentage of farmers contributing labour or money is associated with a higher probability of plots receiving sufficient and timely irrigation. In addition, higher levels of farmer attendance at meetings are positively associated with more timely irrigation. However, the impact of collective action is underestimated if local contextual factors such as irrigation infrastructure, irrigation governance, and farming practices are not controlled for.

Moreover, some managerial and physical factors were found to be significantly correlated with irrigation quality. Specifically, more educated AC leaders are associated with a higher probability of attaining sufficient and timely irrigation, while AC leaders who have been in their posts for longer are associated with a lower probability. An increase in the irrigated area managed by each water deliverer, or which is served by third-level canals, reduces the probability that plots receive sufficient and timely irrigation.

The impact of irrigation on rice farming technical efficiency (Chapter 5)

The essential role of irrigation in rice production is strongly supported in this thesis by the finding that irrigation sufficiency has a significant positive impact on rice farming technical efficiency. Moreover, failure to control for plot-specific environmental factors, such as unfavourable physical attributes, and flooding and damage caused by rats, pests and disease, results in an underestimation of the impact of irrigation on technical inefficiency.

Comparing plot and household-level stochastic production frontiers shows that input use at plot level was more efficient than has been suggested using conventional household-level approaches. Interestingly, controlling for environmental factors while using aggregate household data still gives approximately unbiased estimates of TE as with plot-specific data.

Overall findings on the PIM project

Although the PIM project finished in 2012, it was expected to have a lasting impact on irrigation system management and performance. Therefore, the linkages between the PIM project and farmer participation and irrigation performance are examined in Chapter 3, 4, and 5. Farmers from ACs that were included in the PIM project are more likely to participate (in general), particularly in decision-making and input contribution. However, plots located in PIM ACs receive less timely irrigation than those in non-PIM ACs. This may be because ACs selected for inclusion in the PIM project were more likely to suffer from irrigation problems.

6.3. Policy implications

The findings detailed above reveal the relationship between participation, irrigation quality, and rice farming technical efficiency, by which more farmer participation leads to better irrigation quality which in turn enhances farming technical efficiency. Effective participation is the key: if it is enhanced, then a series of positive consequences are likely to follow. Therefore, policy recommendations should start with measures that can increase farmer participation.

At the scheme level, the integration of PIM into irrigation projects can increase farmer engagement in irrigation management which may then lead to improvements in irrigation quality through farmer involvement in collective action. Moreover, given the finding that sharing of second-level canals is a hindrance for farmer participation, it is suggested that some current aspects of the PIM approach such as (re)-establishing WUGs to avoid sharing of second-level canals and improving cooperation between WUGs under WUAs seem to be useful practices. Policies/institutions to stimulate the establishment of WUGs and WUAs, based on hydraulic boundaries, need to be investigated with the aim of improving farmer participation and irrigation performance.

Local institutions play a key role in supporting effective farmer participation. As such, policymakers should support efforts to improve AC governance, to increase information transparency and democratic decision-making, which create fertile ground for the involvement of farmers in AC irrigation management activities. Moreover, policies to enhance the quality of AC staff, especially leaders, should be developed since this has been shown to affect levels of farmer participation as well as irrigation quality.

The thesis also suggests there is a potential for enhancing rice farming technical efficiency through improving irrigation sufficiency. Government and NGOs should work towards improving irrigation quality, specifically the sufficiency of water delivery in order to increase agricultural production. Measures to support rice production mechanisation (such as the use of medium tractors for improved land preparation) should be considered since this appears to be a potential approach to increasing TE.

6.4. Contributions to the literature

Participatory approaches have been promoted in Vietnam for more than twenty years but this is the first empirical study to use econometric models to examine the determinants of participation and the effect of collective action in irrigation management, on irrigation quality.

Moreover, this thesis provides insights into the involvement of farmers in the daily activities of local water user organisations in Vietnam, a topic which is understudied in the literature.

Principle components analysis is used in a new way to generate participation indices based on twelve different irrigation management activities. This enabled the creation of multi-dimensional indices which more correctly represent the diversity in the pattern and level of farmer participation. This contrasts with previous studies which mostly defined participation based on a small number of activities.

This thesis explores the impact of the AC institution on farmer participation, using farmers' 'insider' perceptions of information transparency and democratic decision-making. This is particularly relevant to the study site where WUAs established as part of PIM projects normally stop working after the project finishes and where the rules set up in PIM projects are no longer followed.

