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Water Resources Management of The Hirmand River Basin in Agricultural and Household Sectors

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ABSTRACT

Supply and demand management of Hirmand water resources is one of the most important problems faced by policymakers and they will not be able to manage this sector properly without specifying the future prospects of the Hirmand Area. The main objective of the research is to allocate water resources in the Hirmand Area by using dynamic optimization models in the agricultural and household sectors. The method of this research is based on the applied scientific method. The required statistics and information are obtained by the library method. In this research, the water demand functions in the agricultural and household sectors are achieved. The general objective function for determining the allocation is estimated by the EVIEWS and GAMS software packages. The results showed that for the agricultural sector, water demand is inversely related to water price, so that when the water price increases by 1%, the product will have a negative value decrease by 4.4%. Moreover, since in this model, the demand function for water is only a function of the price, the return to the scale is decreasing and the Isoquant Curve in the agricultural sector has a negative technical substitution rate in all aquatic conditions. In household demand, the results showed that with the increase in water price, consumption decreases and that the rise in price is a necessary, but not sufficient, condition for reducing consumption. The average consumption based on the current trend is 12.42 m3 per month for each household. The reaction in the amount of demand change versus the change in the number of stormy days is positive and equal to 0.39.

1. Introduction

The prediction of the trend of water consumption from the beginning of the 20th century to the present time and till 2050 has revealed that the cross point of consumption and the amount of available water will be around 2040 on the global scale. This cross has occurred on a regional and national scale, but for some nations has started since many years ago and is happening to many others at the present time (Mohammadghasemi, 2016; Sardar Shahraki and Karim, 2018). A study on Hirmand's water availability in different years has documented that over the period of last 30 years, Hirmand has suffered from 9 various drought years. This is despite the fact that since the Hirmand River is the only source of water supply known for the current social-economic life, any fluctuations in the rate of its inflow affect the local life and whole Iran (Ebrahim Zadeh, 2012; Sardar Shahraki et al., 2018). Although Sistan is geographically a part of the Iranian plateau, it refers to a vast area in the southeast part of the Iranian plateau. Just as Egypt's life depends on the Nile River and India on the Ganga River, the life of Sistan has depended on the Hirmand River for thousands of years (Naroui Rad et al., 2017; Sardar Shahraki et al., 2018). According to the Zabul station statistics, during the past 40 years, the average annual rainfall rate in Zabol was about 61 mm in that the lowest was in 2001 with a total of 7.2 mm and the highest was in 2005 with a total of 129.5 mm (Karim et al., 2012).

A comparison of statistics between the wet and normal conditions of 1996 and the drought period of 2006 indicates that in 1996, the cropping area was over 120 thousand hectares, the gardens were 2,000 hectares and also there were 1100 villages among which only 2/1% of them were vacant, 85% had over 50 inhabitants, 75% were engaged in agriculture, 20% were located on the edge of the Hamoon wetland with approximately 700 households engaged in fishing and hunting of birds and also weaving wool, but in the 2006 drought period, 73% of agricultural crops and 79% of horticultural crops lost their acreage as compared to 1996, 20% of the villages were desolated and 12% had a population of fewer than 50 people. The average age of farmers in the agricultural sector was over 55 years old. 89%

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of people were supported by organizations such as the Committee of Relief, Welfare and so on. There was a sharp decrease in the price of agricultural lands so that land prices in the region were decreased by 48% in 2006 vs. 1996. The livestock production rate was decreased by 64% and the heavy livestock by 71% (Ghasemi, 2012). Therefore, given the essential role of the Hirmand River, it is essential to give priority for allocating future water resources to the agricultural and household sectors in drought-wet and normal conditions.

2. Literature Review

Mohammadghasemi (2017) studied water management allocated in the agricultural sector by using a dynamic randomization method under the conditions of uncertainty for products such as wheat, barley, melon, watermelon, grape, and yoghurt and showed that by considering the amount of water allocated and the percentage of water deficit in relation to the optimal allocation, cultivation of ruby grape can be the best choice among crops with the highest expected value of profit in normal, wet and dry conditions.

