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ECONOMIC AND SOCIAL IMPACTS OF GROUNDWATER OVERDRAFT: THE CASE OF IRAN

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Abstract

Excessive withdrawal of groundwater for irrigation raises the issue of the sustainability of irrigated agriculture in many MENA countries. The objective of this paper is to determine the magnitude of groundwater overdraft and its external costs in Iran. Both quantitative and qualitative impacts of groundwater overdraft are estimated. Optimal control models are used to determine the optimal use of groundwater considering the social cost of groundwater overuse. Assessing the impact of groundwater overdraft shows a gloomy picture — of groundwater resource depletion in the study areas. The findings imply a trade-off between meeting immediate population demand for food and the sustainability of groundwater based farming. For a country like Iran, using foreign exchange earnings to save its vital groundwater resources may be considered a wise investment.

ملخص

يثير الإستخدام المفرط للمياة الجوفية لري المزروعات مسألة استمرارية ذلك الري في معظم بلدان الشرق الأوسط وشمال أفريقيا. تهدف تلك الورقة إلى تحديد مقدار السحب الزائد للمياه الجوفية في إيران التكاليف الظاهرية بالنسبة لها. قدرت الورقة التأثيرات الكمية و الكيفية على المياه الجوفية. واستخدمت الورقة نموذج أمثل لتحديد الاستخدام الأمثل للمياه الجوفية فيما يتعلق بالتكلفة الاجتماعية للسحب الزائد لتلك المياه. تظهر قديرات أثار السحب الزائد للمياه الجوفية صورة مظلمة عن نضوب مصادر تلك المياه في المناطق التي تمت دراستها. تشير النتائج إلى كيفية إحداث توازن مقبول بين سد الاحتياجات الغذائية الآنية للسكان واستمرارية الزراعة التي تعتمد على الري بالمياه الجوفية. و بالنسبة لدوله مثل إيران فان استخدام عائدات العملات الصعبة في حماية مواردها الحيوية من المياه الجوفية يعد استثماراً جيداً.

Introduction

Iran is an arid country with an average annual rainfall of about 250 mm. Nearly 290 billion cubic meters of water is lost due to evaporation, and 130 billion cubic meters of renewable water is available for use. Most of irrigated agriculture depends on groundwater pumping. Several decades of heavy pumping has led to a substantial decline in the depth of water and to consequent increases in water costs. Excessive withdrawal of groundwater for irrigation raises the issue of sustainability of irrigated agriculture in Iran. Such are the conditions found in most MENA countries.

The extraction of groundwater is not only influenced by the competitive behavior of individual users, but also by the prevalence of the high discount (time preference) rate and short planning horizon. Hence, its extraction inevitably results in the generation of an externality. As groundwater is a "common pool" resource, its use is likely to be inefficient in the absence of regulation. Individual users have little or no incentives to consider the effects of their withdrawal on other users or on future water levels. This myopic behavior of individual producers thus leads to collective inefficiencies (Gisser and Sanches, 1980). The drive for self-sufficiency in some strategic crops (notably, wheat) encouraged by low energy costs has placed heavy pressure on the quantity and quality of ground water resources of Iran.

While the socioeconomic impacts of groundwater extraction have been studied by many researchers (Randal, 1972; Brozovic, 2006; Ebaria, 2003; Hussain and Bhattaria, 2001; Koundouri, 2003), such studies on Iran in specific are very limited (Khalilian, 2006). Moreover, other studies have only considered direct costs and benefits of groundwater use on a limited scale (micro or project scope).

According to Hussain and Bhattaria (2001), the development of irrigated agriculture was the main success factor for the green revolution in Asia during 1970s and beyond. Yet, such success has been achieved at the high cost of groundwater depletion.

However, if the social benefits of irrigation exceed its social costs, it may be socially and economically justified — pending a comprehensive assessment of both quantitative and qualitative impacts.

