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Conflict over Underground Water and Pressurize Irrigation in Iran: A Spatial Analysis

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Abstract The objective of this study was to analyze the relationship between underground water extraction (depletion) and development of pressurized irrigation using data for 30 provinces in Iran. A spatial regression was used to study the relationship between variables for data in 2010.Results show that pressurized irrigation, long-run rainfall, spatial dependence and cultivated area in a region have a positive and significant effect on the extraction (depletion) of underground water, while the number of deep and shallow wells did not show such a relationship. In light of these results, it is recommended that the Iranian government should be more watchful of the regions with higher rate of extraction (depletion) for future investment in irrigation systems.

Keywords Water Resources, Spatial Econometrics, Spatial Lag Model

1. Introduction

Population growth and economic development, besides increasing need of human for food, can cause a great demand for water. Moreover, water is used in both productive and consumptive activities and contributes to rural and urban livelihoods in complex ways. Crop and livestock production, agro-processing, fishing, ecosystems, recreation and human health are all influenced by the quality and quantity of available water [1].Under a state of declining water quantities, water management becomes an important issue all over the world, especially in arid and semi-arid areas.

Agriculture is an activity that requires more water than other economic activities. For example about 90 percent of water supply in U.S.A. is allocated to agriculture[2].Similarly in Iran about 95 percent of water resources have been used in agricultural activities[3]. Proper management of water use in these activities could be necessary to meet future demands in these regions, particularly under periods of water shortages.

Surface water resources are scarce in arid and semi-arid regions of the world. As a result, most agricultural activities and development in cultivation rely more on underground water resources. The underground water is a very popular commodity with farmers because of several factors: (i) it is usually found close to the point-of-use; (ii) it can be developed quickly at low capital cost through individual (private) investment; (iii) it is available at the time of crop needs and thus provides small-holders a high level of control year-round; and (iv) it is well-suited to pressurized irrigation and high productivity precision agriculture. This has led to growth in irrigation outside canal command areas [4].

In Iran water market do not exist. Hence, water consumption is not based on economic rationale. Farmers, who have access to water, tend to over-use it. Such practices may lead to underground aquifers reaching an acute shortage condition, as use extraction rate often exceeds their recharge rate. Because of these issues Iranian government decided to develop pressurized irrigation systems on farms to manage water consumption and increase irrigation efficiency.

While many investments in irrigation and agricultural management have improved productivity and enhanced livelihoods, some have been unsuccessful and some have generated notable external costs. Some poorly conceived or poorly implemented water management interventions have incurred high social and environmental costs, such as inequity in the allocation of benefits and undesirable impacts on natural resources [5]. Many of irrigation’s negative environmental impacts arise from the diversion of water away from natural aquatic ecosystems, such as rivers, lakes and other groundwater-dependent wetlands and it may have other negative impacts [6,7].

Many studies in the field of water management have concluded that water management and irrigation system can have a positive effect on crop productivity and through that have a positive impact on farmer’s income and water management[8,9,10]. At the same time, other studies have concluded that irrigation system and water management have an ambiguous impact on natural water cycle and underground water recourses[11,12,7].

Gordon et al[13]have shown the ways in which water for agriculture influences ecosystem services provided by terrestrial and aquatic system, both positively and adversely. Terrestrial ecosystems are affected through changes in groundwater levels and alterations to runoff due to land use changes. They conclude that better agricultural water management can play a key role in mitigating the negative effects. Bossio et al[14]have indicated that paying attention to water natural cycle can be a very effective factor in water recourses management. Sauer et al[15] used a partial equilibrium model to investigate the impact of irrigation management on agricultural land and water use and concluded that different irrigation systems are preferred under different exogenous biophysical and socioeconomic conditions. Without technical progress, substantial price adjustments for land, water, and food would be required to balance supply and demand for water.

Iran depends on irrigation for its food security. However, being a semi-arid region, surface water resources are meagre, which makes underground water more valuable for future development. Overusing of underground water can have an ambiguous impact on natural water cycle and underground water recourses. To investigate the current situation of extraction (depletion) of underground water by irrigation development, this study was undertaken.

