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Research Article

An economic analysis of groundwater markets and water use efficiency in hard rock area of Hosur union Krishnagiri district of Tamil Nadu

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Abstract
Groundwater selling is a guarantee against deficiency rains in areas where farmers do not have access to surface water irrigation. Therefore, examination of groundwater market development and the efficiency of groundwater use under different water regimes needs to be studied. The objective of the study was (a) to analyse the structure and contact of groundwater markets and (b) to estimate the cost of ground water extraction and selling price in Hosur and Kaveripatinam taluks of Krishnagiri district, Tamil Nadu. Based on the Primary survey, water structures were analysed using simple statistics and measured efficiency by Data Envelopment Analysis. The groundwater market structure demonstrated that the number of irrigation water buyers grows as the size of the farm decreases, while the number of irrigation water sellers grows as the size of the farm increases. The efficiency of groundwater use is estimated by data envelop analysis. According to the data, in a sample of groundwater markets, the seller-buyer concentration ratio was 1:1.13. The cropping intensity and irrigation intensity were highest (89.13 and 93.19 %, respectively) for the self-user+seller category. The selling price of groundwater (Rs. 50 per tank) was marginally higher than the total cost of water extraction (Rs. 28.27 per tank), thereby implying the exploitative nature of groundwater markets. According to findings on input consumption and landholdings, water buyers are resource-strapped farmers who are unlikely to be able to afford the large investments required to install a well.

Keywords: Cost of water, Data envelope analysis, Ground water extraction, Water markets, Water use efficiency

INTRODUCTION

In recent years, policymakers and other stakeholders have paid close attention to market-based processes and pricing approaches for governing water markets. The water market laws vary by country due to differences in hydro-geological systems, social structures, institutional structures, technical knowledge, financial viability, and information quality (Varady *et al*., 2016; Wheeler *et al*., 2016).

A variety of studies in developed and developing economies have been done to investigate the structure and effectiveness of the multiple approaches (Singh and Singh, 2006, Grafton *et al.,* 2010, Palomo *et al*., 2015, Bruno, 2018). According to research on organised and formal markets such as the Rio Grande region in the United States, water markets that impose a price and a cap on water use can alter cropping patterns toward higher value or more water productive crops on average. Farmers in the Rio Grande region of the United

States who purchased water switched to more profitable and non-irrigated crops (Debaere and Kapral 2021). Irrigators were able to adjust to weather changes and control risk thanks to water trading. Formal water exchanges in California, USA, have worked as a vehicle for both private and environmental gains. The economic surplus generated by water trade 2 is more than three times bigger than that generated by the centralized system (Bruno, 2018). According to studies done in informal marketplaces, water trade enhances water use efficiency among farmers (Shah and Ballabh, 1997, Manjunatha *et al*., 2016; Wang *et al*., 2016; Razzaq *et al*., 2019).

Water trade provides a consistent source of irrigation water to small and marginal farmers who cannot afford to construct capital-intensive water extraction technologies (Fujita and Hossain, 1995, Shah and Ballabh, 1997, Bjornlund and McKay, 2002, Manjunatha *et al*., 2016, Razzaq *et al*., 2019, Singh *et al.,* 2022). Groundwater selling is a guarantee against deficiency rains in areas where farmers do not have access to surface water irrigation. Furthermore, research shows that water buyers outperform sellers and non-participants in terms of yield (Shah and Ballabh, 1997; Manjunatha *et al*., 2016; Saleth, 1998; Razzaq *et al*., 2019).

There are quite a few studies pertaining to water markets in place where there is sufficient water. However, in water-scarce areas, studies pertaining to water markets are limited. Hence, to understand the dynamics of water markets, with this prelude, the present study was undertaken in the Hosur and Kaveripattinam taluks of Krishnagiri District, Tamil Nadu, to examine groundwater market development and the efficiency of groundwater use under different water regimes.

