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# Quantification of Negative Externalities of Irrigation Well Investment of Overexploited Firka: The Case of Coimbatore District of Tamil Nadu

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***Authors' contributions***

*This work was carried out in collaboration among all authors.* This work was carried out in collaboration among all authors. All authors read and approved the final manuscript. *All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** To study the total negative externality cost of irrigation well investment of overexploited firka.
**Study Design:** Purposive random sampling.
**Place and Duration of Study:** The study was conducted in the Coimbatore district of Tamil Nadu and the survey was conducted during July 2021 and September 2021.
**Methodology:** The sample size selected for the study is 160 which includes farmers (80 farmers+80 farmers) from Annur and Thondamuthur firka. Four villages were selected from each firka, similarly, 20 farmers from each village were selected for the study. Market price method and damage cost method were used to estimate the externality cost of overexploited firka of Coimbatore.
**Results:** The total negative externality cost estimated from the analysis is Rs. 21.19 lakhs per hectare of gross cropped area (GCA). The damage cost of dried wells is dominant when compared

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to all other costs. The cost of increased pumping hours is very negligible.
**Conclusion:** Small and marginal farmers are highly affected among different the category of farmers. The externalities can be reduced by optimal extraction of groundwater which can be achieved by monitoring done by the formal and informal institutions.

*Keywords: Groundwater; irrigation well investment; negative externality; market price method; damage cost; wells.*

## 1. INTRODUCTION

Water is the most valuable natural resource on the globe because it is required for the survival of all living organisms. Freshwater availability, both in terms of quality and quantity, is critical for a country's growth and economic development. The growing use of water for domestic, industrial, and agricultural purposes boosted the demand for freshwater significantly throughout this century. Due to the frequent failure of monsoons in semiarid zones like India, demand for freshwater is higher [1]. Freshwater is found primarily in groundwater in India, although it is also found in surface water bodies such as tanks, rivers, and channels. In India, the total utilizable groundwater and surface water resources are 396 Km and 690 Km [2] per year, respectively [3]. In India, 85 per cent of people rely on groundwater for their daily activities [4].

Agriculture is the world's largest consumer of groundwater. Irrigation accounts for more than 70 per cent of total water withdrawals and more than 90 per cent of total consumptive water consumption worldwide [5]. According to studies, groundwater has a bigger share of the market than surface water since it is available on-demand, at the site of use, and requires little transit. In his study, [6] found that groundwater irrigated areas produced higher yields. The advantages of groundwater irrigation are numerous, and several authors have summarized them [7,8]. These include higher productivity and its more equitable distribution among various classes of farmers, insurance against drought and stabilization of agricultural production, and enhanced employment generation. Data compiled from NSSO 54$^{th}$ Round shows that a high percentage of households hire irrigation services in many states, which in turn reflects the extent of development of the groundwater market in these states [9].

As a common-pool resource, Groundwater has a propensity to diminish and affect other consumers. Groundwater degradation is caused by a lack of acknowledgement of rights and ineffective mechanisms for managing groundwater as a shared resource [10]. According to hydrological research, groundwater systems balance outflows with average inflows in natural settings, but extensive abstraction would eventually disturb this balancing mechanism [11]. found the spatial depletion of groundwater was 2.9 per cent to 3.01 per cent which was very higher. This would eventually result in groundwater depletion and create externalities [12-17]. According to [18], India is the world's greatest user of groundwater, and the problem of over-abstraction of groundwater in both rural and urban contexts is a major issue in India. According to [19]. India experienced the Green Revolution between 1947 and 1967, which resulted in a massive rise in agricultural production and made India one of the world's largest grain exporters. Furthermore, India has accomplished its goal of food security. Unfortunately, this massive increase in agriculture necessitated a substantial amount of water for irrigation, hastening the development of current water constraints, which have been met by groundwater. According to FAO, 2011, It is believed that irrigated agriculture currently accounts for more than 70 per cent of India's foodgrain production, with groundwater playing a key role. In this view, there exist a need to study the trends and current status of groundwater use and depletion over time. These studies examine some of the externalities of agricultural operations and overuse of groundwater resources, but none of the externalities of groundwater extraction has been thoroughly examined [20]. found that the depletion of the groundwater table was mainly due to the flat or fully subsidized electricity pricing policy of Tamil Nadu and [21] found that depletion was due to resource decline. Furthermore, most researchers do not address policy solutions to mitigate negative externalities after evaluating negative externalities. To increase the sustainability of groundwater use, there is an earnest need for the management of groundwater aquifers.