2. Material and Methods

2.1. Agricultural Variable and Underground Water Usage

Agricultural activities are a major user of underground water in Iran. The extraction (depletion) of underground water therefore, can be hypothesized to be affected by such activities. However, climatic variable, such as rainfall, would also impact its rate of extraction (depletion). To relate agricultural activities and underground water extraction (depletion), several variables were hypothesized.The first important variable hypothesized was cultivated area in the region. In other words, the larger the area under cultivation, the more underground water is going to be required. Also, extent of pressurized irrigation (to include various types of irrigation methods such as drip, sprinkler, among others) can be another factor that can affect the extraction (depletion) rate. Although pressurized irrigation systems can have a positive effect on the preservation of underground water recourses by managing the amount of water usage, it can also have a negative effect through overuse on the natural water cycle. It is expected that the impact of this variable on extraction (depletion)could be ambiguous.

Long-run rainfall can have both positive and negative effects on the extraction (depletion) of underground water. The negative effect would be contributed through a higher rate of recharge of aquifers, while the positive effect would be related to water needs for irrigation during periods of lower rainfall. Another variable that could have a negative impact on the extraction (depletion) of underground water is the number of deep and shallow wells, since especially deep wells do have a more destructive impact on the underground water.

2.2. DataSources

In this study data on pressurized irrigation and cultivation were collected from the agricultural census for the year 2010 [16]. Data for the extraction (depletion) of underground water and number of deep and shallow wells were obtained from the Iran's Ministry of Energy [3]. The long-run rainfall data for different provinces were obtained from Iran's Meteorological Organization [17]. Description of these variables along with the study mean values are presented in table 1. On average, in Iran some 2.45 mcm of underground water is extracted for irrigation.

Table 1. Study Variables Used in Estimation.

Variables	Description	Mean value (measurement unit)
Depletion (extraction) of underground water (DUW)	Amount of underground water which has been extracted	2449556 (mcm per year)
Pressurized irrigation (PI)	Area under pressurized irrigation in each province	3982 (hec)
Cultivated area (CUL)	Cultivated area in each province	268288 (hec)
Long-run rainfall (RF)	Average of long-run rainfall in each province	137.13 (mm per year)
Shallow well (SW)	Number of shallow well in each province	8238 (num)
Deep well (DW)	Number of deep well in each province	3900 (num)

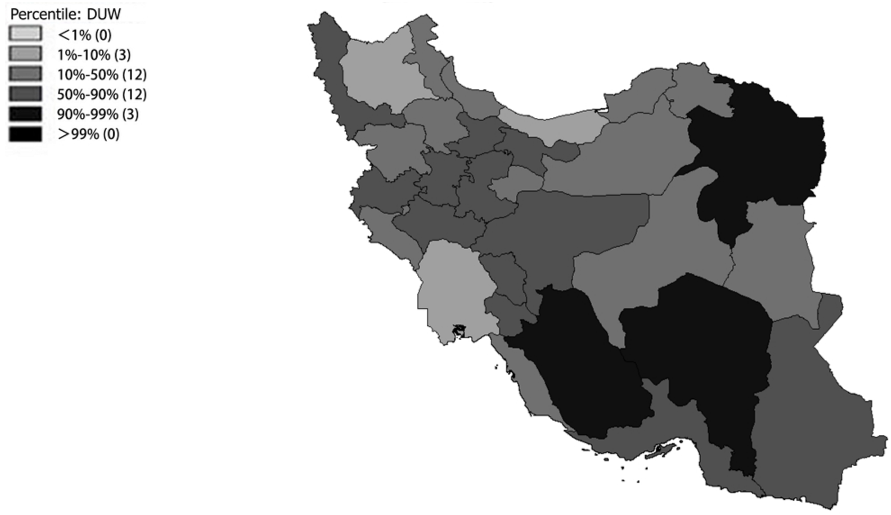

Figure 1. Map Showing Percentile Distribution of Underground Water Extraction for Different Provinces of Iran.

