中華水土保持學報, 51(3):109-116(2020)
Journal of Chinese Soil and Water Conservation, 51 (3)*: 109-116*(2020)
DOI: 10.29417/JCSWC.202009_51(3).0003

Effect of Water Conservation Policies on Groundwater Depletion in Iran

Mohammad Mehdi Farsi Aliabadi[1] Mahmoud Daneshvar Kakhky[1]*
Mahmoud Sabohi Sabouni[1] Arash Dourandish[1] Hamid Amadeh[2]

Abstract The groundwater depletion in Iran is becoming an irreversible catastrophic challenge, calling for an integrative approach combining socioeconomic, technological, and political factors. This study investigates the effect of conservation policy on Iran's groundwater depletion. The adopted spatial panel model includes economic and environmental variables as well as spatial externalities. The results indicated that the gradual removal of energy subsidies for agricultural activities is an effective policy to mitigate water depletion. However, in Iran where water depletion is a serious challenge, a small increase in energy price through the removal of energy subsidies would not lead to a significant reverse in the water depletion. Also, the results demonstrated that irrigation technology subsidies have an undesired effect on water depletion. Taking advantage of these technologies to gain more profit, farmers expand their cultivated area and thus extract more water. Finally, it was found that there is a spatial correlation in the groundwater depletion in different provinces. These correlations should be taken into consideration for adequate policy design. Several policy recommendations were concluded from the results, including restriction of agricultural land in plains with the critical groundwater situation, conductivity of smart water monitoring system in the land equipped with modern irrigation technologies, the codification of drought rehabilitation program, management of agricultural commodity prices in the short run, an increase in energy prices for agricultural activities concerning the inflation rate and water utilization based on *a mutual agreement* between neighbor beneficiaries in provincial borders with the common aquifers.

Key Words: spatial panel econometrics, spatial spillover, water conservation

Introduction

Natural resources are considered as one of the main input factors in the development process, among which water plays a primordial role. The Gross Domestic Product (GDP) growth rate in many countries highly depends on water resources development (zahid and Uddin Ahmed 2006). Water has a great and complex effects on economic activities (Ghorbani et al. 2014). Especially in arid areas such as Iran, some parts of India, and China's extensive extraction of water plays an important role in agricultural activities (Hornbeck and Keskin 2014). However, the massive consumption and increased pollution of water recourses lead to a natural resource degradation and deduction of human welfare.

Irrigated agriculture is a predominant consumer of water resources in the world, with about 60 % of water resources allocated to agricultural needs (Lin Lawell 2016). In some countries, in the arid and semiarid areas, the share of agricultural water consumption reaches 90 %. In these areas, groundwater recourse extraction cover a huge share of agricultural water demand because of the changes in precipitation pattern and occurrence of consecutive and severe drought, which lead to the scarcity of surface water (Kiptum and Sang 2017). Quality, reliability, and accessibility are considered as advantages of groundwater resources, which can play an important role in the sustainability of food security, sanitation improvement, and poverty reduction (Khair et al. 2015), especially in a rural area in arid regions. Similarly, other features of groundwater resources such as low investment cost for exploitation, vicinity to the consumption area, the insignificant short-term effect of drought, availability in a suitable time for the crop, and suitable for any kind of irrigation technology make them a popular input between farmers (Ojo et al. 2012).

Over-extraction of groundwater resources is an important concern in most of the agricultural region of Asia such as India, North of China, Pakistan, and Iran. Food production in these regions are at risk because of water scarcity (Aw-Hassan et al. 2014). In these countries, the energy subsidies policy implemented to support poor farmers in rural areas, accelerate agricultural production, and reduce rural poverty through low-cost pumping technologies (Shah et al. 2008). Hence, over-exploitation of groundwater can continue beyond the economic viability, and environmental sustainability and energy subsidies becomes one of the most important accelerators of groundwater depletion (Shah et al. 2012). In recent years, government gradually reduce the energy subsides and investment in water conservation policies such as irrigation technology subsidies, subsidies for water conservation crops to prolong the aquifer in these regions (Wang et al. 2015). Between these conservation policies, the government looks to irrigated agriculture as a solution for the conservation of groundwater, because they believed these technologies improve irrigation efficiency and could reduce agricultural water

〔1〕Faculty of Agricultural Economics, Ferdowsi University of Mashhad, Iran.
〔2〕Faculty of Economics, University of Allame Tabatabaie, Iran.
*Correspondence Author Email: Daneshvar@um.ac.ir

demand. Therefore, in many developing countries, the government allocates a considerable amount of irrigation technology subsidies to preserve the aquifers (Wang et al. 2015).

In the last decades, Iran's water resources have fallen. The average surface runoff between 1994 and 2014 has decreased by 42 % compared to the long-run average. On the other hand, the groundwater table has fallen due to over-extraction, and the cumulative groundwater deficit has reached 109 billion cubic meters (Khaki et al. 2018). Population growth since the 1980s, inefficient agriculture, farm subsidy programs, focusing on food self-sufficiency, mismanagement, and thirst for rapid development are considered as main elements of water scarcity in Iran (Madani 2014). Because of the limited availability of surface water in the country, most water consumptive activities depend on the groundwater recourses, and Iran is known as a top miner of these resources in the world (Döll et al. 2014).