In response to the public concern related to groundwater overdraft and depletion, the sustainable management of groundwater resources has drawn the attention of many hydrologists, economists, water experts and governments. The economic analysis of groundwater resources is mainly concerned with determining and internalizing the external cost of groundwater use aimed at enhancing the social welfare of individual users collectively.

The objectives of this paper are: 1) to determine the magnitude of groundwater overdraft and its external cost, 2) to determine the sustainability of groundwater irrigated farming considering both private and social costs, and 3) to determine expenditures required to avert groundwater depletion.

Both quantitative and qualitative impacts of groundwater overdraft are estimated, including:

- The magnitude of overdraft in terms of lowering the water tables, its direct effects on the traditional water sources such as springs and *kanats*[*], and reduction of their discharge.
- The number and depth of tube well dislocation.
- The effects of groundwater overdraft on deepening the existing tube wells.
- The effects of overdraft on the quality of groundwater.

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* A series of well shafts dug in the direction of the flow of groundwater connected by a tunnel or gallery.

- The relation between groundwater overdraft and discount (time preference) rate.
- The welfare impact of groundwater over-pumping.

Study Area

Fars and Khorasan provinces are selected for this study. They are located in northeast and southwest of Iran respectively. These provinces are facing severe groundwater over-use. Wheat and sugar beet are the most important agricultural produce in Fars and Khorasan respectively. The irrigation of wheat and sugar beet mostly depends on groundwater pumping. Several years of over-pumping in the provinces has led to a substantial decline in their water tables.

The control and socioeconomic impacts of groundwater overuse is a major concern because, 1) groundwater overuse has been on the rise in the face of increasing wheat and sugar beet prices, and 2) Fars and Khorasan may literally run out of groundwater if the existing groundwater use trend is maintained. As ground water is mined, the water table falls and more energy is required to lift water to the surface and the chemical quality of water deteriorates. In short, trends of groundwater overdraft have serious implications for the sustainability of irrigated agriculture in these provinces, which are major producers of wheat and sugar beet in Iran.

Methodology and Data

The conceptual model used for determining the optimal use of groundwater — considering the social cost of groundwater overdraft — is optimal control. For this purpose, Narimani plain is selected. The plain is located in Khorasan province, northeast of Iran. Data was collected from a random sample of 70 sugar beet farmers. Complementary data was obtained by interviewing some experts in Khorasan Water Corporation.

Optimal control implies that water is pumped until marginal benefits equal marginal pumping costs plus marginal user costs. Marginal user cost is the reduction in discounted future net benefits from a withdrawal of one additional unit in the current period. Calculation of marginal user cost requires knowledge of future optimal pumping levels. This can be determined by dynamic programming. However, assuming that future pumping is just equal to current pumping, marginal user cost (MUC) would be: $\mathrm{Muc} = \frac{ewt(1-\theta)}{Asi}$ and w_t is the solution:

$$a - bw_t = eh_t + \frac{ew_t(1-\theta)}{Asi} \tag{I}$$

where $p = a - bw_t$ = negatively sloped linear water demand function,

w_t = groundwater extraction in time t, h_t = pumping lift in time t, θ = fraction of applied water returning to aquifer ($0 \leq \theta \leq 1$), A = the area of aquifer in k^2m , and S = specific' yield of aquifer, and i = discount rate.

Benefits from groundwater extraction are assumed to be given by the area under a linear demand curve. Pumping costs will be $eh_t\, w_t$, where e is the cost of energy needed to lift one cubic meter of water one meter.

It should be noted that, in equation (I) the marginal cost pricing rule (Pareto optimum criterion) is extended to include both marginal pumping cost (eh_t) and marginal external cost ($\frac{ew_t(1-\theta)}{ASi}$).

