3. Socio-ecology of groundwater irrigation in Thailand

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1. Introduction

Thailand is the centre of communications and agricultural production within the Southeast Asia sub-region. The government has initiated a policy to develop a strong agricultural and food industry sector within the economy. In this respect the development and utilization of water resources is an important factor contributing to the development this agro-industry sector. Until recently, surface water has been used as the main source for irrigation, domestic water supply, industrial processing, services, and other purposes. However, in the last two decades surface water exploitation has developed to its full potential. In order to supplement possible shortfalls in water supply, groundwater utilization has been considered as an alternative source for domestic and industrial supply and irrigation. In order to understand the prevailing situation with respect to groundwater resources in a socio-ecology context, a comprehensive evaluation is needed to document changes that have occurred and allow planning to be undertaken.

In this study, a questionnaire was used to generate primary data and related reports from offices such as National Statistical Office, Office of Agricultural Economics, Department of Agricultural Extension, and Royal Irrigation Department were used as the secondary data or supporting information. Two types of questionnaire were prepared and implemented. The first targeted the head of village and the second, individual well owners. The survey was conducted from August to October 2002 with support from Kasetsart University staff and graduated students and staff of the Royal Irrigation Department. In cases where sampling villages did not undertake irrigation using groundwater, an alternative village in a nearby sub-district was selected as an alternate sample village. Since groundwater was also extensively used for domestic water supply, selective information on well use for domestic water supply was also collected during the field survey.

2. Location and General Description of Study Area

2.1 Geographic location

Sixty villages were selected as being representative for the whole country. However since groundwater is extensively used for irrigation in the central plain, sampling density was greatest in this particular region. The sampling area was divided into 4 regions: north, northeast, central, and south. In each region, the sample locations were confined to agriculture production areas. In addition, the central plain area was further divided into 3 regions: central, east and west. By a random grid technique, the sampling villages were selected as shown in Figure 1. In each village the head of village was interviewed along with a maximum of 12 well owners. The name of selected villages and their locations are summarized in Table 1. Sampling villages were grouped according to their geographic location as listed in Table 2.

2.2 Climatic condition and agricultural resources

Thailand is situated centrally situated in Southeast Asia and has an area of approximately 512,000 km^2 of which the area under agricultural production comprises >60 percent. The country falls within the tropical monsoon zone and is subject to the southwest monsoon during the period May to October and tropical cyclonic storms from the South China Sea during towards the end of the rainy season between September and October. There are three distinct seasons within Thailand, namely, summer season from March to June, rainy season from July to October and cold season from November to February.

Annual rainfall ranges from 900 to >2000 mm per year. The rainfall distribution in classified as bi-modal, with the first peak occurring from June to July and a second occurring from September to October. Irrigation is required for both the wet and dry seasons, such that supplementary irrigation is required during dry spells in the wet season, and full irrigation undertaken in the dry season. The total irrigation area of the country is about 22 percent of total agricultural area and most of this in situated in river basins of the Central Plain since runoff from the major storage reservoirs flow into this region. Due to insufficient available water in the dry season, some farmers use groundwater as an alternative source for irrigation along with farm ponds, rivers and drains.

Due to the tropical latitude of Thailand, the temperature is relatively uniform (28 °C) throughout the year with little seasonal variation. The average temperature in the hottest month (April) is 32 °C while that of the coldest month (December) is 25 °C. Soil variation depends on the history of the region i.e. the North is dominated by clay loams, the Northeastern is predominantly light textured sands of aeolian origin, the Central Plain loams dominate by heavy clay, and the Southern region by loams. The central plain is considered to be the most suitable for agriculture and as it have excellent soil and water attributes.

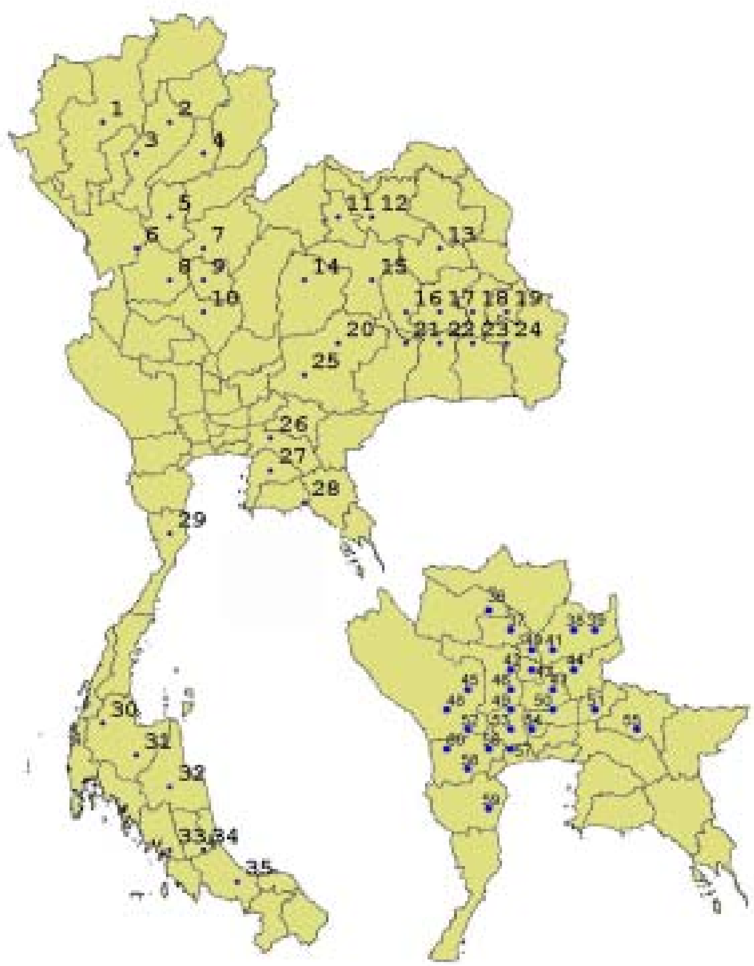

Figure 1. Location of sampling village surveyed. The insert depicts the greater density of sampling undertaken in the Central Plain region of Thailand.