Agriculture is considered as the main water consumer in Iran, so that the water consumption in this sector has reached to 86 billion cubic meters and experienced 200 % of growth since 1961 and about 93 % of Iran's renewable water has been allocated to agricultural activities (Moridi 2017). From a groundwater perspective, agricultural activities are responsible for 87 % of groundwater consumption and 78 % of depletion (Madani et al. 2016). Despite considerable water consumption, outdated farming technology leads to very low efficiency in irrigation and production. Moreover, an inefficient agricultural sector alongside the self-sufficiency program caused the expansion of cultivated areas and over-extraction of groundwater resources (Madani et al. 2016). In such conditions, the fall of the water table causes a water salinity and sudden collapse in the surface (Arfanuzzaman and Atiq Rahman 2017), which affect agricultural production and farmers' welfare negatively. Since many agricultural plains are suffering this circumstance, implementing water conservation policies that mitigate the water depletion and preserve the resources is obliging to prevent catastrophic consequences.

Insufficient water supply conditions, alongside the over-extraction of water resources, ratified the need to use economics, policy, technology, and other management tools to regulate the behavior of human resources utilization (Xia et al. 2011). The effect of water conservation policy has not investigated on the agricultural sector through a comprehensive study in Iran.

Therefore, the main purpose of this study is to survey the effect of energy subsidies reduction and irrigation technology subsidies alongside the other economic, environmental, and technological variables on the groundwater depletion. Moreover, spatial externality caused by the provincial water management unit is not taken into consideration. Therefore, this paper tried to investigate the effect of this matter for the first time in Iran. Based on the results of econometrics estimation, policy implications for mitigation of the groundwater depletion will be presented.

In recent years, many studies focused on investigating the effect of different conservation policies on mitigation of groundwater depletion. Between these policies, modification of energy price and implementation of modern irrigation programs gain considerable attention in the literature (Fishman 2018; Konikow 2015). Most of the studies indicate that increasing energy prices can limit the water depletion because the energy expenditure increases for pumping the same amount of water and it might decline a water depletion (Konikow 2015). Therefore, an increase in energy prices through the removal of price subsidies might become a policy measure for water conservation. In Iran, a gradual liberalization of energy prices can be considered as a water conservation policy. Up to 2010, huge energy subsidies hidden in energy prices, created an economic incentive for groundwater abstraction by farmers. However, in 2010, implementation of targeting subsidies by the Iranian government reduced the energy price subsidies in all the economic sectors, and energy prices drastically increased (Guillaume et al. 2011), and it might have a decreasing effect on groundwater extraction. Irrigation technology subsidies are the other policy employed by the Iranian government to increase irrigation efficiency and preserve the water resources. Most of the cultivated area were equipped with pressurized irrigation systems through government financial subsidies. However, studies showed that the effect of these technologies on groundwater depletion is ambiguous. Ghorbani et al. (2014), and Fishman (2018) showed that irrigation modernization can be effective conservation measure if the surplus water remains in the aquifers compared with the traditional technology. On the other hand, if the saved water is used for expansion of cultivation area and changing the crop pattern to more water-intensive crop, then implementation of subsidizing irrigation modernization leads to an over-extraction of groundwater (Fishman et al. 2015; Li and Zhao 2016).

Besides, water conservation policy, different socio-economic and environmental variables affect water depletion, and many studies have been conducted to identify them from different perspectives. Because of the considerable share of agriculture activities in water consumption, they are the most influential determinants of groundwater depletion. Investigations revealed that intensive irrigation, expansion of the cultivated area, and agricultural development for increasing food production cause a rapid groundwater depletion (Leduc et al. 2017). Some other studies indicate that change in agricultural commodity prices may motivate the farmers to change their groundwater consumption patterns. In other words, an increase in prices can raise the marginal revenue of groundwater pumping, which may lead to the over-extraction of the aquifers (Lin Lawell 2016). Moreover, providing food for a growing population and their extra water demand for drinking and sanitation put an additional burden on the groundwater resources (Pei et al. 2015). Also, the density of well in a region has a strong effect on the groundwater extraction; however, the amplitude of various exploitation methods on water depletion is different, and this matter should be taken into consideration (Massuel et al. 2017). In Iran, three different groundwater extraction methods are used for water abstraction, including the shallow tube well, deep tube well, and qanat. The shallow tube well usually is used in the shallow water table area, and its depth is not over 40 meters; therefore, these wells only affect the shallow aquifer, and their effect on groundwater depletion is not significant (World Bank 2013). Deep tube well installed at a suitable aquifer after penetrating at least one impervious layer, and its depth is usually over 40 meters; so, the effect of these wells on groundwater depletion could be more significant than the shallow wells(World Bank 2013). Finally, qanat consists of a series of vertical shafts in the sloping ground, interconnected at the bottom by a tunnel that conveys water from an aquifer or a water source to less elevated fields. Water extraction in qanat depends on climate condition and in dry year water extraction reduce and in the wet year water flow increase; because of this characteristic, groundwater extraction n this method is more sustainable than the other technologies (Hamidian et al. 2015). Sharing the aquifer by the farmers and issue of common-pool resources create spatial externalities and exacerbate the groundwater depletion especially across the political boundaries; however, the intangibility of the externalities create a difficult condition for researchers to investigate its effect (Sears et al. 2017). Finally, climate change such as the increasing trend in temperature, decreasing trend in rainfall, and increasing the occurrence of drought make the agricultural production more dependent on irrigation. In this condition, the surface water becomes limited, and pressure on groundwater extraction increases; therefore, depletion of groundwater resources will intensify (Bhargava 2018; Li and Zhao 2016).