Estimating Groundwater Pumping Costs

Annual groundwater extraction is measured by the following formula:

W = 3.6 R. H. D. where R = well discharge (liter per day), H= daily pumping hours, and D = the number of pumping days per year

Using operation and maintenance costs of pumping and volume of annual groundwater extraction, cost per unit of groundwater is calculated. Groundwater pumping involves two types of costs: Private or explicit costs, and external costs. Four types of external costs were considered in this study as follows:

1. Increased variable cost of pumping due to increased pumping lift.
2. Reduced farm income due to reduced well discharge and lower water quality (salinity).
3. Reduced land and water prices due to water salinity and lower crop output.
4. Costs of well deepening and relocating.

The Hedonic pricing method was used to estimate the effects of some explanatory factors on the price of land and water in Fars province:

$P = f(x_1, x_2, x_3, x_4, x_5, x_6, x_7)$

Where x_1 = cultivated area, x_2 = dummy variable for water quality, x_3 = the number of wells, x_4 = dummy variable for soil quality, x_5 = distance from water source, x_6 = dummy variable for the quality of distribution canals, and x_7 = age of trees.

Data was collected from a random sample of 30 field and vegetable crops in Fasa plain located in the south of Fars province. Agriculture in the plain is totally dependent on groundwater. The aquifer area is about 190 K^2m.

During the last decade the water table has been declining at the rate of 0.66 meter per annum. Annual reduction in groundwater amounts to 8.77 million cubic meters.

Results and Discussion

1- Khorasan Province

Table 1 shows a general picture of groundwater use in Narimani plain (Khorasan province)

Replacing variables in Table 1 in equation (I), we obtain the results shown in Table 2.

As indicated, annual groundwater use (extraction) is positively related to the discount rate. Annual groundwater pumping, with optimal control, is greater than current groundwater pumping at a discount rate greater than 12 percent. However, due to the higher discount rate in Iran (greater than 20 percent), optimal control in groundwater pumping may not provide a good solution for the groundwater overdraft problem in the study area.

Water demand functions of sugar beet farmers were estimated at

$P = 38659.3^* w^{-0.635}$ where P = Price (cost) of irrigation water in Rials, and w = applied water per hectare of sugar beet.

Water demand elasticity is equal to: $\varepsilon_{w.p} = \frac{\partial w}{\partial p} \times \frac{P}{w}$

Sample means of w and p ($\varepsilon_{w.p} = -1.33$) implies that the sugar beet farmers' demand for water is elastic. Hence, tax policy appears to be a good solution for decreasing (internalizing the cost of) groundwater overdraft in Khorasan province.

Per unit water tax (tariff) is an annual variable cost which tends to discourage annual groundwater use since it shifts the annual water supply curve upward. It means that per unit cost of groundwater is higher for each level of use and that total annual tax varies with quantity used. Since farmers are using electric pumps, increasing the cost of electricity may be considered as an alternative demand management measure for controlling groundwater overdraft.

2. Fars Province

Water resources and uses in Fars province are shown in Table 3.

As shown in Table 3, over 70 percent of total water used in the province is withdrawn from groundwater aquifers.

There are some 180 small and large aquifers in the province. Based on data collected from 1346 wells between 1994 and 2006, the average annual decline of the water table in 80 percent of aquifers is 0.5 meter, ranging from 0.03 to 1.97 meters annually. Accordingly, groundwater decrement due to over pumping has been estimated at 258 million cubic meters.

2.1. Welfare Impact of Groundwater Overdraft

Assuming irrigation water as a variable input, the reduction in producers' welfare (producer surplus) due to the reduction in groundwater is equal to the change in the area under the demand or marginal value product cure. Accordingly, wheat producers' loss of social welfare due to over-pumping of groundwater is estimated at 10.6 Rials per cubic meter reduction in groundwater (Khalilian and Zare', 2005).

Multiplying this loss by the total groundwater reduction of 258 million cubic meters, the total annual welfare loss of wheat growers in the province amounts to about 2.7 billion Rials.

Fars province is the top wheat producer in Iran, producing over 3 million tons annually. The drive for self-sufficiency in this strategic crop, encouraged by low energy costs and increased prices of wheat have placed heavy pressure on the quantity and quality of groundwater resources of province.