MATERIALS AND METHODS

Study area

A multistage random sampling process was used to pick four villages namely Vilagamudi, Mottru, Barigai and Bagalor, which were selected from two taluks (Hosure and Kaveripatinam) (Fig. 1), followed by the selection of 30 farmers from each village, for a total of 120 farmers in the sample. Based on their access to different forms of water, the selected farmers were classified as selfusers (farmers who have modern WEM and only irrigate their own land), selfusers + sellers (farmers who have modern WEM and sell surplus water), selfusers + buyers + sellers (farmers who have modern WEM and buy and sell water), owners + sellers (farmers who have modern WEM and sell water), and buyers (farmers who buy water to irrigate their crops (Table 1). To capture the differences among the categories, the selected farmers were additionally divided into three categories on the basis of farm size: marginal (less than 1 ha), small (1 to 2 ha), and large (more than 2 ha).

Concept

Selfusers

Farmers who own tubewells individually or jointly use them for cultivation on their own plots.

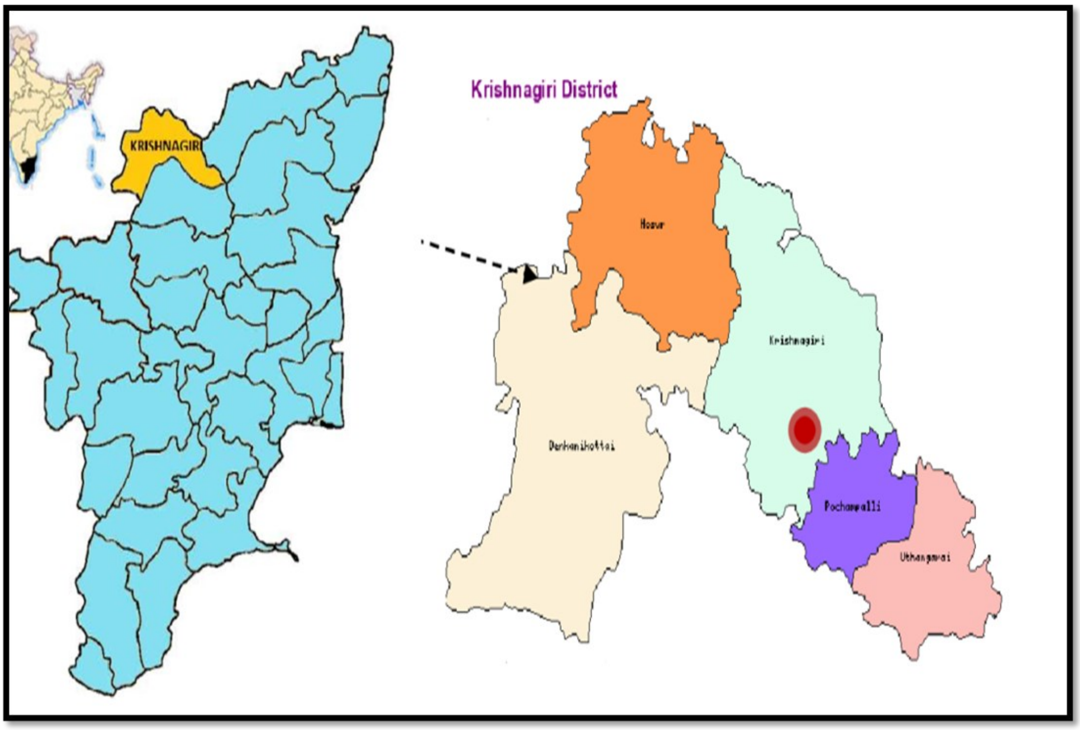

Fig. 1. *Map of study area (Hosur union Krishnagiri district of Tamil Nadu)*

Table 1. Sample farmers from the study area (total respondents)

Name of village	Self-users	Self-user +seller	Self-users +sellers + buyers	Owner + seller	Water buy-er	Total
VILAGAMUDI	5	22	-	3	-	30
MOTTRU	6	2	2	-	20	30
BARIGAI	5	5	1	5	14	30
BAGALOR	8	6	1	-	15	30
TOTAL	24	35	4	8	49	120

Source: Primary data.

Sellers and self-users

Farmers who own tubewells independently or jointly (or both) use the water to cultivate their own plots and sell it to needy farmers in the area, usually after meeting their own needs.

Selfusers + sellers + buyers

The tubewell owners who cultivate their agricultural land with thrir own irrigation water sell water to other farmers "irrigation water buyers" and buy water from the other tubewell owners in another place, particularly if their cultivable land is divided into two or many more plots.