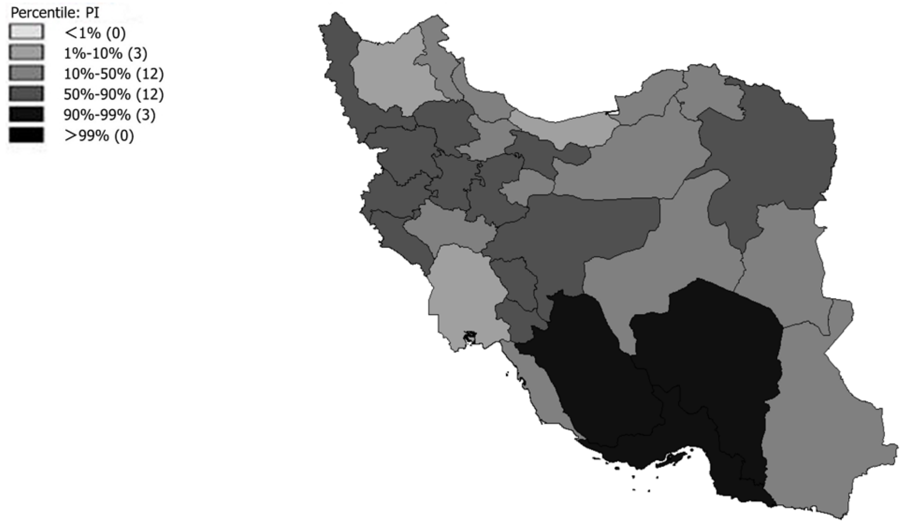

Figure 2. Map Showing A Percentile Distribution of Area of Pressurized Irrigation for Different Provinces of Iran.

2.3. Data Analysis

As it has been indicated in Figures1 and 2 those provinces which have a higher rate of development in the pressurized irrigation also have a higher rate of extraction of underground water. For example, as shown in Figure 1, Kerman, Fars, and Khorasan-Razavi provinces have the highest rate of extraction of underground water. On the other hand Mazandran, Khozestan and East Azrabayjan have the lowest rate of such extraction in Iran. Figure 2 at the same time indicates that Kerman, Hormozgan, and Fars have the highest rate of development in pressurized irrigation, whereas Mazandran, Khozestan and East Azrabayjan have the lowest rate. According to this evidence, it appears plausible that pressurized irrigation has a positive impact on an extraction of underground water.

2.4. Spatial Econometrics

In traditional econometrics spatial structure dependence between the observations and spatial heterogeneity in the relationships has largely been ignored. This leads to the violation of the Gauss-Markov assumptions required for regression modeling. Because of These features in data structure and the problem of violation of Gauss-Markov assumptions the need for alternative estimation approaches has been raised. Similarly, spatial heterogeneity violates the Gauss-Markov assumption that a single linear relationship with constant variance exists across the sample data observations. If the relationship or the variance changes as we move across the spatial data sample, alternative estimation procedures are needed to successfully model this variation and spatial econometric models is solution for these problems [18].

In this study we use a provincial data to investigate the impact of pressurized irrigation on extraction (depletion) of underground water in Iran, because, a catchment of many provinces are thesame, so, groundwater withdrawal in one province can have impact on the other provinces. Hence in this study spatial econometrics has been used.

In Spatial regression more detailed analysis is carried out to consider the influences that spatial dependence can have. Various spatial regressions have been introduced in different studies, including spatial lag model (SAR) and spatial error model (SEM). In spatial lag model another independent variable has been added to traditional independent variable:

$$Y = X\beta + \rho WY + u \quad (1)$$

Where, W is a spatial weights matrix and Y is a vector of values of the dependent variable (DUW);The matrix W represents the idea that area near each other should have a greater degree of spatial dependence than those further away from each other [19], and ρ is a spatial autoregressive parameter coefficient. In the spatial error model (SEM), the error term has two component and spatial dependence works through the model's error term [20]. The error term in this model can be written as: $u = \lambda Wu + e$, where W is the spatial weight matrix and lambda (λ) is a spatial error coefficient [19].

The general spatial model (the spatial autoregressive model with autoregressive disturbance terms), is a combination of two model which have been introduced. In this model spatial dependence works through both spatial lag and spatial error terms [20,21]. This model has been showed in equation (2).

$$y = X\beta + \rho Wy + u \qquad e \sim N(0, \sigma 2In)$$
$$u = \lambda Wu + e \quad (2)$$

Where X represents a matrix independent variables (PI, CUL, RF, DW, SW) and e is an error term normally distributed.

3. Result and Discussion

Using amount of underground water extracted in a province as the dependent variable and the five independent variables listed in Table 1, a regression analysis of factors affecting it was undertaken. To test for the best model using econometric validity criteria, three models were evaluated: (i) Ordinary least squares (OLS), which assumes that there is no violation of classical least squares procedure; (ii) Spatial lag model (SAR), per equation (1); and (iii) Spatial error model (SEM) per equation (2). Specification of each of these models were identical in terms of independent variables. Results are presented in Table 2.