Quantification of groundwater externality study is vital to internalize the externalities created by well investment. The overall objective of the study is to identify and quantify the interventional externalities created by groundwater investment.

## 2. METHODOLOGY

### 2.1 Selection of Study Area and Sampling Design

The study was conducted in the Coimbatore district situated between the latitude of $10^o$ 10' N and $11^o$ 30' N and longitude of $76^o$40' E and $77^o$ 30' E in the western end of Tamil Nadu, with an annual average rainfall of 1215 mm. The district receives rainfall from the southwest and northeast monsoon. The district majorly receives rain from the northeast monsoon and summer rains are negligible. The existence of the Palghat Gap on the Eastern side of the Western Ghats had a significant impact on the district's climate and agriculture. During the southwest monsoon, a large amount of rain is delivered into Pollachi Taluk through this gap. The temperature of the district ranges between 18.6 and 35.7 degrees Celsius.

Groundwater is the major source of irrigation in the Coimbatore district. The net area irrigated by total wells is 97,945 ha. The total net area irrigated in the Coimbatore district is 112,745 ha. The groundwater level is high in July followed by August and it was very low in the cold month of December. The yearly average groundwater availability is 12.35 meters.

As per the recent GO Dynamic groundwater resources assessment for Tamil Nadu dated 23.10.2019 categorization, there are 38 firkas in the district. Firkas are classified into over-exploited, critical, semi-critical, safe, and saline, or poor quality firkas based on their percentage of exploitation. The firkas which are exploited more than 100 per cent are overexploited firkas, between 90 to 100 per cent are critical firkas, between 70 to 90 per cent are semi-critical firkas, and less than 70 per cent are safe firkas. Over-exploited firka was purposively selected for the study since it critically shows the negative externalities of the groundwater. Of the 38 firkas, 26 firkas are overexploited in the Coimbatore district. Based on the stages of groundwater development, Annur and Thondamuthur firka were purposively selected. Four villages from each firka were selected randomly. The villages selected for the study under Annur firka are Kunnathur, Pachapalayam, Naranapuram and Kattampatti and the villages under Thondamuthur firka are Thondamuthur, Narasipuram, Alandurai and Booluvampatti. Twenty sample farmers from each village were selected and the total sample size is 160. Primary data was collected from the sampled respondents through personal interviews with the aid of a pre-tested interview schedule designed specifically for the purpose.

### 2.2 Analytical Framework

#### 2.2.1 Negative externalities of irrigation well investment

Groundwater users face a common pool resource problem: because they share the aquifer with other farmers, their extraction costs and the amount of water they have available to pump are affected by other farmers' pumping [20]. Negative externalities occur when production or consumption imposes an external cost on a third party. The negative externalities of well investments include private cost and social cost. Private cost is the direct cost that is simple and easy to estimate whereas social cost is dynamic and complex to calculate. In the social system, the private and social costs are co-existed and are complementarily related.

The total externality cost includes the cost of installation of new bore wells, cost of dryness of wells, cost by the reduced useful life of wells, cost of increased pumping hours, and cost of salinity. And reduced income to the farmer due to changes in the cropping pattern and decline in net sown area under irrigation.