Table 1. The names of the villages, their district name, province and region that were survey in this study.

Village code	Name of village	Name of district	Name of province	Region
Th01	Namton	Maewang	Chiang Mai	North
Th02	Mea Ta Luang	Chae Hom	Lampang	North
Th03	Sankumphangnue	Hang Chat	Lampang	North
Th04	Mae Kham Mi	Muang	Phrae	North
Th05	Nong Leang	Sawan Khalok	Sukhothai	North
Th06	Namjone	Muang	Tak	North
Th07	Pakladmai	Muang	Phitsanulok	North
Th08	Ko Moo	Khlong Khlung	Kampaengphet	North
Th09	Paithaponua	Popratubchang	Pichit	North
Th10	Khlongplakod	Chumsaeng	Nakhonsawan	North
Th11	Fungdaeng	Naklang	Nongbualampu	Northeast
Th12	Ban Siboonrueng	Muang	Udonthani	Northeast
Th13	Non Sa-Ard	Somdej	Kalasin	Northeast
Th14	Huaymuang	Nongbuadaeng	Chaiyaphum	Northeast
Th15	Banton	Phrayuen	Khonkaen	Northeast
Th16	Yangdinleung	Nadoon	Mahasarakram	Northeast
Th17	Buapa	Muangsuang	Roi-Et	Northeast
Th18	Tadthong	Muang	Yasothorn	Northeast
Th19	Kumyai	Muang	Amnatcharoen	Northeast
Th20	Nonghang	Nonsung	Nakhonratchasima	Northeast
Th21	Krathum	Satuk	Burirum	Northeast
Th22	Koakklang	Thatum	Surin	Northeast
Th23	Kung	Utumpornphisai	Sisaket	Northeast
Th24	Nongbor	Muang	Ubonratchathani	Northeast
Th25	Busano	Sungnern	Nakhonratchasima	Northeast
Th26	Khao Sa Thon	Plaeng Yao	Chachoengsao	East
Th27	Angvian	Ban Bung	Cholburi	East
Th28	Khlongpoon	Klang	Rayong	East
Th29	Nongtatam	Pranburi	Prajuabkirikhan	South
Th30	Kan Ma Prow	Wipawadi	Surat Thani	South
Th31	Handum	Keansa	Surat Thani	South
Th32	Na Suan	Thung Song	Nakhonsithammarat	South
Th33	Nong Wa	Palian	Trang	South
Th34	Muang Toun	Pak Phayun	Phatthalung	South

Table 1. The names of the villages, their district name, province and region that were survey in this study (continued).

Village code	Name of village	Name of district	Name of province	Region
Th35	Loanoon	Kuanneang	Songkha	South
Th36	Dong Ta Kean	Nongchang	Uthai Thani	Central
Th37	Banwangkean	Muang	Chainat	Central
Th38	Koree	Khoaksamrong	Lopburi	Central
Th39	Thasamaesarn	Chaibadan	Lopburi	Central
Th40	Sawaeng Ha	Sawaeng Ha	Ang Thong	Central
Th41	Phi Khwang	Muang	Lopburi	Central
Th42	Nong Oar	Sri Prachan	Suphanburi	Central
Th43	Bo Rae	Pho Thong	Ang Thong	Central
Th44	Huai Yai	Sao Hai	Saraburi	Central
Th45	Krachao	Huai Krachao	Kanchanaburi	West
Th46	Naimuang	Bangplama	Suphanburi	Central
Th47	Samkao	Uthai	Ayutthaya	Central
Th48	Nongsampan	Muang	Kanchanaburi	West
Th49	Huaymuang	Kamphaengsaen	Nakhonpathom	West
Th50	Khlongsong	Khlongluang	Pathumthani	Central
Th51	Bangtakong	Muang	Nakhonnayok	Central
Th52	Ton Lum Yai	Thamuang	Kanchanaburi	West
Th53	Lamboa	Nakhon Chaisi	Nakhon Prathom	West
Th54	Bangmaenang	Bangyai	Nonthaburi	Central
Th55	Nong Kra Bow	Kabinburi	Phachinburi	East
Th56	Banglan	Photharam	Ratchaburi	West
Th57	Lak Song	Ban Phaeo	Samut Sakhon	West
Th58	Pukai	Pakthor	Ratchaburi	West
Th59	Bannongbuay	Thayang	Phetchaburi	West
Th60	Nong Kham	Suan Phung	Ratchaburi	West

Table 2. Regional classification and distribution of sampled villages in study.

Region	Number	Village code
North	10	Th1-10
Northeast	15	Th11-25
East	4	Th26-28, 55
South	7	Th29-35
Central	14	Th36-44, 46, 47, 50, 51, 54
West	10	Th45, 48, 49, 52, 53, 56-60

The Central Plain is considered to be the most suitable for agriculture as it has excellent soil and water attributes. The Northern region is suitable for crops that require a cooler temperate climate such as orchards. The Northeastern region is limited in terms of soil and water resources and the southern region is surrounded by the sea and due to its close proximity to the equator, rainfall is relatively high with good annual distribution that is suited to many crops. The major crops of Thailand are paddy rice, sugarcane, maize, cassava, sorghum, soybean, rubber, mungbean, cotton, groundnut, palm, tobacco, jute, coconut, pineapple, and various kinds of vegetables and fruits. Rice is the staple dietary component of Thai's and is the main export commodity, so it is cultivated throughout the country. The main irrigated crops are rice, sugarcane, soybean, tobacco, and most fruit and vegetables. Surface water is the primary source of irrigation, but in some areas with insufficient water from this source have become dependent on groundwater sources. Since groundwater is relatively expensive and has some quantitative and qualitative limitation it is used as a supplementary source of irrigation. However, some crops with high profit margins are grown solely on groundwater i.e. vegetables and fruits particularly in the dry season.