Owner + sellers

Describes a scenario in which some farm owners have chosen to invest in tube wells to sell irrigation water to other agricultural producers rather than meet their own irrigation needs.

Buyers

Growers who buy irrigation water from other tubewell owners are typically close to their farmland plots.

Structure and conduct

The market structure and conduct characteristics were investigated using simple statistical techniques (conventional analysis), such as the ratio, % age, average, differences, and conversion factors (Bach *et al.,* 2021) of groundwater markets.

Cropping intensity

It is the ratio of gross cropped area to net cropped area and is expressed in %age".

Cropping Intensity (CI) = Gross cropped area/Net cropped areaX 100 Eq.1

Irrigation intensity

"It is the ratio of gross irrigated area to net irrigated area and expressed in %age".

Irrigation Intensity (II) =Gross irrigated area/Net irrigated area X 100 Eq.2

Water extracted from per well/per annum

The amount of water extracted from each farm was calculated and given in acre inches. The following is the process for computing the water extraction:

Water extracted (in acre inches) = (Average number of days pumped in a year X Average number of hours pumped per day X Yield of the bore wells in gallons per hour)/22611 Eq.3

The number of days pumped in a year and the number of hours pumped per year were estimated based on the information given by the farmers. Divisor 22611 was used to convert gallons to acre-inches.

Measure efficiency data envelopment analysis (DEA)

The efficiencies in this study were measured using Data Envelopment Analysis. It is a deterministic nonparametric methodology for evaluating efficiency. Unlike the stochastic frontier approach, there are no assumptions about the conceptual model of the production function or the distribution of the error term. To create a piecewise linear frontier over the data, DEA uses linear programming. Then, in relation to this frontier, efficiency measures are calculated (Coelli *et al*., 2005). The following programming problem is used to determine the efficiency levels of the variable factor k (k) for each farm I.

Minimum $_{\theta}{}^{k}{}_{\lambda}{}^{\theta k}$

Subject to:

$-y_i^M + Y\lambda \geq 0,$

$_{\theta}{}^{k} x_i^k - X^k\lambda \geq 0,$

$x_i^{L-k} - X^{L-K} \lambda \geq 0,$

"N1' λ =1"

"λ≥ 0"

The framework is described as "L" inputs, and "M" outputs for "N" farms are available. The i^{th} farm's input and output data could be represented by the column vectors xiL and yiM, respectively. An L*N input matrix, XL, and an M*N output matrix, YM, are used to represent the input and output data for all N farms in the sample.

Table 2. Various types of water markets: Sample farm holdings and operational size

Number of Farm holdings, Farm Category	Self-user	Self-user +seller	Self-user + seller + buyer	Owner + seller	buyer	Total
Marginal (<1ha)	9 (37.50)	16 (45.71)	2 (25.00)	1 (25.00)	15 (30.61)	43 (100)
Small (1 to 2 ha)	10 (41.66)	12 (34.28)	4 (50.00)	2 (50.00)	23 (46.93)	51 (100)
Large (> 2ha)	5 (20.83)	7 (20.01)	2 (25.00)	1 (25.00)	11 (22.44)	26 (100)
Total	24 (20.00)	35 (29.16)	8 (6.66)	4 (3.33)	49 (40.83)	120 (100)

Source: Based on primary survey.

RESULTS AND DISCUSSION

Structure of groundwater markets

Selfusers (SU), Selfusers + Sellers (SU+S), Selfusers + Sellers + Buyers (SU+S+B), Owners + Sellers (OS), and Buyers are the five market structures studied in the field (Acharyya *et al.,* 2018). Table 2 shows the distribution of farmers in the study area based on their operational holding size under these five different groundwater market structures. Approximately 80% of the farmers are involved in groundwater exchanges, while the remaining 20% are selfusers. The "buyers" are by far the most numerous. (40.83%) followed by "selfusers+sellers" (29.16%), "selfusers+sellers+ buyers" (6.66%), and "owner+ sellers" (3.33%). The majority of the total buyers (46.93%) are small and marginal farmers (30.61%). Buyers in the large category are limited to 22.44 %. The distribution of sample buyers based on the size of their operational holdings clearly demonstrates that as farm volume increased, the number of buyers decreased proportionately. This finding is similar to the informal private water markets of Kathmandu Valley (Raina *et al.,* 2020).