Zhanqi Wang et al. (2015) addressed optimal allocation of water resources for the use in the agricultural, industrial, urban and hydroelectric sectors based on the economic criteria in China and reported an optimal model with dynamic tool that can improve economic revenue compared to other allocation models because, in their study, the functions of the agricultural, industrial, hydroelectric and urban sector profits were investigated by using both static and dynamic methods.

Zeng (2014) used the simulation of dynamics in systems to show how to operationalize water resource management with an interconnected approach. This research developed a methodology for identifying problems by using a dynamic approach to systems and paying attention to the concept of use in the agricultural, industrial, urban and environmental sectors.

Ahmed et al. [2010] used dynamic tools to evaluate water management policies. This study refers to the dynamic simulation in southern Florida. This model represents an internal link between water availability and competition for increasing water demand in the urban, agricultural and environmental sectors.

Lee et al. [2006] assessed water resource management in Canada according to different scenarios. He used a multi-stage random-scheduling model and calculated the optimal amount of water allocation between different uses. Also, the exchange of economic and environmental objectives was also evaluated. Their results were presented within 81 scenarios and for three groups of the urban, agricultural and industrial consumers in three future periods.

Since water resources are among the main factors underpinning the development of any region, attempts have been always made by researchers and the responsible agencies to improve the status and optimal management of these resources. Droughts and excessive water use have been the main causes of the present water crisis in Iran, especially in the Sistan region. Furthermore, the limitation of water resources and the sustainability in its management have made it impossible to meet all water demands. So, a vigorous planning is required for the highly reliable supply of water. This highlights the significance of water resource management by dynamic methods in basins.

3. Methodology

In designing a model, it should be noted that the relationship between the variables within the model can exist in two ways. Whether these relations are linear or nonlinear, this can be the case in mathematical planning and mathematical relations which are divided into linear and nonlinear types. Therefore, it seems necessary and essential to recognize the relationship between the system variables in order to design a model proportional to the relationships within the model. In this regard, before designing a nonlinear model, it should be shown that the relationships between the variables of the allocation system are non-linear because most consumer goods are not complete substitutes. As a result, the utility function and, consequently, the demand function is nonlinear. Therefore, the objective function used in the water resource allocation model is nonlinear because the target function considered for water resources allocation is the total surface area under the reverse curves of supply and demand for water or the total amount of consumer and producer welfare (Mohammadghasemi, 2012).

The net benefit function or the welfare function can be written as follows which should be maximized according to some constraints

$$MAX \quad NB = \sum_{J}\sum_{U}\left[\int_{LL}^{UL} F_{Ju}(Q_d)dQ_d + CP_{Ju}Qd\min\right] - \left[\sum_{J}\sum_{u}\int_{0}^{UL} s_{Ju}(Q)dQ\right] \quad (1)$$

In which *J* and *u* and counters for active areas are the types of water use and the type of purified water, respectively, and $F_{Ju}(Q_d)$ is the inverse demand function for QD use amount in different sections. CP_{Ju} is the price of silencer of demand or the held back technology price (alternative technology), *QdminJu* is consuming on the $F_{Ju}(CP_{Ju})$ surface, $Qdmin = LL$ is lower limit of water consumption, $Qd_{Ju}=UL$ is upper limit of water consumption, $S_{Ju}(Q)$ is inverse supply function for Qs Reliable supply amount, and *NB* is the net benefits of water consumption.