At present, Fars province is facing the problem of choice between producing wheat to feed the growing population and reducing its production to achieve sustainable use of groundwater. Considering irrigation requirements of wheat production in various basins of the province and the estimated groundwater overdraft, the total needed annual reduction in the acreage of wheat to avert external costs of over- pumping amounts to some 40000 hectares. This implies a trade-off between meeting immediate needs of the population and the sustainability of groundwater based farming. For a country like Iran with sizable foreign exchange earnings, importing wheat instead of producing it domestically may be an economically feasible solution to the problem of groundwater depletion. In other words, using foreign exchange to save vital groundwater resources may be a wise investment decision.

2.2. The Effects of Water Quality on the Price of Land and Water

As indicated, the impact of water quality on the price of land and water was estimated using Hedonic function. The function estimation is:

$$P = 21653 + 0.17x_1 - 0.24\,x_2 + 0.36x_4 - 0.11x_5$$

$R^2 = 0.75$ $F = 34.2$ signif = 0.00

As expected, water salinity (x_2) and well distance (x_5) have negative effects on the price of land and water, while cultivated area (x_1) and soil quality (x_4) have positive effects.

2.3. Well Relocation and Deepening Costs

The number of licensed well relocations and deepening during the last five years are shown in Table 4.

Based on the above statistics, the average number of annual well relocations and depth are 1200 and 154000 meters respectively. Likewise, the annual number and depth of well deepening are 926 and 52000 meters respectively. Using the current costs — of around 1000000 Rials per meter of depth — the total costs of well relocation and deepening amount to 206 billion Rials. Dividing this figure by the total volume of groundwater extracted per year results in relocation and deepening costs of 26 Rials per cubic meter.

Considering the reduction of *kanats* and springs discharge due to groundwater over-pumping and costs of well deepening and relocation, the total external costs of groundwater overdraft are estimated assuming different interest rates. Results are shown in Table 5. The estimate excludes the negative impact of water salinity on farm income.

As seen in Table 5, the lowest external cost of over pumping is 24.41 Rials per cubic meter (at a discount rate of 20%). The figure is expected to increase with time to reach 177.15 Rials in 2006 and 440.6 Rials in 2011. Also, the share of external costs in the total costs of over-pumping in Fars province changes with the discount rate. With discount rates of 10, 15 and 20 percent these shares are estimated at 45.131, 28.55, and 18.957 percent respectively.

2.4. Water Quality in Relation to Groundwater Overdraft

As indicated, groundwater overdraft has harmful effects on water quality. The analysis of water quality in 57 plains shows that water salinity is increasing in 37 plains. Table 6 shows the electrical conductivity (EC) of groundwater in critical aquifers of Fars province.

Water salinity is measured by EC of saturated soil extracts from the root zone. However, for practical purposes EC of irrigation water is measured first, then EC of saturated soil is obtained by dividing EC of irrigation water by 1.5. It is reported that if EC of saturated extract of soil reaches 14000 μ micromohs/cm (or) 14 (mmhos/cm), the relative yield of wheat falls by 50% (Abtahi, 1993). ECs of irrigation water in a number of wheat farms in Fars province are shown in Table 7.

Based on the EC of irrigation water shown in Table 7, it could be deduced that reduction in wheat yield (due to salinity generated from groundwater overdraft) may amount to 50%. Adding the value of reduced yield to the external costs of groundwater estimated above shows a gloomy picture for groundwater depletion in Fars province.

Policy Recommendation

Based on the findings of this paper and other related studies, the following policy recommendations are presented.

5. Exploitation of groundwater resources should be regulated so as not to exceed the recharging possibilities.
6. Effective groundwater legislation and tax policies should be introduced to control the over-exploitation of groundwater aquifers which are considered a "common pool" resource.
7. Groundwater recharge projects should be developed and implemented to increase the available supply.
8. Agricultural price policy should induce suitable changes in cropping patterns in the critical groundwater basins so as to ensure the sustainability of groundwater resources.

