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# Value of Water in an Arid Area of Central Iran

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**ABSTRACT**

In this study, the relationship among different economic sectors of Isfahan province (in the arid area of Central Iran) is investigated. The economic value of water from a river passing through the city of Isfahan (the Zayanderood River) is estimated from an aggregated input-output and linear programming model with fuzzy parameters that maximizes the province's value added. The goals of the 4th development plan and other constraints are integrated into the model. The real value of a cubic meter of water in Isfahan is estimated to be more than 10,400 rials ($5.93 in constant 2001 prices). On this basis, the water from the Zayanderood accounts for about 13.55 percent of the province's value added. The development plan will require at least 7.86 percent annual growth in investment. Water resource management and increasing investment are the two most important factors for decreasing production risk under the present economic structure of Isfahan province.

**KEY WORDS**: Isfahan province, linear programming with fuzzy parameters, value of water, Zayanderood River.

## INTRODUCTION

Water is one of the most valuable natural resources available to humankind; it is crucial to life itself. Water covers 75% of the Earth's surface, but only 2.5% of the water stock is fresh and much of that is locked into ice and snow (Shiklomanov and Rodda, 2003). According to Nature (2010), 80% of the world's population lives in water scarce areas. Yet water is often undervalued from an economic perspective and this undervaluation is generating a serious crisis in many parts of the world. Iran is no exception; in fact the potential crisis there is much more serious than many other locations. Isfahan province (particularly its eastern area) is one that faces the most limiting water resources. Per capita water resources in the Isfahan region are 1520 cubic meters, which is, respectively, 24%, 61%, and 80% less than Iran, Asia and the world. Ebrahimi (2007) suggests that 1760 cubic meters per capita is the amount needed to meet critical needs. Therefore, water availability presents an important challenge for the province.

This study estimates the value of water from the Zayanderood River by incorporating the interrelated water needs of the various industrial and consumer segments of Iranian society. An input-output and linear programming model with fuzzy parameters is used to estimate the value of water and the economic importance of the river within the goals of the 4th development plan. The results have important ramifications for economic development in Central Iran.

Isfahan province is ranked third in GDP for Iran (Iran Statistical Yearbook, 2007). It accounts for 14.7%, 6.4%, and 5.9%, respectively, of Iran's value added in industry, services and agriculture. The use of water creates value in all of these sectors and there are important linkages among sectors that involve water. The province is located in the central Iranian plateau and generally has an arid, temperate climate characterized by low humidity and rainfall. The average rainfall is 117 millimeters and potential annual evaporation is 18 times that amount. Water is clearly a concern and rivers and run-off of winter snow are vitally important. Water consumption in Isfahan province for 2006 was 8061 million cubic meters; 25.6% from the surface and 74.4% from groundwater.

The Zayanderood River runs through the middle of Isfahan City and provides over 80% of the drinking water for many cities and villages; its basin supplies 72.8% of the province's water; 66.3% groundwater and 33.7% surface water (Economic- Social Report of Isfahan Province, 2006; Statistical Yearbook of Isfahan province, 2007; and reports of Isfahan Regional Water Organization). Key industries for Iran, including steel, military, nuclear, chemical, electrical, and construction industries, exist along the Zayanderood. The river is obviously important to Isfahan province, but its role and contribution to the province's economy has not been documented. This study uses a model to capture the relationships among the different economic sectors of

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Isfahan province and uses it to estimate the economic value of water for the province and the Zayanderood River's share of that value added. Figure 1 shows the Isfahan province (study area) map.


Figure 1: Map of Isfahan province in Iran indicating the study area

## LITERATURE REVIEW

A few studies have investigated interrelationships among water uses. Wang et al. (2009) used a regional input-output model for Zhangye, China, and found that the industrial and service sectors consume less water directly during their production process compared to food production and forestry. But the industrial and service sectors use many intermediate inputs from the water-intensive sectors during the production process. Mirzaei Khalilabadi, and Abrishami (2007) combined an input-output model and mathematical programming to show that water's production value in all sectors of Iran is 2.9 trillion rials (about $332 million US)[1], which is 0.4% of total production value.

Several studies have focused on determining water's economic value and the relationships that the resource has among different sectors. Shabani (2007) calculated the marginal production value of water in South, Razavi and North Khorasan at 140,000, 74,700 and 81,400 rials per cubic meter ($15.22, $8.12 and $8.85 US, respectively) per cubic meter. Ahmadpoor and Sabouhi (2010) estimated that an additional cubic meter of water for the Jam region in Boushehr province in 2008 is worth between 93.6 and 19,893 rials ($0.01 and $2.078 US). Chen (2000) used an aggregated input-output and mathematical programming model to find that the shadow price of water in 1995 is 6.7 yuan per ton ($0.81 US) for Shanxi province. Liu et al. (2007) used a similar model to calculate the shadow price of industrial and productive (agricultural and commercial) water in nine Chinese river basins for 1999. They found industrial water was valued between 18 to 513 yuans per cubic meter ($2.17 to $61.95 US, respectively), while productive water was valued between 2 to 234 yuan per cubic meter ($0.24 to $28.26 US, respectively). Gomez-Limon and Martinez (2006) used linear programming and a multi-criteria methodology to find that the shadow price of water in Australia's Duero basin is valued between 0.005 and 0.294 euros per cubic meter ($0.01 to $0.31 US, respectively), depending on the scarcity assumptions.