Material and Methods

1. Data

To determine, in this study, secondary data used to investigate the effect of conservation policies and other economic and environmental factors on groundwater depletion. Agricultural variables, such as the area equipped with modern irrigation systems and cultivation area, were collected from the agricultural census (Minestry of Agriculter 2016). Groundwater depletion, energy price for agricultural activities, number of deep and shallow wells, and aqueduct obtained from the ministry of energy and Iran's water resources management company(Iran Water Resources Management 2017). Other variables such as population, precipitation, agricultural commodity price index, and temperature in different years have been collected from the statistical center of Iran (Statistical Center of Iran 2016). Considering the advantage of both cross-sectional and time-series, a panel data set is constructed based on all the available data in 31 provinces from 2010 to 2016. The description of these variables, along with the sample mean values, are presented in table 1.

According to Figure 1 in arid provinces with extensive agricultural activities and limited access to surface water flow such as Fars, Kerman, Esfehan, Khorasan Razavi, and Markazi, level of groundwater depletion is significantly high. On the other hand, provinces with higher access to surface water flow such as Gilan, Mazandaran, and Khuzestan or those with less developed agricultural sectors such as Bushehr, Ilam, and South Khorasan have a lower rate of groundwater depletion.

Table 1 Variables used in the analysis

Variables (Abbreviations)	Description	Data Source	Mean	Standard deviation
Depletion of groundwater (GD)	Difference between the yearly water extraction and the water recharge (MCM per year)	Iran water resources company	2020.7	1878.8
Number of shallow wells (NSW)	Number of shallow well in each province (number)	Iran water resources company	18784.3	24271.9
Number of deep wells (NDW)	Number of deep well in each province (number)	Iran water resources company	6367.9	6711
Number of qanats (NQ)	Number of qanats well in each province (number)	Iran water resources company	1327.7	1753.5
Agricultural cultivated area (ACA)	Cultivated area in each province (hec)	Ministry of agriculture	273326	227355.5
Area under modern Irrigation (MIS)	Area under pressurized irrigation in each province (hec)	Ministry of agriculture	46192.4	39593
Precipitation (PR)	Mean of Precipitation in each province (mm per year)	Statistical center of Iran	221.5	199.4
Temperature (TEM)	Mean of Temperature in each province (°C per year)	Statistical center of Iran	28.7	146.1
Population (POP)	Population in each province (1000 person)	Statistical center of Iran	2515.6	2376.1
Drought Index (DI)	Percent of Normal Index in each province (%)	own calculation	90.6	24.1
Agricultural Price Index (API)	Agricultural Price Index in each province (%)	Statistical center of Iran	199.7	27.6
Cost of Electricity (CE)	Cost of electricity for groundwater extraction in each province (Million rials)	Iran ministry of energy	17912.6	4943.5