The total population of Thailand is approximately 62 million. The majority of the population is associated the agriculture sector with respect to their livelihoods but the major source of income for the country is generated within the industrial sector. The agriculture sector is partially supported by loans from government banks, and through limited free agricultural inputs through the Ministry of Agriculture. Sugarcane is the only crop that has a permanent profit sharing system to assist farmers and also guarantees price stability.

3. Overview of Groundwater Scenario

3.1 General overview of groundwater resource in Thailand

The amount of groundwater recharge is dependent on the holding capacity of porous mediums. In this respect, the amount of recharge in Thailand can be classified into three levels: 10, 3 and 2 percent of average annual rainfall respectively. The total area with high (10%) recharge is estimated to be 40 percent, and the areas with moderate (3%) and low (2%) recharge rate are 35 and 25 percent, respectively. The Central region is the area with the highest groundwater potential, the North and Southern regions are areas with moderate groundwater potential and the East, West, and Northeast regions are areas with the lowest groundwater potential. It is estimated that the total amount of recharge for the whole country is approximately 38000 million cubic meter per year or about 4.75 percent of the annual rainfall and is equivalent to 19 percent of the total runoff for the country.

There are 12 major groundwater basins for the whole country and two basins with the largest storage capacity constitute approximately 80 percent of the total storage capacity are situated in the Central Plain. The other groundwater basins are in the North and Southern regions. The safe yield or potential pumping capacity for the country is about 8.625 million m^3 per days. Due to the presence of abundant groundwater resources in the Central Plain, irrigation from this source is concentrated in this region. User demand and use from groundwater sources in the aforementioned basins are predominantly in sectors other than irrigation (i.e. domestic, industry). In addition, there is over pumping of groundwater in the lower Central Plain (lower Chao Phraya basin) which is the cause of many negative effects such as lowering of groundwater level, salt water intrusion to the lower layer of aquifer near the gulf of Thailand and land subsidence. Groundwater use is an important factor in the regional development of the Central Plain, however measures must be implemented to sustain and stabilize the groundwater basin.

The availability of potable water for domestic use has been a major priority of government over the last decade. During this period thousands of tubewells were sunk throughout the country. The total number of wells developed by government agencies is approximately 200,000. Only a limited number were developed specifically for irrigation and there is only one large scale of groundwater development project in the country. Nevertheless, there is countless numbers of small shallow wells and tubewells constructed by individuals for both water supply and agriculture.

3.2 Overview of prevailing groundwater utilization in study villages

The groundwater level varies from a high of 2 m below ground surface to a low of 40 m (Table 3). This depends on the thickness and permeability of the aquifer in the area. However, a very low groundwater level may indicate that water is not extracted from the upper layer but from the lower layer of the aquifer. In general, groundwater level at the end of dry season (before monsoon) will be lower than the groundwater level at the end of wet season (after monsoon) by several meters. This occurs as a result of vertical recharge from rainfall during the wet season. In addition, the difference of groundwater level varies from a low of 1.5 m to a high of 10 m. This depends on the amount of annual pumping, the storage of the aquifer, and the amount of annual rainfall.

The number of wells per village may be as small as a few wells to many hundred wells depending on the crop and also the size of pump. However, villages with a large number of wells normally use the well for water supply and not for irrigation and the pump size is generally small (less than 0.5 hp). Table 4 indicates that the groundwater potential in the Northeast is the lowest since the average water level is more than 10 m below ground surface and the difference in groundwater water level between seasons is relatively high.

4. Groundwater Economy

4.1 A countrywide groundwater economy perspective

The development of irrigation projects in Thailand has continued for more than 50 years and the irrigation area has increased from 1.6 million hectare in 1962 to about 3 million hectare in 2002. Most of this area is surface water irrigation and there is only one large scale groundwater command project for the whole country located in the northern region constructed in 1983 with an irrigation area of 11,200 ha. Since then the development of groundwater irrigation has mostly been implemented by individual farmers to provide water to small areas using diesel engines from two wheel tractors or small electric motors as the main power supply. Furthermore, the increase in groundwater irrigation area is much lower than the increase in surface irrigation.

4.2 Analysis of village level and individual level groundwater economy

The contribution of groundwater irrigation to the overall development of irrigated agriculture in Thailand is small. Groundwater is considered to be the major source of water supply but not for irrigation. Most of the tubewells developed by government agencies are used for domestic water supply. According to the results of studies on the potential development of groundwater as a major source for irrigation, there are only few suitable locations i.e. the lower part of Northern region, the lower part of Northeast region and selected areas in the Western region. From these candidate locations, only the Sukhothai Groundwater Project, in the lower part of Northern region has been developed as an irrigation area. In another studied area in the lower part of northeast region (Thung Kula Ronghai groundwater development project), the primary objective has been to find sufficient amounts of water for domestic use. Irrigation may only be developed if there is sufficient water for both domestic and irrigation purposes. Other areas have not had enough safe yields to be developed as groundwater irrigation project.