**Model Development**

Water is used directly and indirectly in various sectors of the economy. An input-output model can capture these effects, so the present study constructs a model to maximize the value added of the province and discover the implied value of water. In this case, an aggregated input- output matrix is integrated into a linear programming (LP) model. The coefficients of Leontief's inverse matrix, obtained from Isfahan province's input-output table, are used as technical coefficients in the LP model. Model restrictions are investment, water availability, and goals of Iran's 4th developmental plan. The model is designed to capture the linkages among various sectors in determining, among other economic variables, the economic value of water. The calculated shadow price for water in the model is based on the interaction of different economic sectors and is the value-added by adjusting the water constraint.

The model is as follows:

$Max: V = \sum_{j=1}^{46}\sum_{i=1}^{46}(v_i \times C_{ij}) \times F_j$ maximize value added of the province

[1] The exchange rate used to convert values to dollars is the average rate during July for the year of analysis. The exchange rates came from the International Monetary Fund (http://www.imf.org/external/np/fin/data/param_rms_mth.aspx). The rial is the currency of Iran.

Subject to:

1) $\forall\ i \in \{1,2,\dots,46\} \Rightarrow v_i \times \sum_{j=1}^{46} C_{ij} \times F_j \geq V_{ib}$  plan goals constraints

2) $\forall\ i \in \{1,2,\dots,46\} \Rightarrow v_i \times \sum_{j=1}^{46} C_{ij} \times F_j \leq V_{imax}$  production capacity constraints

3) $\sum_{j=1}^{46} \sum_{i=1}^{46} (h_i \times v_i \times C_{ij}) \times F_j \leq H$  water constraints

4) $\sum_{j=1}^{46} \sum_{i=1}^{46} (g_i \times v_i \times C_{ij}) \times F_j \leq G$  investment constraints

5) $F_j \leq F_{jmax}, \quad j \in \{1,2,\dots,46\}$  demand constraint

6) $F_j \geq 0, \quad j = 1,2,\dots,46$

$F_j$ = final demand of sector $j$ ($j = 1,2,\dots,46$ and shows the sectors in the Isfahan input – output table)

$v_i$ = ratio of value – added of sector $i$ to its output
$C_{ij}$ = $ij$th component of Leontief's inverse matrix and shows direct and indirect effects of a one unit increase in the final demand of sector $j$ on the output of sector $i$
$V_{ib}$ = prescript value – added for sector $i$ in the 4$^{th}$ development plan
$V_{imax}$ = maximum production capacity of sector $i$
$h_i$ = amount of water which sector $i$ needs to create one unit value – added
$H$ = minimum water which is need to achive the goals of 4$^{th}$ development plan
$g_i$ = amount of water which sector $i$ needs to create one unit value – added
$G$ = minimum water which is need to achive the goals of 4$^{th}$ development plan
$F_{jmax}$ = maximum final demand for productions of sector $j$

The objective function is to maximize value added for the province. The first constraint is that the output must meet the goals of the 4$^{th}$ development plan. The second constraint is related to the maximum production capacity of each section. It shows a maximum value-added that each sector can achieve. The third and fourth constraints are for water and investment, respectively. The left hand side of the third (and fourth) constraint shows the total water (and investment) that is need to satisfy final demand for all sectors and the right hand indicates the minimum water (and investment) which is need to achieve the goals of 4$^{th}$ development plan.

***Linear Programming with Fully Fuzzy Parameters***

Classical mathematical programming specifies the objective function and constraints with certainty. The present problem is subject to many swings and uncertainties of the real-world, especially with the availability of water. So the present model uses fuzzy mathematical programming which has a fuzzy objective function and constraints (Azar and Faraji, 2007). In this case, determining the exact value of parameters for the linear programming model is not possible, instead probabilities are applied. Techniques developed by Jimenez (1996) and Jimenez et al. (2007) are used.

The model is estimated for every upper, lower, and probabilistic amount of objective function coefficients and various amount of α (the degree of feasibility for constraints). All imprecise parameters have been considered as triangular fuzzy numbers. The fuzzy objective function for these limits has been denoted by $V^p$, $V^p$ and $V^l$ respectively.

$$Max: V^p = \sum_{j=1}^{46} \sum_{i=1}^{46} (v_i \times C_{ij})^p \times F_j$$

$$Max: V^m = \sum_{j=1}^{46} \sum_{i=1}^{46} (v_i \times C_{ij})^m \times F_j$$

$$Max: V^l = \sum_{j=1}^{46} \sum_{i=1}^{46} (v_i \times C_{ij})^l \times F_j$$

***Fuzzy constraints***

Fuzzy constraints related to the certain constraints (1):

$$\forall\ i \in \{1,2,\dots,46\} \Rightarrow v_i \times \sum_{j=1}^{46} C_{ij} \times F_j \geq V_{ib}$$