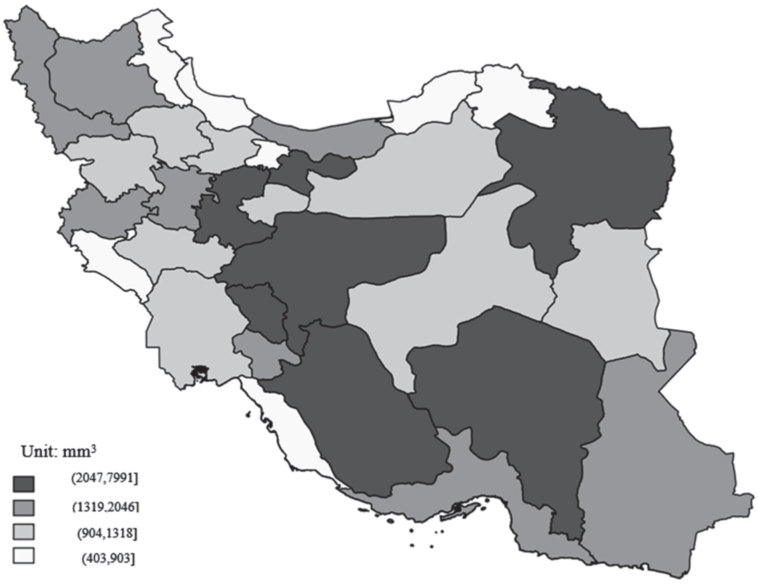

Fig.1 Map of groundwater depletion in Iran in 2016

2. Spatial panel model

Since in Iran, water management is not implemented based on basin territories, and provincial institutes are responsible for water management (Moridi 2017), spatial externalities are important and should be considered in the estimation. A spatial panel model was used in this study to investigate the effect of spatial externalities. The estimation of the spatial panel model follows a four-step procedure. First, the panel unit root test should be done; however, in this study, because of the short time period, this step can be eliminated (Siedenburg, 2010). After that, a spatial dependence test should be conducted. For this purpose, three statistically significant tests had been introduced; these tests were Moran's I, Geary's GC and, Getis and Ord's GO, which spatial autocorrelation can be examined through them (Mathur 2015). Estimation of the different specifications and choosing the best-estimated model considered as the third and fourth steps.

In recent years, a combination of spatial econometrics methods with the panel data gains considerable attention. The development of these models provides a remarkable opportunity for researchers to take advantage of panel data specification and investigate the spatial dependence between data at the same time (Elhorst 2010).

Spatial econometrics method expanded based on three different spatial interactions: (i) endogenous interaction effect, which specifies a decision of one spatial unit depends on the others units: (ii) exogenous interaction effect, where a decision of a spatial unit depends on the independent explanatory variables; and finally (iii) correlated effect, where a similar phenomenon results in the same behavior (Anselin et al. 2008; Elhorst 2010). In spatial econometrics, endogenous interaction effect captured by adding a spatially weighted independent variable in the model specification, the exogenous interaction effect captured by adding spatially weighted dependent variables in the model specification and finally, a spatially weighted error term should add to model specification to capture the correlated effect (Elhorst 2010). Therefore, the expanded spatial model presented in equation (1).

$$Y_{it} = \rho\sum_{j=1}^{N} W_{ij}Y_{jt} + c + \beta X_{it} + \theta\sum_{j=1}^{N} W_{ij}X_{jt} + u_{it}$$
$$u_{it} = \lambda\sum_{j=1}^{N} W_{ij}u_{jt} + \varepsilon_{it} \quad (1)$$

where Y_{it} is the dependent variable; X_{it} is a vector of independent variables; W_{ij} is a positive $N \times N$ contiguity matrix which in this study a binary contiguity matrix used to calculate the spatially weighted variables; $W_{ij}Y_{jt}$ denotes the endogenous interaction effect; $W_{ij}X_{jt}$ indicates the exogenous effect; $W_{ij}u_{jt}$ indicates a correlated effect; ρ is a spatial autoregressive coefficient; λ is a spatial autocorrelation coefficient; β and θ are the vectors of unknown parameters, c is a constant, i, j , t and N are the indices of provinces, year and number of neighbors respectively If $\rho \neq 0$ and $\lambda, \theta = 0$ the model specification is a spatial autoregressive (SAR); if the $\rho, \theta = 0$ and $\lambda \neq 0$ the model specification is spatial error model (SEM) and if $\rho, \lambda \neq 0$ the model specification is spatial autocorrelation model (SAC), and finally if $\rho, \lambda, \theta \neq 0$ the model specification is spatial Durbin model (SDM) (Kang et al. 2016).

A variety of identification tests are designed to choose between different spatial model specifications. Besides, the usual criteria of goodness of fit such as the adjusted R^2 and logarithmic value of likelihood function, the Lagrange Multiplier (LM) test (LM Lag and LM Error), and their robust values should be considered to select the best spatial model. Moreover, for determining the best spatial model specification, LR and Wald should be taken into consideration (Kang et al. 2016).

Results and Discussion

First, the existence of the spatial autocorrelation between water depletion in the different spatial areas should be examined; for this matter, various statistical tests applied. The results for Moran’s I, Geary’s GC and, Getis and Ord’s GO statistically significant tests were presented in Table 2. Based on the result of the spatial autocorrelation test confirmed the existence of the spatial autocorrelation.

Neglecting spatial correlation in a model specification can lead to biased estimates. Therefore, various spatial panel models estimated to overcome the problem. In these models, spatially weighted variables are added to regression specifications. Based on the model specification, weighted variables include the weighted dependent and independent variables, weighted error term, or a combination of them. In this study, a binary contiguity matrix used to calculate the spatially weighted variables, then different spatial model specifications such as SAR, SEM, SAC, and SDM estimated. However, the SDM specification did not show an appropriate result; thus, only the result of SAR, SEM, and SAC specification presented in Table 3.