*2.2.1.1 Cost of installation of new wells*

The dryness and poor yield of the well forces the farmer to increase the depth and made them construct well. It will add extra costs to the farmers. Market price method can be employed to value the cost of installation of new wells. The formula for calculating the cost of constructing a new well follows. The cost of drilling was collected from the farmers and well drillers and employed in the formula.

$$C_N = N_N * D_N * C_d$$

Where $C_N$ is the cost of construction of new wells (in rupees); $N_N$ is the number of new wells; $D_N$ is the average depth of new wells (in feet); $C_d$ is the cost of drilling each meter of the well (in rupees). The amortized cost method is used to calculate the annual uniform cost. The formula for calculating the annual uniform cost is,

$$A_N = C_N \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

Where $A_N$ is the annual uniform cost (in rupees); $C_N$ is the cost of construction of new wells (in rupees); i is the interest rate; n is the economic useful life of each well (in years)

*2.2.1.1.2 Cost of dryness of wells*

Excessive extraction of groundwater reduces the groundwater level in and around the wells and also causes dryness [22]. employed the market price method to estimate the dryness of wells since it forces the farmers to make more well investments. The formula for calculating the dryness of wells by damage cost method is,

$$C_{dr} = N_d * D_d * C_d$$

Where $C_{dr}$ is the damage cost by the dryness of wells (in rupees); $N_d$ is the number of dried wells; $D_d$ is the average depth of dried wells (in meters); $C_d$ is the cost of drilling each meter of the well (in rupees). The amortized cost method is used to calculate the annual uniform cost. The formula for calculating the annual uniform cost is,

$$A_d = C_d \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

Where A is the annual uniform cost (in rupees); $C_d$ is the damage cost by the dryness of wells (in rupees); I is the interest rate; n is the economic useful life of each well (in years)

*2.2.1.1.3 Damage cost by the reduction of the useful life of wells*

Reduction in the useful life of wells and pumping equipment will cause economic damage to the farmers. The drop-in water table will reduce the economic useful life of wells. It also damages the pumping equipment's due to pumping at higher altitudes. The shortened useful life of wells leads to increased uniform annual cost in well drilling and the purchase of a pump engine. Damage caused by the reduction of the useful life of wells and pump motors is another one of the economic externalities that can be calculated using the equation followed by [20].

$$\Delta C_L = P\left[\frac{i(1+i)^{n_2}}{(1+i)^{n_2} - 1}\right] - P\left[\frac{i(1+i)^{n_1}}{(1+i)^{n_1} - 1}\right]$$

Where, $\Delta C_L$ is the increased cost due to the reduced useful life of wells and pump (in rupees); C is the cost of construction of wells (in rupees); $n_1$ is the number of the useful life of well and pump before externality, and $n_2$ is the number of the useful life of well and pump after externality.

*2.2.1.1.4 Cost of increased pumping hours*

The negative externality associated with extended pumping hours will be calculated using the formula below, which is in terms of increased consumption of power,

$$E_v = \frac{\sum_{i=1}^{n} \Delta_i A_i}{\sum_{i=1}^{n} A_i} \psi$$

Where, Ev is the value of additional energy due to extended pumping hours (in Rs/ha); $\Delta_I$ is the increase in the energy consumption for irrigation in agriculture due to over-exploitation of groundwater (kwh); Ai is the area under crop i (in ha); I is the different crops cultivated; $\Psi$ is the value of energy (in Rs/kwh). The crop-wise electricity consumption was computed as one HP pump run for one hour consumes 0.746 kWh of power. Accordingly, kwh for each crop is the product of HP of the pump, 0.746 kwh, number of hours of irrigation and number of irrigations. In Tamil Nadu, the current consumption charge is fully subsidized by the government. But some farmers are using III A current which has meters and the energy charge is Rs. 4 per unit until 500 units and Rs.4.60 per unit for the energy consumption above 500 units.