The targeted objective function, which is equal to the net social interest i.e., the level below the supply and demand curve of the water, is maximized by considering a series of constraints. These constraints are:

1. The equivalence constraint between the flow of water inlet and outlet,
2. The equivalence constraint of the flow of water entering the area based on hydrological conditions,

3. Required share constraint for ecosystem conservation.

In order to estimate the target function, it is necessary that the demand functions of the different sections and the water supply function be obtained individually. Thus, these demands are obtained as follows:

3.1. *Extraction of the* water demand function in the household sector from the Aston-Gary utility function

Based on Aston- Gary utility function, the demand function can be extracted after maximizing the utility function relative to the budget and using the Lagrange method. In this case, the function of the mentioned request is as follows:

$$Q_w = \theta_0 + \theta_1\left(\frac{M}{P_w}\right) + \theta_2\left(\frac{P_{oth}}{P_w}\right) \quad (2)$$

Where Q_w is demand amount or per capita consumption of drinking water per m^3, M is the budget or nominal household income per IRR, and P_{oth} is the nominal value of other goods and services in terms of indicators. Given the assumptions of the Stone-Gary function in the demand function, θ_0 and θ_1 contain positive signs and θ_2 contains a negative sign. In other words, water demand shows a positive reaction to changes in income and a negative reaction to the price of other goods and the price of water.

The demand for water in the presence of a changing climate (number of stormy days) is as follows:

$$Q_w = \theta_0 + \theta_1\left(\frac{M}{P_w}\right) + \theta_2\left(\frac{P_{oth}}{P_w}\right) + \theta_3 W + \varepsilon \quad (3)$$

in which *W* is the number of stormy days and ε is the disruptive component.

3.2. Agricultural water demand function

The profit function was used to estimate the demand function of water in the agricultural sector. Therefore, with respect to the production function, total irrigation profit at the *j* demand site based on water-product function is expressed as follows (Wang et al., 2008):

$$\tilde{B}_j = \sum pcp_{j,cp}.Ya_{j,cp}.AF_{j,cp} - \sum vc_{j,cp}.AF_{j,cp} \quad (4)$$

Where $pcp_{j,cp}$ is the product price and $vc_{j,cp}$ is the variable cost of product production. So, the target function can be written as follow:

$$\begin{aligned} &\max \quad \tilde{\beta}_j \\ &s.t: \quad \sum_{cp} AF_{j,cp} \le A_j \\ &AF^l{}_{j,cp} \le AF_{j,cp} \le AF^u{}_{j,cp} \\ &\sum_{cp} EI_{j,cp}.AF_{j,cp} \le Q \end{aligned} \quad (5)$$

where A_j is the total planting area (ha) in the area *j*، $AF^u{}_{j,cp}$ and $AF^l{}_{j,cp}$ are the upper and lower levels of the planting area (ha), $EI_{j,cp}$ is the amount of effective irrigation water needed during the growing season (m^3/ha) and *Q is the* total amount of irrigation water available in are *j*. Irrigation water demand function is estimated by using the solution of the model for different levels of effective irrigation water in the growing season and the corresponding shadow price and coefficients based on the Kab Douglas function $Q_w = \alpha P^\beta$ in which P_w is the water price and Q_w is the volume of water demand. If one wants to derive a logarithm from the above function, then $Q_w = \ln \propto + \beta \ln P$, and the estimated amount of water demand, and demand function of irrigation water is estimated using econometric methods. The shadow price is the change in the target function for one unit of change to the right side of the resource constraints. It is considered as an indicator for the final value of water in which the shadow price in the algebraic form is expressed as follows (Mahan et al. 2002):

$$MVW_j = \Delta\pi_j / \Delta Q_j \quad (6)$$

where MVW_j is the final value of water (m^3/ha) in area *j*, $\Delta\pi_j$ is the change in profit (IRR) because of one unit change in *Q* in area *j* and ΔQ_j represents the changes in the total amount of available effective irrigation water in area *j*.

4. Discussion

Sistan plain is geologically an alluvial low-sloping plain whose lowest point is the Goodarzeh pond with 470 meters elevation above the sea level. The average rainfall is 58 mm annually and the evaporation rate of the area is about 475 mm. The area has a dry climate and the average annual temperature in Zabul is about 21.83°C. The most significant result of the 120-day windfall is the evaporation of water from the surface of wetlands and fields and this can be stated as one of the main causes of drought occurrence in these areas. From the total lands under cultivation in the Iranian plateau (12 million ha), 196,021 ha (1.59 percent) is located in Sistan and Baluchistan province of which about 52.4% is in the Sistan area.