Table 2 The result of Moran’s I, Geary’s GC and, Getis and Ord’s GO tests

Statistical significant test	Statistic value	P-value
Moran’s I	0.06	0.08
Geary’s GC	0.85	0.03
Getis and Ord’s GO	-0.28	0.08

Table 3 Results of Spatial Panel Model Estimation

Variables	SAR Coefficients	SEM Coefficients	SAC Coefficients
Number of Shallow Well	-0.009^{**}	-0.01^{**}	-0.01^{***}
Number of Deep Well	0.129^{**}	0.14^{**}	0.13^{***}
Number of qanats	0.23^{**}	0.25^{**}	0.24^{***}
Agricultural Cultivated Area	0.001^{**}	0.0001^{**}	0.001^{***}
Area under modern Irrigation	0.015^{**}	0.014^{**}	0.015^{***}
Precipitation	0.4^{Ns}	0.18^{Ns}	0.51^{Ns}
Temperature	-0.18^{Ns}	-0.16^{Ns}	-0.17^{Ns}
Population	0.02^{Ns}	-0.002^{Ns}	0.02^{Ns}
Drought Index	0.34^{*}	35.6^{Ns}	40.5^{**}
Agricultural Price Index	13.6^{Ns}	14^{Ns}	16.72^{**}
Cost of Electricity	-0.156^{Ns}	-0.16^{Ns}	-0.18^{**}
Constant	-3398^{Ns}	-3004^{Ns}	-3941.3^{**}
ρ	0.021^{*}	-	0.03^{**}
λ	-	0.012^{Ns}	0.017^{*}
LM	17.59^{***}	1.15^{Ns}	6742.6^{***}
LM Robust	6741.4^{***}	6725^{***}	-
F-test	73.79^{***}	79.65^{***}	82.7^{***}
R Square	0.85	0.85	0.86
Adjusted R Square	0.79	0.8	0.81
Log of Likelihood Function	-1229.7	-1230.9	-1227.8
Akaike Information Criterion	613316.4	574473	556260
Schwarz Criterion	776270.4	727106.6	704055.6

*°, ** and *** present the level of significance in 5, 1 and 0.1 Percent and Ns shows the non-significant coefficients.

Before looking at the estimated parameters, first, the best-estimated model should choose. To choose between these models, first, LM and robust LM for each model should compare with each other. Since the result of LM and robust LM for SEM are not statistically significant, the comparison showed that SAR and SAC are superior to SEM. Since the LM and robust LM are both significant for the remaining model, other diagnostic tests such as F-Test, Log of Likelihood Function, Akaike Information, and Schwarz Criterion and R and adjusted R- square should take into consideration. Based on these Criterions SAC is superior to SAR. Therefore, the parameter interpretation presented based on the result of SAC estimation.

According to the results from SAC, the number of the shallow wells and cost of electricity for water extraction have a negative and significant effect on the groundwater depletion. On the other hand, some factors such as the number of deep wells and aqueducts, agricultural-cultivated area, the agricultural land equipped with modern irrigation systems, drought index, and agricultural price index have a positive and significant effect on the independent variable. Moreover, coefficients of annual rainfall, temperature, and population in a specific area do not have a significant influence on groundwater depletion. Annual rainfall, temperature, and population usually have a significant impact on water depletion in the long run. However, in this study, because of the short period of investigation (7 years), these variables do not vary significantly during this period.

Table 4 Spatial Spillover Effect of Dependent Variables

Variable	Total Elasticity	Direct Elasticity	Indirect Elasticity
Number of Shallow Well	-0.0884	-0.0756	-0.0127
Number of Deep Well	0.4272	0.3657	0.0615
Number of qanats	0.1573	0.1346	0.0226
Agricultural Cultivated Area	0.1422	0.1217	0.0205
Area under Modern Irrigation	0.3533	0.3024	0.0509
Precipitation	0.0815	0.0698	0.0117
Temperature	-0.0025	-0.0021	-0.0004
Population	0.0292	0.0250	0.0042
Drought Index	1.8076	1.5474	0.2602
Agricultural Price Index	1.6453	1.4084	0.2368
Cost of Electricity	-1.6282	-1.3939	-0.2344

The total, direct, and indirect elasticity of dependent variables on groundwater depletion were presented in Table 4. In this table, the direct elasticity shows the effect of a change of a particular explanatory variable in one unit on the dependent variable of that unit and indirect effects are interpreted as spillover effects from changes in the exogenous variables in one particular unit to the dependent variable in other units. Finally, total elasticity shows the total effect of a change in the explanatory variable on the dependent variable.

Effect of different groundwater exploitation technology indicated that 1 % increase in the number of deep well and qanats in a specific province increase the water depletion for 0.37 % and 0.13 %; moreover, 1 % increase in the number of these variables in neighbor provinces cause a 0.06 % and 0.02 % increase in groundwater depletion (Table 4). Moreover, 1 % increase in several shallow wells in an area can mitigate the groundwater depletion by 0.08 %, and 1 % increase in this variable in neighbor areas decreases the water depletion by 0.01 %. Since in many regions of Iran shallow aquifers dried, it seems that the role of shallow wells changed, and they become an instrument for charging the aquifers. Based on the results, qanat seems to be a better-suited technology for groundwater extraction in Iran's condition because it has a less negative effect on groundwater resources. Besides, since deep wells accelerate the degradation of groundwater resources, policymakers should design a taxation program in order to increase the extraction costs and reduce the motivation of the beneficiaries to drill new deep wells in all the provinces.