*2.2.1.1.5 Reduced income*

The abstraction of groundwater has reduced the water availability to the crops which in turn affects crop production and farmers' income. The value of the lost crop is estimated by multiplying the reduction in crop yield, area, and price of the crop [20]. The formula for calculating the reduced income for the farm is as follows;

$$V_{lc} = (Y_t - Y_{t-1}) * (A_t - A_{t-1}) * P$$

Where, $V_{lc}$ is the value of lost crop (in rupees); $Y_t$ is the yield of the crop in the current year (in kilogram); $Y_{t-1}$ is the yield of the crop in the past year (in kilogram); $A_t$ is the area of the crop in the current year (in hectares); $A_{t-1}$ is the Area of the crop in the past year (in hectares) and P is the price of the crop (in rupees).

## 3. RESULTS AND DISCUSSION

### 3.1 Cost of Installation of New Bore Wells

One of the economic consequences due to the over-extraction of groundwater is the construction of new wells. The over-abstraction of groundwater by the farmer will affect the well yield of farmers nearby and also the wells dry. This forces the farmers around to construct new wells which involve the costs to the nearby farmers. To calculate this externality, the market price method was used to calculate the cost of construction of new wells in the study area. It is calculated by the product of the number of new wells, the average depth of new wells and the cost involved in drilling each meter of the well. It was known from the field survey, there were a lot of externalities was observed during the year 2015. The wells which are constructed after 2015 were considered as new wells due to externality.

It could be inferred from table 1 that the total annual uniform cost of construction of new wells was Rs. 4.89 lakhs per hectare of the gross cropped area [20]. estimated the total economic losses due to negative externality was 2.8 million dollars. The externality cost was high for the marginal farmers which are 45.40 per cent of the total externality cost even though the number of wells (25 wells) constructed by them was very low. 29.65 per cent of the total externality cost was borne by small farmers followed by the marginal farmers (16.77 per cent). But the number of wells constructed by the marginal farmers was very high compared with other categories of farmers. The externality cost for the large farmers was Rs. 0.39 lakhs per hectare of GCA which was very low than the farmers of other categories. Marginal and small farmers were affected more by the externality.

**Table 1. Cost of installation of new wells**

| Landholding size in ha | Number of new wells | Annual uniform cost (Rupees in lakhs per ha of GCA) |
|---|---|---|
| Marginal (<1 ha) | 25 | 2.22<br>(45.40) |
| Small (1-2 ha) | 52 | 1.45<br>(29.65) |
| Medium (2-4 ha) | 60 | 0.82<br>(16.77) |
| Large (>4 ha) | 45 | 0.39<br>(7.98) |
| All categories | 182 | 4.89<br>(100) |

*Source: Primary data collection (2021)*
*Note. Figures in the parenthesis indicate per cent to the total annual uniform cost of installation of new wells.*

**Table 2. Cost of dryness of wells**

| Landholding size in ha | Number of dried wells | Annual uniform cost (Rupees in lakhs per ha of GCA) |
|---|---|---|
| Marginal (<1 ha) | 52 | 3.86<br>(55.62) |
| Small (1-2 ha) | 77 | 1.79<br>(25.79) |
| Medium (2-4 ha) | 84 | 0.33<br>(4.76) |
| Large (>4 ha) | 47 | 0.34<br>(4.90) |
| All categories | 260 | 6.94<br>(100) |

*Source: Primary data collection (2021)*
*Note. Figures in the parenthesis indicate per cent to the total annual uniform cost of dryness of new wells.*

## 3.2 Cost of Dryness of Wells

The excessive extraction of groundwater reduces the yield of the well (litres per second) and eventually the drying of wells. This exploitation dried up the wells around and affects the farmer's livelihood.

The result is shown in table 2 below. There were 260 wells dried in the region. The number of wells dried was high in the case of medium farmers followed by the small farmers. The total externality cost due to dried wells was Rs. 6.94 lakhs per ha of GCA. More than 50 per cent of the total externality cost was borne by the marginal farmers. It was followed by small farmers and large farmers who cost about 25.79 per cent and 4.90 per cent of the total externality cost. Marginal farmers were affected more and the medium farmers were affected comparatively less.