With respect to the storage of groundwater in all aquifers of the country, the upper part of the Central Plain has the highest potential but the amount of use is still moderate and water is mainly extracted from the shallow aquifer. Moreover, the location of wells is uniformly distributed through out the upper part of the central plain so there is enough water for further development of groundwater irrigation in this area. In the lower part of the central plain, there is little development of groundwater irrigation but groundwater from lower aquifers is extensively used for water supply, industry and other purpose, and the region has faced serious problems of groundwater drawdown and land subsidence as discussed previously.

Table 3. Selective groundwater and pumping statistics for the villages sampled in survey.

Village Code	Village Name	Number of groundwater structures		Water table before monsoon (m)	Water table after monsoon (m)
		Electric	Diesel		
Th01	Namton	0	20	Nr	Nr
Th02	Mea Ta Luang	1	49	3	0.5
Th03	Sankumphangnue	0	6	2.6	1.6
Th04	Mae Kham Mi	0	14	2	0.5
Th05	Nong Leang	0	70	11.5	10
Th06	Namjone	5	0	Nr	Nr
Th07	Pakladmai	221	14	10	7
Th08	Ko Moo	0	58	3.5	2
Th09	Paithaponua	1	25	8	6
Th10	Khlongplakod	1	59	12	10
Th11	Fungdaeng	86	20	10	9
Th12	Ban Siboonrueng	1	0	35	30
Th13	Non Sa-Ard	1	0	19	12.5
Th14	Huaymuang	3	0	28	18
Th15	Banton	4	0	17	14
Th16	Yangdinleung	2	0	28	25
Th17	Buapa	3	0	40	25
Th18	Tadthong	21	0	3.5	1
Th19	Kumyai	4	0	6	3
Th20	Nonghang	14	0	25	23
Th21	Krathum	20	0	18	15
Th22	Koakklang	30	0	39	32
Th23	Kung	1	3	3	2
Th24	Nongbor	315	0	4	1
Th25	Busano	2	0	23	20
Th26	Khao Sa Thon	4	0	Nr	Nr
Th27	Angvian	10	270	7	5
Th28	Khlongpoon	78	2	6	1.5
Th29	Nongtatam	8	2	7	6

Table 3. Selective groundwater and pumping statistics for the villages sampled in survey (continued).

Village Code	Village name	Number of groundwater structures		Water table before monsoon (m)	Water table after monsoon (m)
		Electric	Diesel		
Th30	Kan Ma Prow	40	0	6	1
Th31	Handum	120	5	11	4
Th32	Na Suan	120	19	3	1.5
Th33	Nong Wa	100	0	2	0.5
Th34	Muang Toun	16	4	11	3
Th35	Loanoon	150	0	15	2
Th36	Dong Ta Kean	0	15	6	2
Th37	Banwangkean	3	147	7	5
Th38	Koree	5	0	Nr	Nr
Th39	Thasamaesarn	4	1	40	30
Th40	Sawaeng Ha	0	30	4	2.5
Th41	Phi Khwang	0	14	2.5	1
Th42	Nong Oar	0	80	4	1.5
Th43	Bo Rae	0	20	7	3.5
Th44	Huai Yai	20	0	4	0.5
Th45	Krachao	0	0	Nr	Nr
Th46	Naimuang	0	0	Nr	Nr
Th47	Samkao	1	0	Nr	Nr
Th48	Nongsampan	22	0	5	1.5
Th49	Huaymuang	0	0	Nr	Nr
Th50	Khlongsong	0	0	Nr	Nr
Th51	Bangtakong	1	0	Nr	Nr
Th52	Ton Lum Yai	150	0	15	12
Th53	Lamboa	0	0	Nr	Nr
Th54	Bangmaenang	0	0	Nr	Nr
Th55	Nong Kra Bow	40	0	8	0.5
Th56	Banglan	3	0	Nr	Nr
Th57	Lak Song	0	0	Nr	Nr
Th58	Pukai	100	40	4	1
Th59	Bannongbuay	150	40	3	1
Th60	Nong Kham	4	0	6	0.5

Nr = No record

Table 4. Overview of groundwater depths and number of different pumps used on a regional basis in the surveyed villages.

Region	Number of groundwater structures				Water table before monsoon (m)	Water table after monsoon (m)
	Electric		Diesel			
	Total	Average	Total	Average		
North	229	22.9	315	31.5	6.6	4.7
Northeast	507	33.8	23	1.5	20.5	15.3
East	132	33	272	68	7	2.3
South	554	79	30	4.3	6.6	2.4
Central	34	2.4	307	22	9.3	5.75
West	429	42.9	80	8	6.6	3.2

The summary of groundwater use in the 60 sampling villages is listed in Table 5. The average number of wells and tubewells is 49 wells per village. This value seems to be moderate but do not present the actual situation with respect to use for irrigation. In approximately half of the sampled villages water extracted from tubewells was used for domestic purposes. In addition, there are villages that have a few hundred wells and others that have no wells for irrigation at all, especially in the Northeast region, the West region and the lower part of Central region. Their details may be expressed regionally as follows. The Northeast region has problems of high salinity in the groundwater and limited storage within aquifers. The lower Central plain is a developed area and land use has changed from agriculture to industry or residential area or fallow land. The groundwater level in this area is also greatly reduced due to excessive groundwater pumping for other purposes. In the Western region, many wells were abandoned in the last two decades because of the construction of irrigation projects (i.e. Greater Mae Klong project) that supplied sufficient water to meet all objectives including irrigation. Therefore, if villages with a large number of wells using water supply were removed from consideration, the average number of wells would decrease significantly.