Collective action by the members of WUOs has a direct impact on irrigation performance, but only a handful of studies (Mushtaq et al., 2007; Vandersypen et al., 2009) focus on the impact of these actions on irrigation performance. This thesis broadens our understanding of this important relationship by providing further empirical evidence on the relationship between collective action and irrigation quality in Vietnam.

This thesis also provides the first analysis of the effect of sufficient and timely irrigation on rice farming technical efficiency, while controlling for plot-specific environmental factors. Some authors have indirectly evaluated the impact of irrigation quality on farming TE through farm location and the quality of irrigation infrastructure (Alam et al., 2012; Gedara et al., 2012; Mekonnen et al., 2016; Yao & Shively, 2007), but they have not analysed the direct influence of irrigation quality, specifically sufficient and timely irrigation on TE. This thesis provides more insight into the relationship between irrigation and rice production and it highlights the importance of controlling for environmental factors to gain more precise estimates.

An important contribution, detailed in this thesis, is in the comparison of plot and farm level TE while controlling for environmental factors. Measurement of farming TE at the household level, when heterogeneous production conditions across household are not taken into consideration, leads to biased estimates of farming TE, as has been noted in the literature (Fuwa et al., 2007; Sherlund et al., 2002). Using aggregate household data gives approximately unbiased estimates of TE as with plot-specific data if environmental factors are controlled for. This approach challenges previous findings by detailing a practicable method of producing unbiased estimates using household-level data. This also suggests that collection of household-level data on environmental factors can be a good alternative option when information on plot-specific environmental factors is hard and costly to collect.

6.5. Recommendations for further research

One of the limitations of this thesis is that irrigation timeliness and sufficiency had to be assessed based on farmer recall and perceptions. Improvements to water use efficiency are vital to the future development of the agricultural sector in Vietnam. This will require better data, so installation of devices to measure the volume and timing of water distributed to selected representative canals and plots is highly desirable. Once this data has been obtained then more accurate insights into the efficiency of water usage can be obtained using these plot-level measurements.

Spatial analysis is another area that deserves further work. This should focus on spatial aspects of the relationship between participation and irrigation quality and between irrigation and agricultural production. Successful (or unsuccessful) irrigation management and farming practices may have spillover effects which accelerate or reduce adoption by neighbours. This may lead to spatial correlation amongst farmers or ACs in term of participation or rice farming technical efficiency. Therefore, further work using spatial econometric models may provide a better understanding of these spatial correlations and provide some additional insights.

Chapter 7 - Limitations

This thesis mainly concentrates on the relationship between farmer participation in AC irrigation management activities and irrigation performance at the household and plot level. It does not investigate the interaction between ACs and higher-level entities, such as NTHIME, nor does it take account of irrigation performance measured at AC and scheme level. Focusing on households and ACs within one irrigation scheme allows for the control of external contextual factors, such as state regulations and heterogeneity caused by irrigation infrastructure, climate and other factors.

Some other limitations result from the availability of secondary data and the information that it was feasible to collect. Data on the volume of water distributed to individual households and plots is not available. Reverse causality between participation and irrigation quality could not be controlled because I used cross-sectional data which limited my ability to develop lagged instrumental variables. Moreover, the robustness of the relationship between collective action at AC level and irrigation quality at plot level was limited by the relatively small number of ACs that could be included in this study.

This study is based on a relatively small study site with limited diversity in terrain and climate conditions. This limits our capacity to draw broader inferences on the impact of irrigation and environmental conditions on rice farming technical efficiency.

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Appendix 1: Household questionnaire

THE UNIVERSITY OF WAIKATO

Waikato Management School

Department of Economics

HOUSEHOLD QUESTIONNAIRE

Interviewer: ……………………………………………… ………………….

Interviewee ID: ………………………………. .[1] Head of household

[2] Spouse of head of household

[3] Other household member

Do you have rice land irrigated by Nam Thach Han irrigation system ☐ YES ☐ NO ➔ Stop interview

Date of Interview: Day…….. Month………Year……… Name of the AC………………………………………

Start time: ………………… End time:………………. Address: District………………………………………

Data checked by:………………………………… Under PIM project: ☐ YES ☐ NO ☐ Don't know

Data entry by:…………………………………………… Village: ………………………… Ward No………………

Survey supervisor Interviewer

(sign) (sign)

Note: Survey supervisor only sign after checking all the sections of the questionnaire and visiting households in order to check that they are interviewed on the mentioned day.

