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# Optimal Utilization of Underground Water Resources: A Case Study of Fasa City

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**ABSTRACT**

Since the excess use of underground water resources in recent decades has created problems for farmers, an estimation of the amount of water utilization from wells and comparing the diversity of farming have led to the conclusion that: The more the amount of summer cultivation, the more water utilization. Corn as an agriculture product occupies the first position of water consumption. Besides, farmers with a high water consumption rate have been cultivating corn in addition to on of the wheat species. Besides, an estimation of the rate of utilizing underground water resources in the free competition and management imposition has led to the conclusion that since in free competition state, water users do not take into account peripheral costs they tend to use water resources excessively. Therefore, considering additional or peripheral costs seems essential. However, in high discount rates even the calculation of peripheral costs cannot solve the problem of excess withdrawal of water resources. As a result, it seems that the best way to prevent damages to underground water resources is to ration the use of water resources.

**KEYWORDS:** water utilization, excessive extraction, exploitation of water resources.

## 1. INTRODUCTION

One of the major dilemmas in today's world is the limitation of water resources for various uses, ranging from drinking, industry, agriculture and natural environments. Iran's agriculture is dependent on groundwater extraction and since in arid and semiarid regions, water is the most important preventive factor for agricultural development, not only water shortage resulting from climatologic factors has caused some problems in the agriculture sector but also non-optimal use of extracted water and excessive use of underground water resources in recent decades has led to a significant decrease in the stationary level of water resources, leading to the less access of agricultural lands to water .

Groundwater resources are among renewable natural resources, whose reasonable and balanced exploitation will lead to sustainable exploitation and nonobservance of balanced use and thus causing the destruction of these resources. Therefore, to sustainably exploit underground water resources, the extracted volume should be equal to the amount of rainfall water added to the resource. Ezat Abadi and Sultani (1997) compared optimal exploitation of underground water resources in the two states of free competition and management imposition and concluded that in free competition mode, since the users do not take into account the peripheral costs, the extraction of underground water is more than optimal level. Therefore, to prevent the annihilation of the underground water resources, it is needed to calculate peripheral costs and have the user pay for them or alternatively the use of water resources be rationed.

## RESEARCH METHODOLOGY

### Water extraction

The amount of water extraction from wells can be determined by measuring the flow of wells, the number of days in a year, the number of hours spent per day for water extraction, and the amount of water extraction from wells in terms of cubic meters per year.

$$W = 3.6\, R.H.D$$

W: the amount of water extraction in terms of cubic meters per year

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R: instant flow (L/s)
H: water extraction hours
D: number of days spent on water extraction per year

One of the questions that the farmers were asked in the questionnaire to answer was related to the flow of the well used for irrigation. In the case that a farmer used more than one well for irrigation, the means of flow for all wells were determined. Then, the number of hours spent per day for water extraction needed for each hectare of all crops was asked separately from the farmers and all numbers obtained were added together and the resulting figure was divided by the sum of the annual plantation density to determine the amount of water extraction from each well ($m^3$/year) through the following equation. It should be noted that the amount of water extraction for all annual crops has been calculated, i.e. the total annual amount of water extraction from well by all farmers in the sample was determined.

The obtained results are in the following table (the numbers given in bold rows present the farmers' number in the sample):

**Table (4-5): The total amount of annual water extraction from wells under study in 2009-2010**

| **10** | **9** | **8** | **7** | **6** | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|---|---|---|
| 534.303 | 840.78 | 680.157 | 072.63 | 304.47 | 912.141 | 216.189 | 144.126 | 594.27 | 565.29 |
| 20 | 19 | 18 | 17 | 16 | ***15* | 14 | 13 | 12 | 11 |
| 172.260 | 245.170 | 824.283 | 252.751 | 647.1567 | *472.1851* | 560.709 | 720.630 | 216.189 | 880.551 |
| 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 |
| 19.710 | 101.703 | 94.600 | 94.608 | 756.864 | 157.680 | 342.968 | 216.1211 | 711.210 | 714.290 |
| 40 | 39 | **38* | 37 | 36 | 35 | 34 | 33 | 32 | 31 |
| 709.56 | 788.40 | *243.12* | 234.154 | 15.768 | 125.355 | 767.675 | 47.304 | 31.536 | 23.652 |
| 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 |
| 189.216 | 1892.16 | 630.72 | 157.680 | 307.47 | 630.72 | 157.68 | 788.40 | 532.17 | 788.40 |
| 60 | 59 | 58 | 57 | 56 | 55 | 54 | 53 | 52 | 51 |
| 808.543 | 378.143 | 567.648 | 441.504 | 378.432 | 378.432 | 126.144 | 946.108 | 126.144 | 179 .755 |
| 70 | 69 | 68 | 67 | 66 | 65 | 64 | 63 | 62 | 61 |
| 664.56 | 456.434 | 189.343 | 70.867 | 95.600 | 98.700 | 78.880 | 123.354 | 474.105 | 236.54 |
| 80 | 79 | 78 | 77 | 76 | 75 | 74 | 73 | 72 | 71 |
| 2314.57 | 890.45 | 234.780 | 878.76 | 187.909 | 556.470 | 189.80 | 454.511 | 207.47 | 767.80 |
| 90 | 89 | 88 | 87 | 86 | 85 | 84 | 83 | 82 | 81 |
| 125.329 | 843.70 | 432.78 | 218.790 | 83.290 | 78.700 | 315.801 | 749.121 | 349.51 | 768.45 |
| 100 | 99 | 98 | 97 | 96 | 95 | 94 | 93 | 92 | 91 |
| 543.98 | 564.76 | 989.80 | 123.122 | 9.898 | 872.34 | 432.654 | 312.211 | 981.23 | 76.219 |
| | | | | | | | 103 | 102 | 101 |
| | | | | | | | 343.211 | 97.723 | 74.329 |