In the survey area, in the case of sellers, approximately 45.71 % of the total sample under "self-users+sellers" are marginal farmers, and 34.28 % are smallholders. In the large and large categories of farm holdings, the number of "self-users+sellers" is approximately 20.01%. The majority of water sellers are small and marginal farmers. As a result, this research contradicts the widely held belief in the water market literature that all sellers are large-scale farmers. Furthermore, despite not owning any cultivable land, a few members of the owners+sellers group own shallow tubewells and sell water, as shown in Table 2.

Conduct of groundwater markets

Each seller assisted 1.13 customers in our research area's groundwater market. Each water seller irrigated an average of 3.51 hectares. On average, each water seller supported buyers' land up to 30% of the average area irrigated by them, as shown in Table 3.

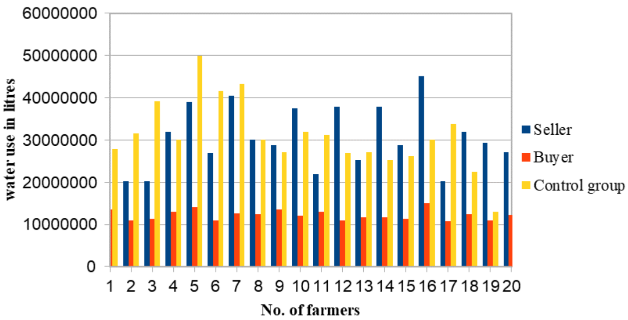

Fig. 2. *Showing the efficiency of three groups*

Water markets and cropping pattern

Rose occupied first place in the total cropped area, followed by mango, ragi, and rice, which came in second and third, respectively, in terms of the total planted area (Table 4). The share of total cultivated land under rose was somewhat lower on the waterbuyers' farm, accounting for approximately 43%, while the share of cropped area under high water intensive rice crop was zero. Mango and ragi occupied a higher proportion of cropped area under buyers when compared to other types of water markets, owing to insufficient irrigation facilities and the crop's less water intensive nature. The self-users + seller category had the highest cropping and irrigation intensity (89.13 and 93.19 %, respectively).

Cost of groundwater extraction and selling price

The entire cost of water extraction for modern diesel-powered WEMs came to Rs. 27.23 per tank. Fixed and operational expenditures accounted for approximately

Table 3. Extent of groundwater markets

S. No.	Particulars	Number
1	Sellers*	42
2	Buyer	49
3	Buyers/Seller	1.3
4	Average irrigated area by sellers (ha)	3.15
	a) Own field (%)	70
	b) Buyers field (%)	30

* Sellers include self-users + sellers and Owner + sellers

Table 4. Agricultural land operation across the water markets

Particulars	S_U	S_U+S	S_U+S+B	O+S	B
Net area sown (ha)	37.21	75.24	4.01	1.50	23.74
Total cropped area (ha)	45.04	84.41	7.25	4.75	47.75
Cropping intensity (%)	82.61	89.13	55.31	31.57	49.71
Irrigation intensity (%)	80.98	93.19	43.57	13.33	80.21
Share of different crops in gross cropped area (%)					
Rice	32	55	10	0	0
Ragi	25	19	70	0	45
Mango	25	19	70	0	45
Rose	33	20	10	0	43
Others	5	4	10	100	12

B: buyers; O+S: Owner+ Sellers; S_U+B+S: Self-users + buyers + sellers; S_U+S: Self-users + sellers; S_U: Self-users.

43 and 57 % of the overall cost, respectively. The price of groundwater each tank was Rs. 50.00. Over the whole cost of water extraction, water merchants made a net profit of Rs. 22.77 per tank. In addition, "the total cost of water extraction for modern electric WEMs came to Rs. 21.73 per tank". As shown in Table 5, fixed and operational costs accounted for approximately 56 and 44 % of the overall cost, respectively. The sellers of electric operating water also sell water for Rs. 50 and earned a net profit of Rs. 28.27 per tank. Thus, selling water was an economically profitable business for sellers of water in the study village.

DEA to measure water use efficiency

The efficiency of a farm can be evaluated using efficiency measures, which led to the creation of DEA. Efficiency analysis can be done in two ways: deterministic and stochastic. "Data envelopment analysis" (DEA), DEA is being utilised in this study to calculate farmers' water consumption efficiency (Speelman *et al*., 2008).