SECTION 1A: HOUSEHOLD ROSTER (GENERAL CHARACTERISTICS OF HOUSEHOLD MEMBERS BELONGING TO HOUSEHOLD)

HOUSEHOLD MEMBER CODE	1A1	1A2	1A3	1A4	1A5	1A6	1A7	1A8	1A9	1A10	1A11	1A12	1A13
	Names of each household members	Relation to head of household 1. Head 2. Spouse 3. Child 4. Parent 5. Parent in law 6. Grandparent 7. Grandparent in law 8. Grandchild 9. Sister/brother 10. Other relatives 11. Not related	Gender 1. Male 0.Female	What year was [NAME] born?	Education (No. of years spent in formal education)	Has [NAME] been a migrant labourer for the last 12 months? (member aged ≥ 15 only) 1 = NO 2 = Yes, seasonal migrant labourer 3 = Yes, permanent migrant labourer	Why [NAME] has migrated? 1. insufficient arable land due to farmland revocation 2. to earn higher income than rural jobs 3. to diversify income sources 4. unable to find a job in the village	What occupation has [NAME] done for the last 12 months? 1. Farming 2. Labour hire in non-farm activities 3. wage employment 4.trading, service and self-employment business 5. Other……..	How many days has [NAME] done rice farming activities in the last 12 months?	How many days has [NAME] done other farming activities in the last 12 months?	How many days has [NAME] done as hired labour in the last 12 months?	How many days has [NAME] done wage employment in the last 12 months?	How many days has [NAME] done self-employed business in the last 12 months?
	TEXT	CODE	CODE	YEAR	No of YEAR	CODE	CODE	CODE	DAYS	DAYS	DAYS	DAYS	DAYS

SECTION 1B: HOUSING

1B2	How long has the household lived in this commune?	**…….. YEAR**
1B3	How many m^2 does your household occupy? This excludes area used primarily for business activity	**…………M²**
1B4	What is the main construction material of the outside walls?	1. Leaves/branches/ bamboo 2. Wood 3. Galvanized iron 4. Earth 5. Brick (fired or unfired) 6. Concrete 7. Other (specify)
1B5	Flooring material?	1. Earth, lime and ash 2. Cement 3. Brick 4. Marble, tile 5. Other…………
1B6	Roof material?	1. Straw, leaves 2. Canvas, tar paper 3. Galvanized iron 4. Tile 5. Concrete, cement 6. Other……….
1B7	Does this household have a television?	1. Yes 2. No

1B8	Do you store your perishable food in a refrigerator?	1. Yes 2. No 3. Don't have a refrigerator
1B9	What is the main source of energy for cooking in your household?	1. Firewood 2. Electricity 3. Kerosene 4. Coal 5. Natural gas 6. Other
1B10	What is the main source of cooking/drinking water of your household?	1. Private tap water 2. Public tap water 3. Bought water 4. Water pump from drill wells 5. Water from hand-dug wells 6. Water from tank 7. Springwater 8. River, lake, pond 9. Rainwater 10. Other
1B11	What type of toilet does your household have?	1. Flush toilet with septic tank 2. Suilabh (Squat toilet) 3. Double vault compose latrine 4. Toilet directly over water 5. No toilet
1B12	Is your household currently classified as poor by the authority? (MOLISA)	1. Yes 2. No 3. Don't know

SECTION 1C: LAND

1C1	What size is your family's owned farmland in the last 12 month?	1. Rice land. ……………………… *sao* 2. Other cropland.. ……………..… *sao* 3. Forest land. …………………..…*sao* 4. Aquaculture land. ……………… *sao*
1C2	What size of farmland is rented out in the last 12 month?	……………………………………. *sao*
1C3	What size of farmland is rented in the last 12 month?	. ………………………… *sao*

1C4	What size of farmland is cultivated by your household in the last 12 month?	1. Rice land. ………………………… *sao* 2. Other cropland……. …………..… *sao* 3. Forest land. ……………………..……*sao* 4. Aquaculture land. ………………… *sao*
1C5	What size of farmland is irrigated in the last 12 month?	. ……………………………………… *sao*

SECTION 2. RICE PRODUCTION
2.A. PLOTS – CHARACTERISTICS

Plot code	2A1	2A2	2A3	2A4	2A5	2A6	2A7	2A8	2A9	2A10	2A11
	What is plot region's name?	Plot size	Number of rice cropping season per year 1. One season 2. Two seasons 3. Three seasons	Other crops cultivated in that plot LIST ALL OTHER CROPS GROWN ON EACH PLOT	Distance from plot to home	How many cropping seasons is irrigated? 1. One 2. Two 3. Three 4. None ➔ 2A8	Which source of irrigation water is mainly used on the plot? 1. Canal 2. Pump station 3. Water from spring, river 4. Water from pond or lake 5. Other	Who/what organization operate the water source? 1. NTHIMC 2. Agricultural cooperative 3. Household 4. Other	How does water in the plot drain off? CAN CHOOSE MORE THAN ONE 1. Flows directly to drainage canal 2. Flows through other plots 3. With automatic pumps. 4. Taken manually 5. Other	Who/what organization drain water in the plot? 1. NTH IMC 2. Agricultural cooperative 3. Household 4. Other	Does the plot have separate irrigation and drainage canals? 1. YES 2. NO
	TEXT	M^2	CODE	PLOT USE CODE	M	CODE	CODE	CODE	CODE	CODE	CODE
P1											
P2											
P3											
P4											
P5											
P6											
P7											
P8											
P9											