*: The minimum rate of annual water extraction
** The maximum rate of annual water extraction
Source: Research findings

The maximum rate of annual water extraction is related to a farmer whose cultivation density was 8, indicating that eight different crops including wheat species of Chamran and Darab 2, barley, corn, watermelon, tomatoes, and two types of vegetables. The reason for excessive water use by this farmer was the farming of highly water consumed crops including crops. The minimum rate of annual water extraction was related to a farmer who was growing Chamran wheat and barely.

## Calculating explicit cost of water extraction

Using the data from the completed questionnaire, the means of variable costs including the rate of fuel consumption, electricity, annual maintenance fees, and other expenses were calculated and divided by the means of water extraction from the wells to determine the variable cost for each cubic meter of water. In addition, the means of water extraction cost per cubic meter was calculated through the sum of annual fixed costs (fixed cost). Besides, the average of variable cost for each cubic meter of water was determined.

**Table (9-4): Calculating the fixed costs (IRR) per unit of water extraction from wells in 2009 -2010**

| **Cost type** | **Well samples** |
|---|---|
| **Annual cost of water extraction ($m^3$)** | 131.88 |
| **The means of fuel and repair and maintenance costs for each cubic meter of extracted water** | 208.12 |
| **The mean costs of each cubic meter of extracted water** | 340 |

Source: Research findings

As it can be seen from the table, the cost for extraction of each cubic meter of water (explicit cost of water extraction) is determined as equal to 340 Rials.

**Optimal and economic amount of water extraction**

An underground aquifer naturally has input and output flows of water. In the case that the water aquifer is not exploited, only natural inflows and outflows of water run through it. However if the aquifer is exploited, there will be an interference in its natural flow. And finally, the excessive exploitation of underground water resources will destroys such resources and the amount of underground water will drop sharply.

Most economists in the field of natural resources believe that if underground water resources are exploited freely and uncontrollably, economic welfare will decrease since the exploitation of users from a shared resource leads to excessive utilization of that resource.

In free competition state, consumer's behavior is so that the final cost underground water extraction will be equal to final benefits it offers. Since the exploitation of shared resources such as water results in peripheral costs not taken into account by consumers, as a result the utilization will exceed the optimal conditions. However, when the exploitation of water resources is managed correctly, farmers can maximize the present value of future income flows. In this case, all farmers in a given area are always under the water demand curve.

Pumping water from a shared underground water source will lead to additional costs which implicitly make a difference between utilization rates in free competition state and optimal utilization of underground water sources. Some economists believe that this difference is very small and disposable. However, these results appear to oppose the actual results of exploitation of shared underground water resources as the most of the underground water resources have been obliterated. Thus, the significance of water management will become obvious.

A principle used in free competition of exploitation of water resources is the principle of ultimate benefits with ultimate pumping costs.

$$a - bw_t = eh_t$$

$a - bw_t$: Water demand linear function with a negative slope

a: coefficient of water demand

$w_t$: Extraction of underground water at the time of t (consumption rate)

$eh_t$: Supply costs for a cubic meter of water (Rials)

$h_t$: Water extraction depth at the time of t

$e$:Cost of energy required to lift up one cubic meter of water for one meter high

But in case of applying water management requirements, the following principle is used:

Peripheral costs of underground water resource utilization + final pumping costs = ultimate benefits

Peripheral costs of underground water resource utilization are at least equal to the decline in discounted benefits resulting from a single excessive water extraction unit. As a result, in the case of water management and the optimal control of utilizing water resources, the exploitation of these resources is less than the free competition state.

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

$\theta$: A fraction of water extracted returning to the underground water aquifer

*A*: The surface of the underground water aquifer

S: Special efficiency (%)

i: Discount rate

The population under study consisted of all wheat farmers in Fasa City (Fars Province). Then a two-stage cluster sampling was used to randomly select a number of wheat growers as the sample of the study.

Since VMP = $P_w$, then we have:

$$\frac{dY}{dW} = p_w$$

$$MPW = \frac{dY}{dW} = 1.97 - 0.0009\text{١}W + 0.0\ 52X_1 + 38.9\ X_3 + 68.\text{٢٨}X_4 =$$

163046.7 – 0.00091W =340

**=> *w = 178798582*.6 (lit)**

In the free competition mode if all costs are not considered for farmers, the economic optimal rate of underground water source exploitation for each farmer would be about 178000 $m^3$ more than normal the current volume per hectare. (The average amount of water utilized by each farmer for the production of wheat per hectare is 5637.7 $m^3$.), indicating that if the peripheral costs of water exploitation are not received from the consumers and no control is exercised over exploitation of underground water source, the water exploitation will be performed excessively. As a result, when the user does not pay for peripheral costs, free market competition can not be efficient. In such cases, either the peripheral costs should be calculated and collected from water users or water utilization be rationed to prevent unauthorized water exploitation.