Table 2. Results of Underground Water Extraction In Iran, by Provinces and Alternative Models

Variables	OLS	SAR (spatial lag)	SEM (spatial error)
Constant	0.056^{NS} (0.364)	-0.87^{***} (-2.42)	0.122^{NS} (0.816)
LN(PI)	0.296^{***} (2.98)	0.21^{***} (2.49)	0.283^{***} (3.56)
LN(CUL)	0.92^{***} (8.5)	0.88^{***} (10.07)	0.816^{***} (8.72)
LN(RF)	0.17^{NS} (0.70)	0.45^{**} (2.02)	0.402^{**} (1.95)
LN(SW)	-0.005^{NS} (-0.124)	0.0006^{NS} (0.020)	0.0163^{NS} (0.502)
LN(DW)	-0.017^{NS} (-0.362)	-0.025^{NS} (-0.64)	-0.03^{NS} (-0.78)
ρ	-	0.15^{***} (2.71)	-
λ	-	-	0.654^{***} (4.27)
R^2	0.984	0.987	0.988
Log likelihood	0.17	3.37	2.91
Akaike info criterion	11.64	7.24	6.16
Schwarz criterion	20.04	17.05	14.57
Moran's I (error)		2.57 [0.009]	
Lagrange Multiplier	-	5.49 [0.019]	3.38 [0.065]
Robust LM	-	3.92 [0.047]	1.814 [0.025]

t-values are presented in ();
P-values are presented in [];***,**,*indicate level of significant for 1%, 5% and 10%.

The first econometric test performed was related to violation of classical least squares assumptions using the Moran's I statistic. According to this test, spatial dependence was found to exist in the data. For this reason, the OLS model is not reliable and rejected. Furthermore, a positive Moran's I statistic shows a positive dependence of extraction of underground water between provinces suggesting that extraction of underground water in one province has a positive impact on the extraction level in neighboring provinces.

Next, the other two spatial models were examined. To choose between these two models (SAR and SEM), a test based on a comparison of the Lagrange multiplier was used. In both of these models this estimate was significant, thus not showing superiority of any of these two models (both were equally valid).This necessitated the use of another criterion – Robust LM criterion. This estimate is not significant for SEM, but is significant for the SAR. Based on these results, the SAR model was accepted as the best model to explain the variability in underground water extraction in various provinces of Iran.

According to the results of the SARpressurized irrigation, long-run rainfall, cultivated area and spatial dependence have positive and significant impact on underground water extraction. However, the number of deep and shallow wells did not affect the extraction level. Coefficient for pressurized irrigation was estimated at 0.21, suggesting that a one percent increase in the pressurized irrigation area in a province would cause a 0.21 percent increase in the underground water extraction. Thus, pressurized irrigation system in Iran has a negative impact on the underground water resources and the related natural water cycle. Similarly, a one percent increase in the cultivated area in a province would cause 0.88 percent increase in the underground water extraction. The sign of this variable is consistent with intuitive knowledge. The climatic variability also affects underground water extraction in Iran, as shown by a positive coefficient. Atone percent increase in the long-run rainfall would likely cause 0.45 percent increase in the extraction rate. Since, agriculture in provinces with high long-run rainfall is more developed than in other provinces, usage of underground water in these provinces is higher. The spatial dependence variable (ρ) has a positive impact on the dependent variable which means underground water usage in one province has a positive impact on the neighbor provinces and one percent increase in the underground water usage in one province can cause a 0.15 percent increase on the extraction (depletion) of neighboring provinces.

4. Conclusions

The objective of this article was to analyze the relationship between underground water extraction (depletion) and development of pressurized irrigation in various parts of Iran. Using data for 2010 for 30 provinces, results suggest that pressurized irrigation system in Iran has a negative impact on the underground water resources and natural water cycle. These findings are supportive of the findings of Khan et al [6] and Falkenmark et al [7]. However, these results contradict results reported by Hamdy [8] and Baysan et al [9]. Moreover, long-run rainfall has a negative impact on the underground water resources through agricultural development.

According to these results Iranian government should be more vigilant in the regions that have developed pressurized irrigation system. Further development of such irrigation would likely result in further damage to the natural ecosystem. Future investment in these provinces must be fully scrutinized through extensive studies.

Results of this study also indicate that there is a conflict between maintenance of underground water resources and development of pressurized irrigation. Water managers must keep the balance between safe recharge level of aquifers and underground water extraction level in various provinces. Maintenance of such a balance would ensure a healthy natural water cycle and avoid major water crises in the future.

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