PLOT USE CODES:				
1.Maize	3. Sweet potato	5. Soy Bean	7. Other crop…………..	9. Left fallow.
2.Peanuts	4. Cassava	6. Vegetables	8. Aquaculture.	10. Not used.

PLOT CODE	2A12	2A13	2A14	2A15		2A16		2A17		2A18		2A19		2A20		2A21		2A22	
	Problems of this plot 1. Dry land 2. Low-lying land 3. High-lying land 4.Sedimentation 5. Other 6. No problem	Compared to the average water retention in the village, is the capacity of this plot 1. Less than average 2. Average 3. Better than average	Compared to the average land fertility in the village, is the quality of this plot 1. Less than average 2. Average 3. Better than average	Which plant disease and pest infestation affected your plot (over 20% of plot area)? (Referring plant disease and pest infestation code below)		Which rice growth stage did the plot suffer plant disease and pest infection? 1. Seeding /transplanting 2. Tillering 3. Panicle formation 4. Flowering 5. Maturity		Did the plot suffer waterlogging stress? 1. YES 2. NO		Which rice growth stage did the plot suffer waterlogging stress? 1. Seeding /transplanting 2. Tillering 3. Panicle formation 4. Flowering 5. Maturity		Was the plot affected by rodents (over 20% of plot area)? 1. YES 2. NO		Which rice growth stage were the plot affected by rodents (over 20% of plot area)? 1. Seeding /transplanting 2. Tillering 3. Panicle formation 4. Flowering 5. Maturity		Did the plot suffer water stress? 1. YES 2. NO		Which rice growth stage did the plot suffer water stress? 1. Seeding /transplanting 2. Tillering 3. Panicle formation 4. Flowering 5. Maturity	
				a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA
	CODE	CODE	CODE	CODE		CODE		CODE		CODE		CODE		CODE		CODE		CODE	
P1																			
P2																			
P3																			
P4																			
P5																			
P6																			
P7																			
P8																			
P9																			
P10																			

(WS = winter-spring season; SA = summer – autumn season)

PLANT DISEASE AND PEST INFECTION CODE				
1. Planthopper	4. Rice caseworm, fall armyworm	7. Blast disease	10. Bacterial bright of rice	13. Other…….
2. Rice leafroller	5. Thrips	8. Sheath blight	11. Bacterial leaf streak of rice	
3. Stem borer	6. Yellow rice disease	9. Rice tungro disease	12. Damping off	

2B. PRODUCTION OUTPUT (WS = winter-spring; SA = summer – autumn)

PLOT CODE	2B1 Rice varieties 1. KD 2. HT1 3. TU8 4. HC95 5. PC6 6. NA2 7 Nep 8. HN6 9. Other		2B2 Output (kg)		2B3 Selling price (000 VND/kg)		2B4 Total output loss (kg)	
	a. WS season	b. SA season	a. WS season	b. SA season	a. WS season	b. SA season	a. WS season	b. SA season
P1								
P2								
P3								
P4								
P5								
P6								
P7								
P8								
P9								

2C. PRODUCTION COST
2C1. Material input

Plot code: ………………	1. Winter-Spring season		2. Summer-Autumn season	
	a. How many units of this input did you use?	b. How much did you spend on this input?	a. How many units of this input did you use?	b. How much did you spend on this input?
	Kg/*Sao*	000 VND/ *Sao*	Kg/ *Sao*	000 VND/ *Sao*
2C11. Seeds				
2C12a.Organic fertilizers (self-provided)				
2C12b. Organic fertilizers (bought)				
2C13a. Urea				
2C13b. Phosphate				
2C13c. Potassium				
2C13d. NPK - Ratio……………				
1C14a. Pesticides	X		X	
1C14b. Herbicides	X		X	
2C15. Cost for rent/borrow land	X		X	
2C16. Fees of AC's services for rice farming	X		X	