The total irrigated area for the sampling village is about 40 percent that is much higher than the average figure of the country. This occurs because the sampling villages are taken from the Central Plain (with a higher density of irrigation area) than any of the other areas sampled. The results also show that the major techniques used for irrigation are canal, canal and well, and well respectively. This indicates that the majority of farmers rely heavily on surface irrigation and groundwater is only used as supplementary irrigation for times of water shortage. Furthermore, diesel engines are a more popular source of power supply than electric motors. This issue will be discussed in the following section.

The results also show that the majority of villages have some means of groundwater recharge which will make the use of groundwater a sustainable option since there are reliable ways of recharge within the village area. Moreover, the average size of farmland per household is about 1.87 hectare and groundwater contributes to about 55 percent of the irrigated area. This percentage will be reduced to 22 percent when considering the net cultivated area.

The percent of villages considering groundwater irrigation as an important factor for agriculture economy is only 18 percent, here groundwater is much less important than the surface water for irrigated agriculture in Thailand. Surface water may be taken from many sources such as irrigation canals, rivers, drains, and farm ponds. Groundwater is also less important in comparison with some farm inputs such as labor.

Table 5. Summary of groundwater use and selected socio-economic attributes for the villages surveyed.

Indicators	Value
1. No of sample villages	60
2. Average number of wells & tubewells per village	48.5
3. Total net cultivated area of the sampling villages (ha)	23,458
4. Total net irrigated area of sampling villages (ha)	9,275
5. By canals	3,808
6. By wells/tubewells	1,910
7. By canals & wells	3,252
8. By other sources	304
9. Number of diesel pumps	1,027
10. Number of electric pumps	1,885
11. Number of manual devices	0
12. % of villages with river/rivulet (%)	38
13. With tanks/ponds (%)	56
14. With canals (%)	63
15. Other irrigation/ recharge sources (%)	7
16. % of villages perceiving groundwater irrigation's importance to be high or very high	18
17. Average farm land/household (ha)	1.87
18. Farm land/person (ha)	0.42
19. Irrigated land/person (ha)	0.17
20. Tubewell density (TW/100 ha of NCA)	12.4
21. Groundwater irrigated to Net Cropped Area (%)	22
22. Groundwater irrigated to Net Irrigated Area (%)	55

Based on primary data

Table 6. Profile of well owners in surveyed area.

Indicators	Value
1. Number of sample villages where 10 well owners could not be found	40
2. Number of sample farmers	318
3. Number of sample wells	391
4. Tubewell/farmer {3/2}	1.23
5. Average farm size for sample well owners (ha)	4.12
6. Average cultivated area for sample well owners (ha)	3.9
7. Average number of parcels/ sample well owner	1.72
8. Average irrigated area/ sample well owner (ha)	2.83
9. Rainfed area (ha)	2265
10. By only canals (ha)	964
11. By only wells (ha)	1760
12. By wells and canals (ha)	2138
13. Neighbor's well	0
14. By other i.e. pond, river (ha)	614
15. Average area cropped once/year (ha)	2.22
16. Average area cropped twice/year (ha)	1.32
17. Average area cropped 3 or more times/year (ha)	0.36
18. Cropping Intensity	1.52
19. Abandoned wells as % of total wells	4.4
20. Electric as % of total wells	42.9
21. Diesel as % of total wells	52.7
22. Dug and dug-bores as % of total wells	28.6
23. Borewells as % of total wells	71.4
24. Average depth of well (m)	17.9
25. Average depth of water table (m)	6.3
26. Average size of outlet pipe (cm)	6.32
27. Average hp of electric pumps	1.56
28. Average hp of diesel pumps	13.4
29. Average hp of tractor diesel pumps	10.6
30. % of wells with piped distribution	80
31. Average length of pipes used/ well (meters)	281
32. % of wells with lined channels	0
33. Average length of lined channel/well (meter)	-
34. % of wells using unlined channels	20
35. Length of unlined channels/well	215
36. % of well owners who used bank loans for financing irrigation	25
37. % of well owners who used own funds	69
38. % of well owners who used other (relative, merchant, subsidy)	6
39. Average hours of operation of diesel pumps/year	756
40. Average area irrigated by diesel pump (ha)	2.5
41. Average hours of operation of electric pumps/year	423
42. Average area irrigated by electric pump (ha)	0.84
43. % of wells with a recharge source (%)	64
44. Average distance from the closest source (meters)	186

4.3 A profile of well owners

The majority of villages in Thailand do not use or only partially use groundwater for irrigation since in about two-third of the sampling village we could not find 10 well owners for interviews as shown in Table 6. On average there is only 1.23 wells per farmer, therefore each farmer owns only one groundwater well/tubewell. The average farm size is 4.12 hectare and nearly 95 percent of the land is cultivated. The irrigation area is about 72 percent of the total cultivated area. Farmer tends to cultivate larger pieces of land rather than many small pieces since the average number of parcels is only 1.72 parcels per well owner.

Among the owners of wells, canals and wells are the most common way of irrigation which confirms the information from the villages that surface water is the primary source of irrigation water and groundwater a secondary source. It was also observed that farm ponds an important source of water for many farmers. All well owners tend to invest in wells or tubewell to ensure a sufficient supply of water to their farm therefore there is nearly no record at all about the use of neighbor wells for irrigation.

The role of wells to the economy of farmers depends greatly on the cropping pattern of individual farmers. Wells are the most popular way of irrigating vegetables and orchards since the pipe distribution system makes irrigation less labor intensive. In addition, farmers will have more choices for irrigation method and the most popular irrigation method for vegetables is mini-sprinklers. Wells are also used by many farmers for supplementary irrigation of rice and sugarcane, and in these cases canal distribution will be selected instead of pipe distribution systems. Wells/tubewells are an un-favored choice for the irrigation of upland or field crops. Most field crops will use water from irrigation canals rather than any other source.