4.1. Water resources

4.1.1. Estimation of demand for agriculture

The water demand function of the agricultural sector is as follows:

$$lnQ = 67.2 - 1.29lnp \quad (9)$$

$$t: \quad (31.11) \quad (-4.95)$$

$$R^2 = 0.58 \quad DW = 1.87 \quad F = 356$$

As the results of estimation show, the water demand has an inverse relation with water price. If the price of agricultural water is increased, the demand for water in the agricultural sector will be decreased.

It can also be observed that water demand has an inverse relation with water price so that the increase in the price of the agricultural water entails the decrease in the demand for water in the agricultural sector

4.2. Estimate of Household Demand Function

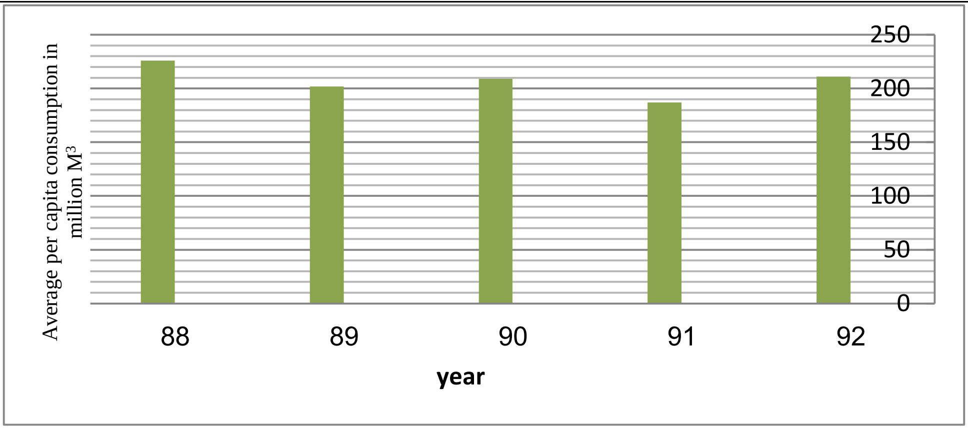

Figure 1. The trend of average changes in per capita consumption of water in the Sistan region during 2009-2013

According to Figure 1, in 2009, prior to subsidy reforms, monthly per capita water consumption was 2.45 m^3 which declined by 4.40 m^3 after the reforms in subsidies in 2011 and the realization of prices. In 2009, per capita consumption reached 8.41 m^3 per person. In 2010, after the second phase of subsidy reforms and the rise in prices, per capita consumption decreased to 4.37 m^3. In 2013, per capita consumption reached 2.42 m^3 per month. These statistics indicate clearly that rising prices only could affect water consumption in a short time and people become accustomed to higher prices and they get used to the price growth again. Increasing prices seems to be a necessary, but not enough, condition for reducing consumption.

4.2.1. The number of stormy days

From the average number of stormy days, different months were used for each year during the study period for the Sistan region which these data is available in the weather stations of the region and Sistan and Baluchestan province and the average number of monthly stormy days was calculated for each year. Figure 2 shows the average variation in the number of stormy days during the study period.

The average consumption is obtained based on the current trend which is 42.12 m3 per month for each household. If, on average, five people are considered as a family, the average daily consumption of each household is 280.08 liters. The reaction to the change in the amount of demand versus the change in the number of stormy days is 0.39, suggesting that one stormy day would increase water demand by more than 39 percent and the rise effect of a stormy day on demands is positive.