Plot code: ………………	1. Winter-Spring season		2. Summer-Autumn season	
	a. How many units of this input did you use?	b. How much did you spend on this input?	a. How many units of this input did you use?	b. How much did you spend on this input?
	Kg/*Sao*	000 VND/ *Sao*	Kg/ *Sao*	000 VND/ *Sao*
2C11. Seeds				
2C12a.Organic fertilizers (self-provided)				
2C12b. Organic fertilizers (bought)				
2C13a. Urea				
2C13b. Phosphate				
2C13c. Potassium				
2C13d. NPK - Ratio……………				
1C14a. Pesticides				
1C14b. Herbicides				
2C15. Cost for rent/borrow land				
2C16. Fees of AC's services for rice farming				

Plot code: ………………	1. Winter-Spring season		2. Summer-Autumn season	
	a. How many units of this input did you use?	b. How much did you spend on this input?	a. How many units of this input did you use?	b. How much did you spend on this input?
	Kg/*Sao*	000 VND/ *Sao*	Kg/ *Sao*	000 VND/ *Sao*
2C11. Seeds				
2C12a.Organic fertilizers (self-provided)				
2C12b. Organic fertilizers (bought)				
2C13a. Urea				
2C13b. Phosphate				
2C13c. Potassium				
2C13d. NPK - Ratio……………				
1C14a. Pesticides				
1C14b. Herbicides				
2C15. Cost for rent/borrow land				
2C16. Fees of AC's services for rice farming				

2C2. Labour input

Activity		1. Technology	2. Winter-Spring season			3. Summer–Autumn season		
			a.Family labour	b.Hired labour	d.Cost of hiring labour/machine	a.Family labour	b.Hired labour	d.Cost of hiring labour/machine
			Labour/*sao*	Labour/*sao*	000 VND/*sao*	Labour/*sao*	Labour/*sao*	000 VND/*sao*
2C21	Land preparation -ploughing, harrowing,	1. Buffalo or Manual 2. Small tractor 3. Medium tractor						
	- levelling, repairing bunds							
2C22	Seed treatment	1. Seed priming 2.Chemical stimulate germination 3. None			X			X
2C23	Planting and replanting	1. Broadcast seeding 2. Transplanting 3. Row seeding with drum seeders			X			X
2C24	Weeding	1. Herbicide 2. Manual			X			X
2C25	Fertilizing				X			X
2C26	Spraying of Pesticides	1. Chemical 2. Biological			X			X
2C27	Water management - Water delivery - Water conservation				X			X
2C28	Harvesting	1. Manual 2. Mechanical						
2C29	Dry and storage				X			X

2D. EXTENSION SERVICE

2D1	Over the last 12 months, how many time did members of your household attend training courses on rice cultivation techniques?	………….. TIMES
2D2	What was the content of those training courses	……………………… ……………………….
2D3	How many time did members of your household seek advice/assistance from staffs of extension agents or plant protection stations?	………….. TIMES
2D4	How many time did staffs of extension agents, or plant protection stations visit your field?	………….. TIMES

2E. IRRIGATION SERVICE

2E1. WATER ADEQUACY:

2E11	**2E12**		**2E13**		**2E14**		**2E15**	
Plot code	What is the duration between 2 sequent rotations?		What is the duration that water is kept in the plot?		How many rotations does the plot receive insufficient water (water depth less than 7 centimetres)?		Generally, is the quantity of water available adequate to meet the needs of your particular field 1. Strongly disagree 2.Disagree 3. Agree 4. Strongly agree	
	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA	a. WS	b. SA
CODE	DAYS		DAYS		TIMES		CODE	
	2E16. Over the last 5 years, what is the trend of duration between 2 sequent rotation?		**2E17**. Over the last 5 years, what is the trend of duration that water is kept in the plot?		**2E18**. Over the last 5 years, what is the trend of the number of rotations with insufficient water?		**2E19**. Over the last 5 years, what is the trend of overall water adequacy?	
	1 = decrease 2= unchanged 3= increase							

2E2. TIMELINESS:

2E21	**2E22**	**2E23**		**2E24**		**2E25**	
Plot code	Was the water delivery schedules informed? 1= YES 2 = NO	How many rotations does water delivery delay?		How long is a water delivery delay?		Generally, is timeliness of water delivery reliable? 1. Strongly disagree 2.Disagree 3. Agree 4. Strongly agree	
		a. WS	b. SA	a. WS	b. SA	a. WS	b. SA
CODE	CODE	TIMES		DAYS		CODE	
		E26. Over the last 5 years, what is the trend of the frequency of water delivery delay?		**E27.** Over the last 5 years, what is the trend of duration of water delivery delay?		**E28.** Over the last 5 years, what is the trend of overall timeliness of irrigation service?	
		1 = decrease 2= unchanged 3= increase					