## 3.3 Cost of Reduction of the Useful Life of Wells

The over-extraction of wells than recharge reduces the useful life of wells. The overexploitation of wells reduces the water table. Furthermore, as the water table drops due to pumping at a greater altitude and the presence of more mud, the pump engine's useful life diminishes. The higher drawdown would also induce aeration of the screen, as well as scaling and fouling, reducing the well's useful life. The increasing uniform annual cost of well-digging and the purchase of a pump engine is due to the shortened useful life of wells.

Table 3 shows that the initial investment is highly made by the marginal farmers (Rs. 149.10 lakhs) of overexploited firka and simultaneously the increased annualised cost (Rs. 3.08 lakhs) due to reduced useful life of well and pumps of them is also very higher. It is followed by small farmers who have invested Rs.35.24 lakhs and their annualised damaged cost is Rs. 0.73 lakhs. The damage cost is very low for large farmers (Rs. 0.19 lakhs). The total annual uniform damage cost due to the reduction in useful life of wells is Rs. 4.31 lakhs per hectare of GCA.

## 3.4 Cost of Increased Pumping Hours

Groundwater resources are the major source of production in the study area. The agriculture production needs water which has been pumped by electric motor pumps from the wells. The negative externality associated here is extended pumping hours. The pumping hours have extended from 5 to 6 hours per irrigation per hectare. In Tamil Nadu, the cost of electricity used for agricultural purposes is fully subsidised by the government. So, farmers are very freely extracting the water. The value of energy is calculated by the proxy of electrical charge which comes under the III-A (1) classification made by the Tamil Nadu Electricity board. This classification is for cottage and tiny industries, agricultural and allied activities, sericulture, floriculture, horticulture and fish/prawn culture etc.

**Table 3. Damage cost by the reduction of the useful life of wells (Rupees in lakhs/ ha of GCA)**

| Landholding size in ha | Initial investment | Increased cost due to the reduced useful life of wells and pump |
|---|---|---|
| Marginal (<1 ha) | 149.10 | 3.08 (71.46) |
| Small (1-2 ha) | 35.24 | 0.73 (16.94) |
| Medium (2-4 ha) | 15.16 | 0.31 (7.19) |
| Large (>4 ha) | 8.95 | 0.19 (4.41) |
| All categories | 208.46 | 4.31 (100) |

*Source: Primary data collection (2021)*

*Note. Figures in the parenthesis indicate per cent to the total annual uniform cost of the reduced useful life of wells and pump.*

**Table 4. Cost of increased pumping hours**

| Landholding size in ha | Increase in the energy consumption for irrigation | Value of energy (Rs/kWh/ha of GCA) |
|---|---|---|
| Marginal (<1 ha) | 12422.85<br>(0.32) | 0.019<br>(14.39) |
| Small (1-2 ha) | 85945.17<br>(2.19) | 0.025<br>(18.94) |
| Medium (2-4 ha) | 681242.06<br>(17.39) | 0.039<br>(29.55) |
| Large (>4 ha) | 3137283.85<br>(80.10) | 0.049<br>(37.12) |
| All categories | 3916893.93<br>(100) | 0.132<br>(100) |

*Source: Primary data collection (2021)*
*Note. Figures in the parenthesis indicate per cent to the total.*

**Table 5. Reduced Income for the Farmers**

| Crops | Reduced income (Rupees in lakhs/ha of GCA) |
|---|---|
| Onion | 0.55<br>(11.13) |
| Banana | 0.57<br>(11.64) |
| Tomato | 2.88<br>(58.67) |
| Turmeric | 0.90<br>(18.30) |
| Coconut | 0.01<br>(0.25) |
| Total crops | 4.92<br>(100) |

*Source: Primary data collection (2021)*
*Note. Figures in the parenthesis indicate per cent to total reduced income of farmers.*