The results showed that the extension of agricultural-cultivated area for 1 % could increase the groundwater depletion by 0.12 %; besides, the spatial spillover of this extension on the neighbor provinces is 0.02 % (Table 4). Since the development of the cultivated area can accelerate the depletion of aquifers, it seems that restriction on the development of the cultivated area should be considered in plains with the restricted groundwater availability (Kong et al. 2016). Based on these strategy policymakers should indicate that the development of cultivated in the region with a critical groundwater situation is impermissible. Moreover, implementation of land surface zoning based on the groundwater restriction should consider as policy measures.

The development of a modern irrigation system would exacerbate the groundwater depletion; the direct effect of a 1 % increase in an area under a modern irrigation system would result in a 0.30 % increase of depletion, and the spatial spillover effect is 0.05 % (Table 4). It seems that employing a modern irrigation system increases the ability of the beneficiaries for the extraction of groundwater resources; therefore, the rights and duties of a groundwater user should strictly monitor by authorities. Even though the adaptation of efficient irrigation technologies has a substantial potential for water conservation, however, the result of this study indicated that the policy outcome depends on farmers' decisions. In other words, farmers take advantage of these technologies and expand their cultivated area to gain more profit. In such circumstances, the irrigation technology subsidy policy fail to preserve the water resources (Fishman 2018; Wang et al. 2015); thus, using other effective measures such as soil water-saving technology, smart water monitoring system, make full use of water resources such as rainwater and limiting the water extraction by the farmer should be considered. Moreover, modern irrigation technologies only can be effective if the saved water does not assign for cultivation development. Therefore, the government should modify the law of water productivity, which allows the farmers to expand their irrigated cultivation area by the water they saved as a result of the implementation of more efficient irrigation technology.

The direct effect of a 1 % increase in drought index is 1.54 %, and the spatial spillover of drought is 0.26 % (Table 4). The severity of the drought can be considered as the most substantial factor of depletion. This result is in harmony with the results of Simon Wang et al. (2016). They indicate that groundwater depletion caused by intensified drought. Therefore, the codification of drought rehabilitation programs similar to the program, which is initiated by Pakistan, is recommended to policymakers (Khair et al. 2015). The direct effect of 1 % increase in agricultural price index leads to intensified water depletion by 1.41 %, and the spatial spillover of this variable is 0.24 %, and after that growth in the agricultural price, the index can be deliberate as the second effective factor. Ringler et al. (2013)discuss that in the short time increase in food price motivate the food production in response to higher demand and increase the consumption of the natural resources, including the groundwater. However, in the long run, an increase in agricultural commodity price alongside the resource constraint accelerate the investment in new technologies, promote agricultural production, and decrease the groundwater depletion. Therefore, the management of agricultural commodity prices in all the provinces should be considered by the government to mitigate the water depletion in the short run.

The cost of electricity, which consumed for water extraction, is the only variable that can maintain the groundwater depletion, based on the estimation results 1 % increase in an electricity cost would decrease the groundwater depletion for 1.39 % and the spatial spillover of this variable is -0.23 % (Table 4). Therefore, a 1 % increase in electricity cost in one province would lead to a 0.23 % decrease in groundwater depletion in neighbor provinces. Therefore, increasing the cost of energy can work as an immediate strategy to maintain the groundwater depletion because; this strategy not only, restricted the depletion increasing the extraction cost but also it can maintain the depletion through restricting the development of the cultivated area and increasing the usage cost of modern irrigation systems. Therefore, the gradual removal of energy subsidies for agricultural activities is the most effective water conservation policy that maintains the water depletion in Iran. Although the energy prices increased significantly in the last five years; however, its growth rate is not in coordination with the agricultural commodity prices. Therefore, farmers are still willing to withdraw water from deep wells and utilize it for agricultural activities. Based on this result increase in energy prices in coordinate with the inflation rate is recommended to policymakers (Khair et al. 2015; Shah et al. 2012). Plus, policymakers should notice in Iran's condition, where water depletion is a serious challenge, a small increase in energy price would not lead to a significant change in water depletion trend (Wang et al. 2015).

Finally, based on the estimated coefficient for ρ (Table 3) it can be indicated that water depletion in one province intensifies the water depletion in neighbor provinces. According to this result 1 % increase in water depletion in one province intensifies the water depletion for 0.03 % in neighbor provinces. Therefore, spatial externalities should be considered in common aquifer management. Pfeiffer and Lin (2012)discussed that the spatial externalities are a common issue in the common pool resources and whether it caused by physical movement, environmental reason, or other causes could be solved by the well – though policies (Pfeiffer and Lin 2012). In Iran, spatial externalities can be caused by common aquifer in the provincial borderline; in this situation, water utilization base on the mutual agreement between neighbor beneficiaries in these regions is the best solution to decrease the effect of spatial externalities.