2E3. EQUITY

2E31	Does your household involve in any water-related dispute over the last 12 months?	1. Yes ⇩ 2. No ➔ 2E39
2E32	Which kind of dispute did you involve?	1. Water theft 2. Stolen turn 3. Different watering routine 4. Other……………
2E33	Has there been a time when your neighbours' plot received better treatment than yours?	1. Never 2. Hardly ever 3. Sometimes 4. Always

2E37	In general, who are the persons benefitting most from the system?	1.Head farmers 2. Middle farmers 3.Tail farmers 4. Rich farmers 5. Other…… 6. All equal➔2E311
2E38	If Not All equal, what favour do they receive?	1. More water 2. Take turn earlier 3. Other…………
2E39	Over the last 5 year, has the equity in AC's irrigation service declined, unchanged or increased?	1. Decrease 2. Unchanged 3. Increase 4. Don't know

2E4. AWARENESS OF WATER CONSERVATION

2E41	Which irrigation method is better for rice farming?	1. Continuous flooding 2. Alternative wetting and drying
2E42	What is sufficient duration for irrigation rotation 1. 2-3 days 3. 4-5 days 2. 3-4 days 4. 5-6 days	1. For Spring-Winter season……….. 2. For Summer-Autumn season……..

2E44	What is the sufficient depth of water in different growth stages of rice?	1. Seeding - 3 leaf seedling…………….cm 2. 3 leaf seedling - tillering …………….cm 3. Tillering - Panicle formation…………cm 4. Panicle formation – Flowering………cm
2E45	What water conservation practice did you apply to your plots?	**1.** Construct bund 2. Prepare land 3. Level the field 4. Construct field canals

2E5. IRRIGATION FEE

2E41	How much do you pay for irrigation fee annually?	…………….. 000 VND/*sao* Or ……………….kg of unhusk rice/*sao*
2E42	Have you ever owed irrigation fee over the last 5 years?	1. Never ➔ 2E44 2. Hardly ever 3. Sometimes 4. Always
2E43	What is the reason?	1. High irrigation fee 2. Financial constraint 3. Unsatisfied with irrigation service 4. Other………………………………

2E44	How much do you willing to pay more if you get a more adequate and reliable supply of irrigation water?	……………….. 000 VND/ *sao* Or ……………….kg of unhusk rice/ *sao*
2E45	What is your perception about the fairness of water charge, you pay in terms of receiving water services?	**1.** Totally unfair 2. Not fair 3. So- so. 4. Very well

SECTION 3: PARTICIPATORY IRRIGATION MANAGEMENT

3A. Please indicate the extent/level of your participation in the flowing irrigation management activities in the last 5 years

Code	Irrigation management practices	3A1 How many time does the event occur in AC over the last 12 months	3A2 How many times does you/your family member participation in this activity over the last 12 months	3A3 Over the last 5 years, what is your extent/level of participation in this activity 1. Never, 2. Rarely, 3. Sometimes, 4. Always
		TIMES	TIMES	**CODE**
1	Labour contribution for canal cleaning			
2	Labour contribution to repair canals and flood protection dike			
3	Fund contribution to construct or lining canals; to operate pump station in drought/flood; to repair flood protection dike			
4	Attention in General Meeting			
5	Attendance in water-related meeting			
6	Participation in electing AC's Board members			
7	Speak up in the meeting to discuss irrigation-related issue proposed by Board members	X		
8	Speak up in the meeting to propose irrigation-related issue to Board members	X		
9	Request responsibility of AC Board members	X		
10	Request explanation of AC's expenditure and revenue	X		
11	Report illegal water withdrawal	X		
12	Report equipment theft	X		
13	Report damage and leaking	X		
14	Participation in monitoring water delivery	X		
15	Participation in monitoring repair/maintenance	X		

3A4	Did you or any of your household members participate in the main activities of the PIM component of the CRWR project (2010-2013)?	1. Meeting to inform PIM component 2-6/2010 2. Meeting to choose WUG model (9/2010) 3, Meeting to generate operational rule (9-11/2010)	4. Training course on enhancing capability of WUG staffs 5. Design in-field canals 6. Monitoring and evaluation of canal construction