Crop intensity depends greatly on the age of crop and the availability of water. For low-lands, rice is a primary crop in the wet season followed by dry season rice or upland crops or vegetable as the second crop. Rice may be grown twice a year if there is enough water but in the upper part of the central plain rice may be grown up to three times a year. Field crops will normally be cultivated in the upland area and the most popular field crop is sugarcane followed by maize and soybean. Vegetables are a favored cash crop with a growing period of only 45 days to 75 days thus farmer may cultivate 3 to 5 times per year. However, on average crop intensity is only about 1.52 since there are many annual crops such as sugarcane and orchards.

There is a low record of abandoned well (only 4.4 percent) for the sampling villages even though many of them have been used for several decades. The shallow wells or tubewells are more popular than dug wells in all parts of the country and most of the newly constructed wells are tubewells. The type of power supply for pumps depends on the demand for water such that if a large quantity of water is required, diesel engines or engine power provided by tractors will be favored. On the other hand, if a small amount of water is required, electric motors become a more attractive alternative.

Diesel engines are generally used for irrigation of rice, sugarcane and most field crops since farmers may need large quantities of water and they may also use engines from their two-wheel tractors as the source of power for pumps. An electric motor is predominantly used for the cultivation of vegetables, since pump may need to be operated daily and the amount of water requirement is rather low due to the small area cultivated. Thus the average power of diesel engine is about 10 hp but the average power of the electric motors is approximately 1.5 hp.

The size of pipe outlet may vary from several centimeters for the irrigation of rice and sugarcane to considerably smaller diameter for the irrigation of vegetable. This is a function of the amount of water required. The average length of pipe distribution system is about 300 m since it may need to cover the whole plot of vegetable in case of mini-sprinkler irrigation. On the contrary, the average length of canal is about 200 m even though the cultivation area is normally bigger since the water will be transferred to the top of the field only.

Finally, the total number of operating hours and the average hours of operation clearly indicate that rice and upland crops receive supplementary irrigation by groundwater pumping. On the other hand, vegetables have full irrigation since the operation hours per hectare of diesel engine (for rice cultivation) is rather small in comparison with the operation hours of electric motor (for vegetable cultivation).

Source of financing

More than 60 percent of the well owners use their own funds for the purchase of pumps, power supply and distribution system as shown in Table 7. The second source of funds is bank loan followed by multiple sources of funds, relatives or merchants, and government subsidies respective. It would appear that farmers have sufficient capital to undertake these activities without having to resort to other financing sources. However, the figures on agricultural debt indicate that most of farmers were carrying a greater degree of debt in 2000 – 2001 when compared to 1990-1991 (Table 8). The situation for individual farmers is different depending on the power supply such that farmers may be classified into two groups: well owners with diesel water supply and well owners with electric motor supply. The pumps and electric motors are normally small and cheap so farmers are able to pay for them with their own funds. In addition, electric motors are mostly used for the irrigation of vegetable and orchard where farmers have higher returns when compared to other crops. On the contrary, diesel engines are mostly used for the irrigation of rice and field crop where farmers may earn less money and the cost of equipment is normally more expensive.

The second source of funds is bank loans from either commercial or agricultural and cooperative banks. Farmers will endeavor to borrow money from the government bank since it has a lower discount rate and there may also be other benefits for using this source. Funds from multiple sources are mostly a combination of personal funds and other sources.

Table 7. Source of finance accessed by well owners for the infrastructure and running.

Source of funds	Value
1. % of well owners who use bank loans for financing irrigation	25
2. % of well owners who use own funds	63
3. % of well owners who received subsidies	3
4. % of well owners who used funds from relative or merchant	3.5
5. % of well owners using funds from multiple sources	5.5

Based on primary data

Table 8. Agricultural debt and refinance, from 1990-91 to latest figures available

Years	Agricultural debt ($US per family)	Overall debt ($US per family)	Agricultural refinance by government
1990-1991	544	768	Nr
2000-2001	697	1088	Nr

Source: National Statistical Office

The financial situation of farmers from the report of the National Statistical Office shows that farmers borrowed money to use for both agricultural production and household consumption. The borrowed money for agriculture production on average is about $US 697 per family and the total debt is about

$US 1088 per family. This debt has increased in the last two decades and the rate is about 40 percent for a decade.

4.4 Analysis of cropping pattern

Rice is the prominent crop for the whole country of Thailand and is the major export crop . The other main crops in terms of cultivated area are sugarcane, orchard, rubber tree, and vegetable. The total cultivation area of these five major crops is 1,115 ha for the 60 sampling villages and the land use intensity is about 90 percent of the total cultivation area. The cultivation areas under these major crops are 630, 282, 86, 76, and 40 ha respectively as show in Table 9.

The number of villages that predominantly cultivate rice under rainfed conditions is about 40 percent of the total villages sampled. The sum of percentage for number of village predominantly cultivating rice by surface water from canal and surface water and groundwater from well is about 45 percent but the number of villages cultivating rice by using only water from wells is only 9 percent. This information confirms that rice is a crop partially irrigated by groundwater since surface water is the main source of water supply. These percentages for sugarcane are similar to rice therefore sugarcane is also another crop with partial irrigation by groundwater. For orchards, the number of villages use rainfed sources of water is only 18 percent whilst the other 72 percent of the villages grow their crop using groundwater as the main source of water. Rubber trees are totally rainfed crop since there is no irrigation at all. Finally, the number of villages predominantly cultivated vegetable under well and tubewell irrigation is about 58 percent and the other 25 percent of the village cultivated under irrigation by both surface and groundwater. This confirms that vegetables are a crop that is normally grown under irrigation.