9. Economic analysis of groundwater development projects should be based on a comprehensive assessment including both the private and social costs and benefits of these projects.
10. As groundwater management problems are common in MENA countries (notably Yemen and Oman), the findings of this study can be extended to these countries as well.

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Table 1: Data on Groundwater Use in Narimani Plain

Well age	22.6 years
Initial lift	21.8 meters
Pumping cost	66.2 Rials/m^{3*}
Annual groundwater use	93.650 million m^3
Annual licensed use	81.05 million m^3
Aquifer area (A)	3047 km^2
Specific yield	0.09
Return flows to aquifer (θ)	9.6 percent
Water table at time of well digging	40.77 meter
Daily pumping hours	23
Length of pipes	109.62 meter
Applied water per Ha	17392 m^3
Demand intercept	38659.3
Demand slope	-0.635

Approximately 9000 Rials equal one US Dollar
Source: Khorasan Water Corporation and research findings.

Table 2: Water Use per Hectare of Sugar Beet in Relation to Discount Rate

Discount Rate	**Water use per Hectare (m^3)**
6	11665
7	13110
8	14746
9	15381
10	16265
12	17656
14	18670
16	19425
18	19994
20	20429
24	21040
28	21432

Source: Research findings

Table 3: Water Resources and Uses in Fars Province (million cubic meters)

Sources **Use**	**Surface water**	**Groundwater**	**Total**
Agriculture	2549	6657	9206
Industry	21	54	75
Residential	30	295	325
Total	2600	7006	9606

Source: Fars Water Corporation (2005-2006)

Table 4: Number of Licensed Well Relocation and Deepening

Year	Well Relocation		Well Deepening	
	Number	Depth (m)	Number	Deepening
2006	1325	174270	1060	55747
2005	823	109516	473	28112
2004	1008	132380	644	41695
2003	1616	190571	1154	66825
2002	1561	163354	1300	71505

Source: Data obtained by personal interview

Table 5: External Costs of Groundwater Extraction (Rials/m^3)

Year	Explicit Costs			External Costs			Total Costs		
	10%	15%	20%	10%	15%	20%	10%	15%	20%
1996	53.3	78.17	104.36	43.85	31.262	24.41	97.163	109.412	128.77
2001	85.88	157.2	254.648	70.643	62.82	60.73	156.53	220.0	320.38
2006	138.29	316.27	646.19	139.74	152.4	177.15	278.0	468.67	823.34
2011	222.68	636.0	1607.87	224.16	306.63	440.6	447.65	942.48	2048.56

Table 6: Increasing Electrical Conductivity of Groundwater (Fars Province)

Aquifer	Number of Years	Δ ECμ mohs/cm	Situation
Kavar-Maharloo	6	+ 376	Fairly critical
Sarvestan	6	+563	Critical
Farrash band	11	+692	Critical
Nimah	6	+1227	Very critical
Khasuyeh	8	+1518	Very critical
Dasht khak	8	+1459	Very critical

Source: Fars Water Corporation

Table 7: Electrical Conductivity of Irrigation Water in Selected Wheat Farms of Fars Province

Plain and Farm	Electrical conductivity EC$\times 10^6$ (μ mohs/cm)	Plain and Farm	EC
Abadeh Tashk 1	6321	Sarvestan 2	8611
Abadeh Tashk 2	15300	Sarvestan 3	3140
Arsanjan 1	1527	Lar 1	3000
Arsanjan 2	7265	Lar 2	8160
Arsanjan 3	17895	Lar 3	8259
Stahban	7843	Larestan	18300
Kharameh	1858	Lamerd 1	4744
Khonj 1	12700	Lamerd 2	8580
Khonj 2	1768	Lamerd 3	12480
Khonj 3	9460	Mehr	20614
Daryoon	8600	Nairiz 1	8880
Sarvestan 1	2240	Nairiz 2	8921
		Nairiz 3	12280

Source: Research data from salinity assessment of irrigation water in wheat growing areas (Fars province)