SECTION 4: PERCEPTION TOWARD AC

4A. OPERATIONAL RULE

4A1	Which allocation rule does AC apply	1. Fixed time slot 2. Fixed order 3. Other……………….. 4. Don't' know➔ **4A3**
4A2	Do you think it is a proper water distribution criteria?	1. Strongly disagree 2. Disagree 3. Agree 4. Strong agree
4A3	Which input contribution rule (for maintenance, repair, construction etc.) does AC apply	1. Equal rule per household 2. Proportional rule 3. Equal rule per *sao* 4. Don't' know ➔ **4A5**
4A4	To what extent do you think input rule is fair	1. Strongly disagree 2. Disagree 3. Agree 4. Strong agree

4A5	Which payoff/penalty rule does AC apply for not participating or paying irrigation fee?	1. Loss of appropriation right 2. Fines 3. Community shunning 4. Other…………… 5. Don't' know ➔ **4B**
	a. Not contribute labour/money for maintenance b. Not pay irrigation fee c. Water theft and stealing turn d. Cause damages for irrigation system	a.…………………… b.…………………… c.…………………… d.……………………..
4A6	Is there a gradation of penalty rules that varies with the severity of rule violations?	1. Yes 3. Don't know 2. No
4A7	Do you think that the penalty rules are enforced completely?	1. Never 2. Rarely 3. Sometimes 4. Always

4B. PERSONNEL

		1. Deficient	2. Adequate	3. Good	4. Excellent
4B1	In general, how would you characterize the quality of leadership in AC in terms of				
	a. Education/training	1	2	3	4
	b. Dynamism/vision	1	2	3	4
	c. Honesty/transparency	1	2	3	4
4B2	In general, how would you characterize the quality of irrigation teams in AC in terms of	1. Deficient	2. Adequate	3. Good	4. Excellent
	a. Capability in irrigation operation and maintenance	1	2	3	4
	b. Responsibility (complete tasks on time)	1	2	3	4
	c. Fair in water delivery	1	2	3	4

4B3	Do you think that board members of AC always keep promises	1. Never 2. Hardly ever 3. Sometimes 4. Always
4B4	Do you think that board members of AC are open and upfront with farmers	1. Never 2. Hardly ever 3. Sometimes 4. Always

		1. AC management	2. Irrigators	3. Community authority	4. District authority	5. Neighbours	6. Relatives
4B5	Who do you turn for help if (CAN CHOOSE MORE THAN ONE)						
	a. Canals are broken	1	2	3	4	5	6
	b. There is no water in your plots	1	2	3	4	5	6
	c. Water dispute in your plots	1	2	3	4	5	6
	d. Water dispute in your neighbour plots	1	2	3	4	5	6

4C. DECISION-MAKING PROCESS

4C1	When there is a decision related to irrigation management to be made in the AC, how does this usually come about?	1. The leader decides and informs to AC's members 2. The leader asks AC's members what they think and then decide 3.The group members hold a discussion and decide together 4. Don't know/not sure
4C2	What do you think about the influence of members' on AC's decision?	1. No 2. Low 3. Medium 4. High

4C3	What is the process for members to raise concerns in a meeting? (CAN CHOOSE MORE THAN ONE)	1. Speak out straight away in the meeting 2. Send requests to AC's office before the meeting 3. Contact with the Board members personally 4. Other……………………………… 5. Don't know/not sure
4C4	How likely are concerns raised by members resolved in the meeting?	1. Never 2. Hardly ever 3. Sometimes 4. Always

4D. TRANSPARENCY: If you want to know the following information, how accessibility is it?

		1 = Never	**2 = Hardly ever**	**3 = Sometimes**	**4 = Always**
4D1	Information about irrigation schedule	1	2	3	4
4D2	Information about maintenance schedule	1	2	3	4
4D3	Information on individual farmer's financial contribution	1	2	3	4
4D4	Information about AC revenue and expenditure	1	2	3	4
4D5	Information on penalty of individual farmers for rule violations	1	2	3	4

4E. SATISFACTION: Do you satisfy with services provided by AC?

4E1		1. Strongly unsatisfied	2. Unsatisfied	3. Satisfied	4. Strongly satisfied
	a. Irrigation and drainage service				
	b. Input supply				
	c. Land preparation				
	d. Harvesting				
	e. Plant protection				
	f. Extension				
	g. Veterinary				

SECTION 5. HOUSEHOLD INCOME

During the last 12 months, approximately how much was your household's net income from the following sources - including cash and in-kind payments?