Some conclusions from the analysis of cropping pattern are the following. Rice and sugarcane are the crops cultivated predominantly under both rainfed and partial irrigation conditions. Fruit trees are a crop cultivated predominantly under irrigation. Vegetables are a crop cultivated totally under irrigation and wells are the most favor source of supply. Finally rubber trees are cultivated exclusively by under rainfed conditions.

The cropping pattern was also analyzed regionally for only groundwater irrigation as shown in Table 9. The result indicates that rice is the predominant crop for the Central, North and Northeast regions under groundwater irrigation. The predominant crops for the East, West and South regions under groundwater irrigation are sugarcane, orchards and vegetables. The power supply for the pumps of wells/tubewells is also another unique character for each region. Diesel engines are the predominant source of power supply for the North and Central regions. In these two regions, two-wheel tractors are extensively used for tillage and its diesel engine can also be used as the source of power supply for groundwater pumping. Electric motors are the predominant source of power supply for the South and West regions. The motor is a favored choice because the major crops are fruit trees and vegetables that need to be irrigated frequently so that electric motor are more appropriate for their operation than diesel engines. The power supply for the Northeast and East region is a mixture between electric motors and diesel engines depending on the crop as previously discussed.

The total income generated from each crop is slightly different regionally depending on the crop yields as shown in Table 9. Orchards seem to be the most attractive choice in terms of income for all regions of the country. In addition, the net returns for the major crops are analyzed using the secondary data from the office of Agriculture Economics as summarized in Table 10. The net return per crop for rice and other field crops is amongst the lowest. Sugarcane and pineapples are the field crops that give an adequate net return but their returns but are dependent on market prices. Sugarcane is the only crop that has a quota and profit sharing system so it is the most attractive field crop. However, it may grow only in particular areas due to restrictions on quotas and the transportation distance from field to factory. Rice may be cultivated up to 3 times per year and is still a favorite crop for most places because of the reasonable net income, the market, and the knowledge and experience of farmers in rice cultivation. The attractive crops with the highest net return are orchard crops and vegetables but they have a high labor component. In practice, orchard crops may be cultivated in a large area but vegetables may be grown only in a limit area due to its highly intensive labor requirement.

Table 9. Cropping pattern of well owner farmers and the total value of revenues generated.

Region	**Motive power**	**Crop (5 major crops as per area)**	**Total area (ha)**	**Total hours of pumping/ha**	**Yield/ha (kg)**	**Price ($US/kg)**	**Total value generated**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8=6*7)**
North	Diesel	Rice	256	69	5000	0.116	580
		Sugarcane	46.2	10	70531	0.0105	741
		Soybean	14.7	112.5	1837.5	0.209	384
		Orchard	14.1	100	5956	0.3	1787
		Tobacco	8.35	94	2422	-	-
		Gross Cropped Area	339.35				
Northeast	Diesel	Rice	38.4	70	2869	0.116	333
	Motor	Vegetable	4.5	205	5312	0.14	744
		Gross Cropped Area	42.9				
East	Diesel	Sugarcane	84.5	10	76700	0.0105	805
	Motor	Orchard	18.8	400	7181	0.3	2154
	Diesel	Rice	7.4	69	5000	0.116	580
		Gross Cropped Area	110.7				
South	Motor	Orchard	31.4	94	8140	0.3	2442
		Vegetable	18.6	170	8625	0.14	1208
		Rice	6.3	35	4797	0.116	556
		Gross Cropped Area	56.3				
Central	Diesel	Rice	192.3	62.5	6312	0.116	732
		Sugarcane	45.6	50	78469	0.0105	824
		Orchard	5.9	62.5	6250	0.3	1875
		Soybean	1.5	50	1685	0.209	352
		Gross Cropped Area	245.3				
West	Motor	Vegetable	23.8	281	5325	0.14	746
		Sugarcane	19.5	37	84375	0.0105	886
		Orchard	13.1	100	6250	0.3	1875
		Gross Cropped Area	56.4				

Source: Primary data

Groundwater irrigation may raise additional costs for farming, but locations with insufficient surface water or no surface water, well irrigation becomes an attractive choice for farmers especially for crops with high relative returns such as vegetables and orchards. The collected information during the survey is inadequate to estimate the fixed investment in wells and pumps so only operation costs were evaluated in the analysis. It was found that operation cost only slight increases the investment or cost to each crop. Therefore, groundwater should certainly be implemented in the areas with insufficient or without other sources of water supply.

Table 10. Relative returns from surface and groundwater irrigation (major crops only)

Crop	Total cost ($US/ha)	Total earning ($US/ha)	Pumping cost+ ($US/ha)	Net returns ($US/ha)	
				Surface	Groundwater
Rice (Wet season)	296	436	20	140	120
Rice (Dry season)	410	509	20	99	79
Sugarcane	540	783	5	243	238
Soybean	248	340	12	92	80
Maize	235	337	12	102	90
Pineapple	854	1381	-	527	-
Orchard (mango)	726	1220	10	494	484
Vegetable (onion)	1962	2616	20	654	634

Source: Secondary data, * from Office of Agricultural Economics, + estimate from operation cost of pumping

4.6 Energy costs

Both electric motors and diesel engines are used widely in groundwater irrigation pumping in Thailand. Their unit price and operation cost are summarized in Table 11. In general, electricity is very reliable and very efficient in terms of energy consumption but it is only suitable for a small farm or a farm with small to moderate water demand. Large motors are extremely expensive and hence are only used where large quantities of water are required. The pumps are usually diesel powered engines. The cost of electricity is relatively cheap in Thailand especially if small amounts of water are required. There is no tax reduction or subsidy policy for individual farmers regarding electricity charges. However, groundwater pumping and river pumping irrigation projects do get a lower rate of electricity charge.