Behaviors of the control group, water sellers and water buyers

Among the three farm classifications of small, marginal, and large farmers, large farmers dominated the groundwater sale for irrigation, while small and marginal farmers were the principal buyers of groundwater for agriculture. On the other hand, small and marginal farmers were also involved in groundwater sales (Baig *et al.,* 2021). A lopsided distribution of land and water ownership was also reported by the latter. They claim that well owners are typically resource-rich farmers who sell water, whereas small farmers operate as purchasers because they are often unable to make the huge investments required to build a well. Smaller farmers may have wells and tube wells, but if they fail due to a lack of ground water, they lack the resources to address the situation, such as deepening the well and tube well.

Water seller

The farmers who participate in sale of irrigation water

Water buyer

The farmers who buy irrigation water for agriculture

Control group

Farmers who do not participate in selling or buying activities

Table 5. Cost of groundwater "extraction and selling price" (Rs./tank)

S. No	Particulars	Diesel operated	Electric operated
1	**Cost of water extraction**		
a)	Fixed cost[a]	7.33 (43)/tank	11.73 (56)/ tank
b)	Operating cost[b]	15.5 (57)/tank	10.00 (44)/ tank
c)	Total cost	27.23 (100)/ tank	21.73 (100)/tank
2	**Selling price**	50.00	
3	**Net income**		
a)	On fixed cost	42.67	38.27
b)	On operating cost	34.5	40
c)	On total cost	22.77	28.27

Values in () parenthesis are %ages of total cost

Statistical analysis of inputs and output used in DEA

The "input and output variables used in the DEA model" are summarised in Table 6 and 7. Water sellers' and control farmers' average water use is 25% and 20% greater than that of water purchasers, respectively. Since they have their own water source and easier access to water, "water sellers and control farmers" use larger quantities of water than water buyers. Water purchasers, and the only people who are paying more for irrigation water than the cost of extraction, appear to use it more economically and efficiently than the rest of the population. To determine whether the water usage efficiency between groups genuinely differs in terms of the use of other inputs, a multidimensional measure for each group, such as the DEA efficiency measure, is necessary (Phillips and Teng 2020). As shown in Fig. 1 and 2, Water sellers are the highest usage next, followed by control farmers. According to both the findings on input consumption and the findings on landholdings, water buyers are resource-strapped farmers who are unlikely to be able to afford the large investments required to install a well (Razzaq *et al.,* 2019). As a result, they must purchase water on the open market. Sellers provide about 30% out of 100% irrigation to buyers. The number of buyers (25) was more under the small farmers' category and they have 80.21% irrigation intensity across the water markets (Table 2 and 4).

Conclusion

Irrigation is one of the most significant components in agricultural transformation, and it has previously been proven to be a key determinant for the success of the Green Revolution in the 1960s when combined with technological progress. Because of the temporal and spatial variance in rainfall, irrigation becomes even more important for a country such as India. Although canal irrigation was dominant at the outset of irrigation development, its inefficiency and lack of reliability forced policymakers to emphasise groundwater development, which is more reliable and efficient in comparison. Agriculture is currently primarily reliant on groundwater irrigation. On the other hand, private WEM ownership has largely been restricted to large farms. Small and marginal farmers and major farmers with fragmented holdings will engage in informal transactions with nearby WEM owners to purchase irrigation water. This led to the spontaneous emergence of the informal groundwater market.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Table 6. Number of farmers in the efficiency category under three groups

Technical	Farm category			Total
	No. of seller	No. of buyer	No. of control group	
≥ 0.9	12(60)	17(85)	10(50)	39(65)
< 0.9	8(40)	3(15)	10(50)	21(35)
Total	20(100)	20(100)	20(100)	60(100)

≥ 0.9 is highly efficient; < 0.9 is less efficient

Table 7. Descriptive statistical analysis of "inputs and output" used in DEA

Input Variables	Farm types		
	Water sellers	Water buyers	Control group
Water (m^3)	84.58	33.91	85.3
Labour (mandays)	2.94	2.61	2.72
Manure (tones)	6.31	4.12	4.37
Fertiliser (kg)	4.25	3.36	3.98
Gross returns(INR)	901.25	820.72	885.92

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