Based on Fasa irrigation statistics, the numerical value of parameters used in the mentioned formulas are:

θ: A fraction of the extracted water that returns to the underground aquifer = 20%

S: special efficiency = 10%

In mentioned equation, $\frac{ew_t(1-\theta)}{ASi}$, peripheral costs are discounted as in $\frac{w_t(1-\theta)}{AS}$ the annual increase in water extraction depth is excessive. In addition, e is the cost of extracting one cubic meter of water. As a result, $\frac{ew_t(1-\theta)}{AS}$ shows annual peripheral costs imposed on the user (2).

Since the optimal utilization of water resources is calculated for an area of a hectare, the value for parameter *A* in this equation is chosen as equal to one.

**Table (10-4): The optimal utilization of water resources in the water management mode at various discount rates**

| The optimal utilization of water resources ($m^3$) | Total water extraction costs (peripheral + explicit) (IRR/$m^3$) | Discounted peripheral costs (IRR/$m^3$) | Discount rate |
|---|---|---|---|
| 131882197.8 | 43033.9 | 42693.9 | %27 |
| 130077692.3 | 44676 | 44336 | %26 |
| 128128901.1 | 46449.4 | 46109.4 | %25 |
| 126017582.4 | 48370.7 | 48030.7 | %24 |
| 123722857.1 | 50458.9 | 50118.9 | %23 |
| 121219340.7 | 52737.1 | 52397.1 | %22 |
| 118477472.5 | 55232.2 | 54892.2 | %21 |
| 121219340.7 | 57976.8 | 57636.8 | %20 |
| 112127912.1 | 61010.3 | 60670.3 | %19 |
| 108423956 | 64380.9 | 64040.9 | %18 |
| 104284285.7 | 68148 | 67808 | %17 |
| 99633736.3 | 72380 | 72046 | %16 |
| 94349011 | 77189.1 | 76849.1 | %15 |
| 88316923 | 82678.3 | 82338.3 | %14 |
| 81356813.2 | 89012 | 88672 | %13 |
| 73236703.3 | 96401.3 | 96061.3 | %12 |
| 63640109.9 | 105134.2 | 104794.2 | %11 |
| 52124285.7 | 115613.6 | 115273.6 | %10 |
| 38049340.7 | 128421.8 | 128081.8 | %9 |
| 20455714.3 | 144432 | 144092 | %8 |

Source: Research findings

As it is indicated in the table, an increase in the discount rate will lead to a decrease in the amount of optimal exploitation of underground water resources when water management practices applied, as rising the discount rate is suggestive of the existence of much uncertainty and high risk. As a result, the use of water resources increases extremely by the farmer leading to the destruction of groundwater resources.

## Conclusion

In this study, a comparison of water extraction rate and cultivation diversity has led to the conclusion that the more summer crop growing, the more water extraction rate. Corn occupies the first position of using water resources. Furthermore, it was noted that the farmers with high water extraction rate has been growing corn in addition to one of wheat species. However, it also should not be ignored that most farmers use the maximum amount of water available to them regardless of irrigation needs of cultivated crops.

An estimation of optimal utilization of underground water resources per hectare in two modes of free competition and water management, it has been concluded in free competition mode, since the users do not take into account the peripheral costs, the extraction of underground water is more than optimal level. Therefore, to prevent the obliteration of the underground water resources, it is needed to calculate peripheral costs and have the user pay for them or alternatively the use of water resources be rationed to prevent unjustified exploitation of water resources. However, in high discount rates even the calculation of peripheral costs cannot solve the problem of excess withdrawal of water resources. As a result, it seems that the best way to prevent damages to underground water resources is to ration the use of water resources and to take legal preventive measures to stop destruction of the God-given resources.

**Suggestions**

Based on the results of the study, here a number of suggestions are provided, hoping to improve the status of using water resources:

1. Since the government is taking some steps in protecting producers and indiscriminate extraction of available underground water sources will cause a sever drop in underground water level, paying more attention to optimal use of such resources seems highly essential. To do so, efforts should be taken to increase water productivity using modern and highly efficient irrigation methods which are of particular importance.
2. Since a reduction in groundwater reserves makes water available to farmers less than what is needed for cultivated crops, as a result the government should take some policies to restrict cultivation of crops. As restricting cultivation of crops makes more water available for plants and it is possible to produce higher quality crops in lower costs.
3. Given that an increase in the discount rate (due to high risk and uncertainty) will aggravate the problem of excessive extraction of groundwater, any attempt to reduce risk and uncertainty faced by farmers can contribute in protecting groundwater resources. Besides, measures such as increasing crops insurance coverage and providing low interest credits may help the realization of this objective.

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