The diesel engine is less efficient than the electric motor but it is more appropriate for a large amount of water supply. In addition, farmers with two-wheel tractors will generally use the tractor engines as a source of power supply for pumps, so it is a very effective strategy in terms of capital investment. The total cost of power supply is relatively small to moderate in comparison with the total production costs of crops so the farmer will select the power system based on water demand and available equipment. It can be concluded that the unit price of energy is not the constraint for the selection of power supply but is dependent on the amount and frequency of pumping.

Table 11. Average prices paid for energy in Thailand and costs of operation of different pumps.

Indicators	**Unit price**	**Total energy cost for a pump/engine operating for 500 hours in a year**
1. Average price paid for diesel ($US/litre)	0.33	82.4
2. Average price for metered electricity	0.058	48.5
3. Average flat rate ($US/hp)	No	No

Source: Primary data

4.7 Problems' facing well irrigators

The critical problems faced by well irrigators in the study villages are summarized in Table 12. According to the information from the head of village, some villages have no problems with well irrigation, but most of the villages will have some problems, and only some villages have many problems facing well irrigation. Therefore, only the first three problems raised by the village head will be considered and analyzed in this section. The most critical problem is the discontinuing of pumping due to reduction in groundwater level. Some farmers address the problem by extending the depth of well. However, this problem rarely occurs (normally in the dry season) so many farmers will wait for the recovery of groundwater level by curtailing pumping until levels have returned to their previous height. A second issue is the high cost of energy that occurs for farmers with diesel engines. The diesel price has increased in the last few years and the price is still relatively high. However, the amount of fuel use for pumping is still relatively low since it is not used for the whole cropping season but only for partial irrigation in most cases. The third issue outlined is the falling of water table that may increase the cost of pumping and may result in discontinuing of pumping. This problem basically occurs in locations where the aquifer has a low storage capacity or transmissivity. The effective way to solve the problem is the extension of depth of well or a reduction of groundwater usage. Salinity seems to be the most serious problem for the northeast region since the foundation of their aquifer is salt-rock and there is no solution to this problem.

Table 12. Critical issues faced by well irrigators in study villages.

Indicators	**First**	**Second**	**Third**
1. High rate of failure of wells/tubewells	4.5	6.8	9.1
2. Salinity	15.9	9.1	2.3
3. Wells can be pumped only for a short time	29.5	11.4	2.3
4. High energy cost	25	11.4	4.5
5. Unreliable power supply	4.5	0	6.8
6. Falling water table	11.4	18.2	13.6
7. Other (iron oxides)	6.8	0	0

Source: Primary data (% of villages considering as the most critical problem facing tubewell irrigation)

Another minor problem is the failure of wells/tubewells. From the reports and the results of the survey, this is not a serious issue since there is a low percentage of abandoned wells from the sampling villages. The least critical problems for the well irrigators in the study villages are unreliable power supply and contamination by iron-oxide of groundwater.

From the national survey of groundwater problems by Kasetsart University (2000), the most serious problem is the reduction of water level and the second critical problem is turbidity due to contamination by calcium carbonate. In addition, the North, Northeast and some parts of the Central Plain may also face salinity problems. This is in agreement with this groundwater survey.

4.8 Groundwater market

There is no groundwater market in Thailand since most farmers will invest in the construction of their own well. Only 10 percent of well owners allow neighbors to use pump irrigation (Table 13). There will be no charge but the farmer has to pay for the energy costs himself. Normally the average hours of usage are low since farmers will ask for help only at the critical times. In addition, there is only one well owner that uses neighbors' wells to irrigate his field and he is only charged for power supply. In conclusion, there is no groundwater market in Thailand but farmers may ask for help from their neighbors for the use of pump irrigation.

Table 13. Dynamics of groundwater markets in the study villages.

Indicators	Value
1. % of well owners let neighbor use pump irrigation	9.75
2. Average number of farmer help	1
3. Average annual hours of use	72
4. Average size of area served per farmer (ha)	3.2
5. Average price charged ($US/hour)	No
6. % of well owners who use neighbor pump irrigation	0.3
7. Average number of hours use/year	30
8. Average price paid for pump irrigation ($US/hour)	No
9. Average area irrigated with neighbor pump irrigation (ha)	1.9

Source: Primary data

Conclusions, Policy Implications and Future Directions

At present, groundwater irrigation is still less important in comparison with surface irrigation in Thailand. Most of the wells are used as supplementary irrigation in cases where these insufficient irrigation from surface water. However, there is a trend of continuous increases in water requirement for all user sectors and there are water shortages during the dry spells in the rainy season and the dry season in many areas. In this situation, groundwater will become a more important alternative for irrigated agriculture.

The major crops for supplementary groundwater irrigation are rice and sugarcane. Orchards and vegetables are crops that receive full groundwater irrigation. With a shortage of surface water, more farmers will pursue groundwater irrigation. Therefore, better groundwater management and integrated water resources management must be implemented in order to cope with over exploitation and competition for resources by different sectors.

At the basin level, many river basins in the Central Plain have already faced serious water shortage and water quality problems. Groundwater is currently being used more than the safe yield in this area such that groundwater laws are needed to control the amount of groundwater extraction in the area. At present, this measure is enforced mainly for industry and domestic water supply but enforcement should also be extended to the agricultural sector in the near future and it may also be expanded to other river basins. This may have a direct effect on the use of groundwater irrigation.

The other issues needed to be studied are: the land subsidence due to excessive groundwater extraction in the forgotten river basins such as Mae Klong Basin, the comprehensive study of groundwater water potential in many river basins, and groundwater development and groundwater recharge for the poor region of the country.

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