**Table 6. Negative externalities of groundwater well investment (Rupees/ ha of GCA)**

| Sl. No. | Particulars | Cost of negative externalities |
|---|---|---|
| 1. | Installation of new wells | 4.89<br>(23.07) |
| 2. | Dryness of wells | 6.94<br>(32.75) |
| 3. | Reduction of the useful life of wells | 4.31<br>(20.34) |
| 4. | Increased pumping hours | 0.13<br>(0.62) |
| 5. | Reduced income | 4.92<br>(23.22) |
| | Total cost | 21.19<br>(100) |

*Source: Primary data collection (2021)*
*Note. Figures in the parenthesis indicate per cent to total cost of negative externalities.*

Among the farmers, the value of energy was higher for large farmers (37.12 per cent) followed by medium (29.55 per cent) and small farmers (18.94 per cent). It was because of the larger area and the extended pumping hours was very high of about 6 hours per hectare. The total cost of increased pumping hours by the farmers was Rs. 0.132 lakhs per hectare of GCA.

### 3.5 Reduced Income for the Farmers

One of the economic consequences of the declining groundwater table is reduced area under cultivation which in turn affects the farmer's income. The comparison was done using the benchmark year of 2015. The crops cultivated in the firka is onion, banana, tomato, turmeric and coconut. The table below shows the crop-wise reduced income for the farmers.

More than 50 per cent of the income of tomatoes was reduced (Rs. 2.88 lakhs/ ha of GCA) followed by turmeric (Rs. 0.90 lakhs/ha of GCA). As the perennial crop, the income of coconut reduced was very negligible which was 0.25 per cent of the total externality cost. The total income reduced was Rs. 4.92 lakhs per hectare of GCA.

### 3.6 Negative Externalities of Groundwater well Investment

Groundwater is the common pool natural renewable resource. When the groundwater is extracted in a balanced way it could be used sustainably. Unbalanced extraction creates negative impacts on others. These negative impacts are known as negative externalities. It affects the economic benefits of the farmers as well as the environment. The Total economic value of negative externalities of groundwater well investment per hectare of irrigated area is presented in the table below.

The total cost of a negative externality in the overexploited firka is Rs. 21.19 lakhs per hectare of the gross cropped area. The per cent of negative externalities is high in the case of dried wells (32.75 per cent). It is followed by the cost of reduced income (4.92 per cent) and installing new wells (4.89 per cent). The cost of increased pumping hours is very negligible (0.62 per cent). The number of dried wells (260 wells) is very high compared to several new wells installed (182 wells).

## 4. CONCLUSION

The study was conducted in overexploited firka of Coimbatore district to critically examine the negative externalities imposed by irrigation well investment. Because the natural ecosystems of the region rely on groundwater resources, a reduction in water level has resulted in the loss of ecosystem services. To estimate the externalities, the study has employed the market price method, damage cost method of valuation for the different categories of farmers. Then the costs were amortized to get the annual cost of the externalities. Water over extraction produced significant damages, as per the results of the externality appraisal.

The total negative externality cost of overexploited firka is Rs. 21.19 lakhs per hectare of the gross cropped area. The maximum burden to the farmers is the damaged cost of the dried wells which is 29.20 per cent of the total externality cost. The cost of installation of new wells is 23.07 per cent of the total cost of a negative externality. Over-extraction of groundwater has affected farmers and society, as well as raised crop production costs. Mostly small and medium farmers were affected due to extraction. This cost will affect the welfare of the farmers. The study will drive the policymakers to internalize the externalities. Policies must be implemented to sustain regional productivity, income, and welfare, as well as to improve the efficiency of water resource usage and prevent its irregular use.

This cost could be reduced by the optimal extraction of groundwater in the study area. Optimal extraction by one farmer will not reduce the water availability in the wells nearby. Hence the externalities could be internalized and there will be sustainable extraction of groundwater. This could be achieved by groundwater institutions to monitor the groundwater extraction in the particular firka which may be formal or informal institutions.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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