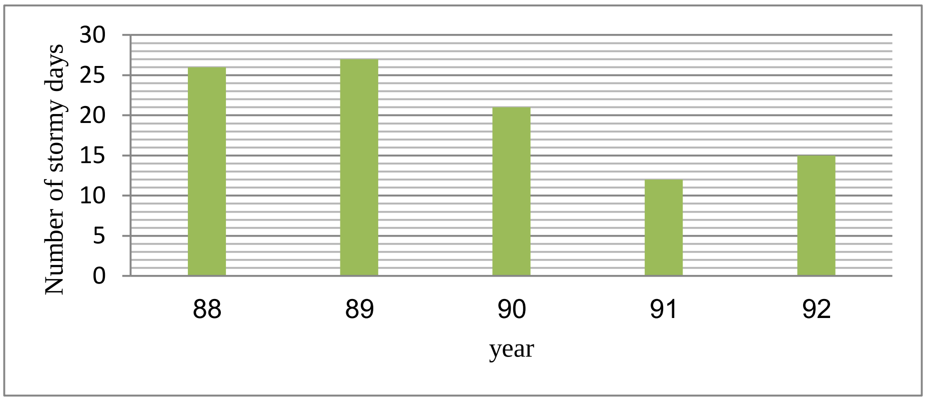

Figure 2. Changes in the number of stormy days

4.2.2. Model Estimation

Table 1. Estimation of the coefficients of the model of household demand functions

		Parameter coefficients						
Type of demand	θ_0	Inc_{it}		$Price_{it}$		W		R^2
total	12.42	coefficient	Statistics t	coefficient	Statistics t	coefficient	Statistics t	
Consumption classes less than 15	35.37	0/0025	9.12	-5.72	-7.16	0.37	63.12	0.83
Consumption classes less than 20-15	42.01	0.0056	45.11	-25.12	-56.18	0.12	32.18	0.80
Consumption classes less than 20-25	23.51	0.011	23.14	-37.16	-03.25	0.13	52.21	0.81
Consumption classes less than 25-30	89.57	0.10	21.15	-8.19	-6.13	0.16	14.25	0.84
Consumption classes more than 30	34062	0.09	25.17	-5.21	-4.75	0.18	17.26	0.88

Source: Research findings.

4.2.3. Estimation and analysis of the economic allocation of water resources in Hirmand Area in Sistan and Baluchistan province

In this study, meteorological data was first evaluated for a 30-year period by SPI index for drought, wet and normal conditions. After determining the type of year, information for 5 years of drought, wet and normal years through the equilibrium of supply with total demand for water in different price conditions and equilibrium value was obtained. This is done by writing a code in the GAMS software. The equilibrium price is 4570.45 and the equilibrium amount is 2145.87 million m^3. Because the equilibrium price is fixed for each consuming segment, by entering the equilibrium price in the water demand function of each section, the amount of consumption followed by the amount of welfare is obtained. Finally, using the results, information was evaluated for the next year. This is done in the next section.

The results of the estimation of the economic allocation of water resources in the Hirmand area are presented in Table 2.

Table 2. Estimation of the economic allocation of water resources in the Hirmand Area

Type of water usage	period		
	Amount of consumption Million m^3	percent	Welfare (Billions)
Agriculture	136	51	73419400
Household	110	36	92741852
Total net welfare at the basin level		237896571	

Source: Research findings.

5. Results

The results show that water demand has a reverse relation with water price in the agricultural sector under various water conditions. If the price of agricultural water increases, the demand for water in the agricultural sector will decrease. This is consistent with previous investigations. In addition, as in this model, the demand function for water is only a function of the price. Therefore, the returns relative to the scale are downward. Therefore, if the price of water increases by 1%, the product amount will decrease to -4.4%. The same production curve of the agricultural sector in all water conditions has a negative technical substitution rate. In the demand side, the estimated results show that with increasing water prices, consumption decreases, which is consistent with previous research. In addition, the average consumption was calculated as to be 12.42 m^3 per month for each household. If every household is considered to be composed of 5 people, the average daily consumption of each household will be 280.8 liters. The reaction to changes in the amount of demand versus the change in the number of stormy days is 0.39 suggesting that one stormy day would increase water demand by more than 0.39% and the effect of a stormy day's rise on demand is positive.

Executive Suggestions:

- Agricultural sector

Sustainable water is available to the user.

- The household sector

Considering too much water consumption in this sector both in the whole region and in the consumer classes, it is recommended that this consumption pattern is modified and investments are done on religious beliefs to reduce water consumption. The risk of the economic and social benefits of providing or not providing water for the Hamoon Wetlands should be investigated.

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