Conclusion

Groundwater resources are the most important production factor in Iran, and it plays a vital role in the sustainability of food security, sanitation, and social welfare improvement. In past decades, over-extraction of these resources reduces the availability of groundwater, and many aquifers have been depleted. This situation turns in to one of the greatest concerns of policymakers in Iran, and they tried to mitigate the groundwater depletion by the implementation of subsidizing irrigation technology schemes and the gradual removal of energy subsidies in the agricultural sector. However, fallen off the water table in most aquifer indicated that these policies were not efficient.

In this study, the effect of water conservation policies, such as energy subsidies reduction and irrigation technology subsidies alongside the other economic, environmental, and technological variables were investigated on groundwater depletion in Iran. The results indicate that different groundwater exploitation technology, development of the cultivated area, and area equipped with modern irrigation systems, drought index, agricultural price index, and the cost of energy have a significant effect on groundwater depletion; furthermore, there is a spatial correlation in the groundwater depletion in different provinces.

Based on the results from restriction on agricultural land in plains with the critical groundwater situation, conductivity of smart water monitoring system in the land equipped with modern irrigation technologies, the codification of drought rehabilitation program, management of agricultural commodity prices in the short run, increase in energy prices for agricultural activities in coordinate with the inflation rate and water utilization based on the mutual agreement between neighbor beneficiaries in provincial borders with the common aquifers are the main policy measures. Consequently, it is recommended to policymakers to reduce the groundwater depletion in Iran.

References

[1] Anselin, L., Gallo, J.Le., and Jayet, H. (2008). "Spatial Panel Econometrics." *The Econometrics of Panel Data*, 625-660.

[2] Arfanuzzaman, M., and Atiq Rahman, A. (2017). "Sustainable water demand management in the face of rapid urbanization and ground water depletion for social-ecological resilience building." *Global Ecology and Conservation*, 10, 9-22.

[3] Aw-Hassan, A., Rida, F., Telleria, R., and Bruggeman, A. (2014). "The impact of food and agricultural policies on groundwater use in Syria." *Journal of Hydrology*, 513, 204-215.

[4] Bhargava, A. (2018). "Climate variability, rice production and groundwater depletion in India." *Environmental Research Letters,* 13(3), 1-8.

[5] Döll, P., Müller Schmied, H., Schuh, C., Portmann, F.T., and Eicker, A. (2014). "Global-scale assessment of groundwater depletion and related groundwater abstractions: Combining hydrological modeling with information from well observations and GRACE satellites." *Water Resources Research*, 50(7), 5698-5720.

[6] Elhorst, J.P. (2010). "Applied Spatial Econometrics: Raising the Bar." *Spatial Economic Analysis*, 5(1), 9-28.

[7] Fishman, R. (2018). "Groundwater depletion limits the scope for adaptation to increased rainfall variability in India." *Climatic Change*, 147(1-2), 195-209.

[8] Fishman, R., Devineni, N., and Raman, S. (2015). "Can improved agricultural water use efficiency save India's groundwater?" *Environmental Research Letters,* 10(8), 084022.

[9] Ghorbani, M., Kulshreshtha, S., and Farsi, M.M. (2014). "Conflict over Underground Water and Pressurize Irrigation in Iran : A Spatial Analysis." *Universal Journal of Agricultural Research*, 2(6), 185-190.

[10] Guillaume, D.M., Zytek, R., and Reza Farzin, M. (2011). "Iran: The Chronicles of the Subsidy Reform." *IMF Working Papers,* 11(167), 1-28.

[11] Hamidian, A., Ghorbani, M., Abdolshahnejad, M., and Abdolshahnejad, A. (2015). "Qanat, Traditional Eco-technology for Irrigation and Water Management." *Agriculture and Agricultural Science Procedia*, 4, 119–125.

[12] Hornbeck, R., and Keskin, P. (2014). "The historically evolving impact of the ogallala aquifer: Agricultural adaptation to groundwater and drought." *American Economic Journal: Applied Economics*, 6(1 A), 190-219.

[13] Iran Water Resources Management. (2017). *Iran Water Resources Status*. Tehran, Iran.

[14] Kang, Y.Q., Zhao, T., and Yang, Y.Y. (2016). "Environmental Kuznets curve for CO2emissions in China: A spatial panel data approach." *Ecological Indicators,* 63, 231-239.

[15] Khair, S.M., Mushtaq, S., and Reardon-Smith, K. (2015). "Groundwater Governance in a Water-Starved Country: Public Policy, Farmers' Perceptions, and Drivers of Tubewell Adoption in Balochistan, Pakistan". *Groundwater*, 53(4), 626-637.

[16] Khaki, M., Forootan, E., Kuhn, M., Awange, J., van Dijk, A. I. J. M., Schumacher, M., and Sharifi, M. A. (2018). "Determining water storage depletion within Iran by assimilating GRACE data into the W3RA hydrological model." *Advances in Water Resources*, 114, 1-18.