Agricultural income		'000 VND
51a	Rice crop (plus amount consumed at home)	
51b	Non-rice crop (plus amount consumed at home)	
	Crop 1 (Specify:………………………………..)	
	Crop 2 (Specify………………………………..)	
	Crop 3 (Specify:………..…………………..…..)	
51c	Livestock/poultry	
	Specified…………………………………	
	Specified…………………………………	
51d	Aquaculture - Specify…………………………….	
	- Specify……………………………..	
51e	Labour (on-farm worker as a hired labour)	
51f	Capital rentals	
	machinery rented out	
	land rented out	

Non-agricultural income		'000 VND
52a	Wage/salary	
52b	Self-employment	
52c	Off-farm hired labour	
52d	Private pension	
52e	Remittance	
52f	Other (specify)……………………………………	

Appendix 2: Agricultural cooperative questionnaire

QUESTIONNAIRE FOR AGRICULTURAL COOPERATIVE

Agricultural Cooperative:………………………………………………………………………..

Interviewee: ……………………………………………………………………………….

Position in AC of interviewee:…………………………………………………………….

A - Human capital:

A1. How many staff in each division of ACs?

Division	Number of staff
Management board	
Control board	
Accounting unit	
Service unit	
Irrigation unit	

A2. Please specify education level, working experience and the number of training course/certification related to irrigation that each Board members and irrigators hold

Board Members	Education (yrs in school)	Experience (yrs)	# of training course attended	Certification/ Qualification (specific)
Director				
Vice – director				
Vice – director				
Irrigator 1				
Irrigator 2				
Irrigator 3				
Irrigator 4				
Irrigator 5				
Irrigator 6				
Irrigator 7				
Irrigator 8				

B. Irrigation rule:

B1. Does the AC have writing rules for irrigation

□ YES □ NO

B2. Which content is mentioned in AC irrigation rule

Content	Yes	No
Operation		
Maintenance		
Labour contribution		
Finance (irrigation fee and expenditure)		
Reward and fine		
Other………………………………………….		
Other…………………………………………..		

B3. How water is allocated in AC?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

B4. How often irrigation system within ACs is maintenance?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

B5. How on-farm irrigation fee is estimated for an individual household?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

B6. How on-farm irrigation fee is collected?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

B7. What type of irregular expenditure that ACs have to call for money contribution apart from irrigation fee?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

B8. How does AC penalise members who do not pay irrigation fee, not contribute labour, money, withdraw water illegally, damage irrigation canal?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

C. Rule compliance

C1. How many members have been penalised for non-compliance of rules in 2017?

□ None □ ……………. members

C2. How many members have evaded penalty for violation of rules in 2017?

□ None □ ……………. members

C3. Is there an unresolved conflict at present? And if yes what is it

□ YES □ NO

……………………………………………………………………………………………..

D. Institution for farmer participation

D1. How many meetings have been organised annually?

Type of meeting	Frequency
General meeting	
Board meeting	
Other meetings with farmer attendance	

D2. When there is a decision related to irrigation management to be made in the AC, how does this usually come about?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

D3. What is the process for members to raise concerns?

……………………………………………………………………………………………

……………………………………………………………………………………………

D4. What collective action that AC organise to involve member in irrigation management?

Collective action	For what activity
Labour contribution	…………………………..
Money contribution	…………………………..
Meeting	…………………………..
Other……………………..	…………………………..
Other……………………..	…………………………..

E. Farmer participation

E1. How many percentages of member participation in collective action in 2017?

Collective action	% participation
Labour contribution	
Money contribution	
Meeting	
Other……………………..	
Other……………………..	

E2. How many percentages of members complain about water allocation in 2017?

Sufficiency ………….. Timeliness …………. Equity…………..

E3. How many percent of members report issues in irrigation canals in 2017?

Water leaking/canal damages…………

Illegal water withdraw…………..

Equipment theft…………..

F. Accountability mechanism (formal and informal):

F1. What are the statutory reports prepared by AC for the members?

Type of report	Availability	Frequency in year
Annual report and business plan	□ YES □ NO	
Financial report– revenue and expenditure	□ YES □ NO	
Other……………………………………….	□ YES □ NO	
Other……………………………………….	□ YES □ NO	

F2.By what way irrigation operation and maintenance schedules are informed to AC members?

…………………………………………………………………………………………

…………………………………………………………………………………………

F3. By what way are violations of rules by members or staffs informed to AC members?

…………………………………………………………………………………………

…………………………………………………………………………………………

F4. What is the procedure for a member to register a complaint or appeal against performance of AC?

…………………………………………………………………………………………

…………………………………………………………………………………………

F5. By what way are members' complaints and resolution are reported?

…………………………………………………………………………………………

…………………………………………………………………………………………

F6. Do members have unrestricted access to all information pertaining to AC?

□ YES □ NO

F7. In what circumstances was the information access refused?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………