[17] Kiptum, A.R., and Sang, C.C. (2017). "Determinants of Groundwater Retention in Wells: A Case of Keiyo North District, Elgeyo Marakwet County, Kenya." *Journal of Water Security*, 3(1), 1-7.

[18] Kong, X., Zhang, X., Lal, R., Zhang, F., Chen, X., Niu, Z., Han, L., and Song, W. (2016). "Groundwater Depletion by Agricultural Intensification in China's HHH Plains, Since 1980s." *Advances in Agronomy*, 135, 59-106.

[19] Konikow, L.F. (2015). "Long-Term Groundwater Depletion in the United States". *Groundwater*, 53(1), 2-9.

[20] Leduc, C., Pulido-Bosch, A., and Remini, B. (2017). "Anthropization of groundwater resources in the Mediterranean region: processes and challenges." *Hydrogeology Journal*, 25(6), 1529-1547.

[21] Li, H., and Zhao, J. (2016). "Rebound Effect of Irrigation Technologies? The Role of Water Rights Haoyang." *Agricultural & Applied Economics Association Annual Meeting*, Boston, Massachusetts, 1-25.

[22] Lin Lawell, C.-Y.C. (2016). "The Management of Groundwater: Irrigation Efficiency, Policy, Institutions, and Externalities." *Annual Review of Resource Economics*, 8(1), 247-259.

[23] Madani, K. (2014). "Water management in Iran: what is causing the looming crisis?" *Journal of Environmental Studies and Sciences*, 4(4), 315-328.

[24] Madani, K., AghaKouchak, A., and Mirchi, A. (2016). "Iran's Socio-economic Drought: Challenges of a Water-Bankrupt Nation." *Iranian Studies*, 49(6), 997-1016.

[25] Massuel, S., Amichi, F., Ameur, F., Calvez, R., Jenhaoui, Z., Bouarfa, S., Kuper, M., Habaieb, H., Hartani, T., and Hammani, A. (2017). "Considering groundwater use to improve the assessment of groundwater pumping for irrigation in North Africa." *Hydrogeology Journal*, 25(6), 1565-1577.

[26] Mathur, M. (2015). "Spatial autocorrelation analysis in plant population : An overview." *Journal of Applied and Natural Science*, 7(1), 501-513.

[27] Minestry of Agriculter. (2016). *Agricultural Year Book*. Tehran, Iran.

[28] Moridi, A. (2017). "State of Water Resources in Iran." *International Journal of Hydrology*, 1(4), 111-114.

[29] Ojo, O., Otieno, F., and Ochieng, G. (2012). "Groundwater: Characteristics, qualities, pollutions and treatments: An overview." *International Journal of Water Resources and Environmental Engineering*, 4(6), 162-170.

[30] Pei, H., Scanlon, B.R., Shen, Y., Reedy, R.C., Long, D., and Liu, C. (2015). "Impacts of varying agricultural intensification on crop yield and groundwater resources: Comparison of the North China Plain and US High Plains." *Environmental Research Letters*, 10(4), 1-14.

[31] Pfeiffer, L., and Lin, C.Y.C. (2012). "Groundwater pumping and spatial externalities in agriculture." *Journal of Environmental Economics and Management*, 64(1), 16-30.

[32] Ringler, C., Bhaduri, A., and Lawford, R. (2013). "The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency?" *Current Opinion in Environmental Sustainability*, 5(6), 617-624.

[33] Sears, L., Lim, D., and Lin Lawell, C.-Y.C. (2017). "The economics of agricultural groundwater management institutions: The case of California." *Water Economics and Policy*, 4 (3), 1850003.

[34] Shah, T., Bhatt, S., Shah, R.K., and Talati, J. (2008). "Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India." *Agricultural Water Management*, 95(11), 1233-1242.

[35] Shah, T., Giordano, M., and Mukherji, A. (2012). "Political economy of the energy-groundwater nexus in India: exploring issues and assessing policy options." *Hydrogeology Journal*, 20(5), 995-1006.

[36] Statistical Center of Iran. (2016). *Iran National Censues*. Tehran, Iran.

[37] Wang, T., Park, S.C., and Jin, H. (2015). "Will farmers save water? A theoretical analysis of groundwater conservation policies." *Water Resources and Economics*, 12, 27-39.

[38] World Bank. (2013). Environmental Assessment and Environmental Management Framework of Secondary Education Quality & Access Enhancement Project. World Bank, Dhaka.

[39] Xia, D.P., Guo, H.Y., and Huang, D. (2011). "Discussion on the demand management of water resources." *Procedia Environmental Sciences*, 10(PART B), 1173-1176.

[40] Zahid, A., and Uddin Ahmed, S.R. (2006). Groundwater Resources Development in Bangladesh: Contribution to Irrigation for Food Security and Constraints to Sustainability. IWMI Books, International Water Management Institute.

2020 年 06 月 14 日　收稿
2020 年 07 月 21 日　修正
2020 年 09 月 06 日　接受
(本文開放討論至 2020 年 12 月 31 日)