Left hand of fuzzy constraint (1):

$$\forall\ i \in \{1,2,\dots,46\} \Rightarrow \sum_{j=1}^{46}\left[\frac{(1-\alpha)}{2}\left((v_i \times C_{ij})^p + (v_i \times C_{ij})^m\right) + \frac{\alpha}{2}\left((v_i \times C_{ij})^p + (v_i \times C_{ij})^l\right)\right]F_j$$

Right hand of fuzzy constraint (1):

$$\geq \left[\frac{\alpha}{2} \times \left((V_{ib})^p + (V_{ib})^m\right) + \frac{(1-\alpha)}{2} \times \left((V_{ib})^p + \right.\right.$$ 403

Fuzzy constraints related to the certain constraints (2):

$$\forall\ i \in\ \{1,2,\dots,46\} \Rightarrow v_i \times \sum_{j=1}^{46} C_{ij} \times F_j \leq V_{imax}$$

Left hand of fuzzy constraint (2):

$$\forall\ i \in \{1,2,\dots,46\} \Rightarrow \sum_{j=1}^{46}\left[\frac{\alpha}{2}\left((v_i \times C_{ij})^p + (v_i \times C_{ij})^m\right) + \frac{(1-\alpha)}{2}\left((v_i \times C_{ij})^p + (v_i \times C_{ij})^l\right)\right]F_j$$

Right hand of fuzzy constraint (2):

$$\leq \left[\frac{(1-\alpha)}{2} \times \left((V_{imax})^p + (V_{imax})^m\right) + \frac{\alpha}{2} \times \left((V_{imax})^p + (V_{imax})^l\right)\right]$$

*p*, *m*, and *l* denote probabilistic value and upper and lower abounds of a fuzzy number, respectively. So:

$(v_i \times C_{ij})^p =$ probabilistic value of coefficient $F_j$ in the certain constrains (1) and (2)

$(v_i \times C_{ij})^m =$ maximum value of coefficient $F_j$ in the certain constrains (1) and (2)

$(v_i \times C_{ij})^l =$ minimum value of coefficient $F_j$ in the certain constrains (1) and (2)

$(1-\alpha) =$ a measure for the risk of unfeasibility of constrains

**Data Description**

The data are from the Isfahan input-output table for 2001 (Hayatgheibi, 2010); National Document of Isfahan Province Development (for the data related to value added growth of each sector in the 4th development plan); Management Organization of Isfahan Province (Economic- Social Report of Isfahan Province 2006) (for the data related to investment in various sectors and the amount of water used in each sector); Statistical Yearbook of Isfahan province 2007 (for the data related to investment in various sectors and the amount of water used in each sector); National Account of Iran, Regional Account of Isfahan province (for the data related to value added and maximum production capacity of each sector), 1999 and 2001 Iran input-output tables (to make fuzzy parameters); report of Isfahan Regional Water Organization entitled "Plan of resources and uses of Zayanderood Basin water;" and unpublished statistics of Isfahan Regional Water Organization (for the data related to the amount of water used in each sector). Data are analyzed using Excel and winQSB software.

All parameters have entered the model in fuzzy form because of uncertainty with respect to the data. The data and the input-output matrix for Isfahan province allow the construction of the mathematical program that is solved for different levels of risk. Shadow prices for water in this model are obtained from the optimization process and are considered water's economic value. The amount of water and investment required to achieve the 4th development plan goals are determined. The value-added by the Zayanderood River is calculated by multiplying the river's water volume by the shadow price of water. The average water output from the Zayanderood dam (1,400 million cubic meters per year) is used as the river's volume.

The feasibility degrees (αs) are needed in order to solve the linear programming model with fuzzy parameters. Because the parameters are not known with certainty, the model deals with more than a 0% chance that the constraints are not met. So (1-α) is the risk that the constraints are not feasible. The initial α value is specified as 0.6, which means that the maximum acceptable risk that the constraints are not met is 40%. Thus, the imposed constraints are provided with 60% confidence. The model is also estimated for smaller risks.

## RESULTS AND DISCUSSION

The model with α equal to 0.6 calls for 8,795 million cubic meters of water to meet the goals of the 4th development plan, which leaves Isfahan province approximately 735 million cubic meters short. Table 1 presents the estimation results of the model for α=0.6. Based on the results, agriculture would use 89.8% of the water supplied, while industry/mining and the service sectors would use 3.4% and 6.8%, respectively. The amount of water necessary to satisfy the final demands is 7,724 million cubic meters (mcm) for agriculture, 491 mcm for industry and mining, and 581 mcm for services. The total value added for Isfahan province is 107,460 billion rials (in constant 2001 prices) or $61.4 million US. The minimum investment that is needed to meet the goals of the 4th development plan under this scenario is 35,251 billion rials (in constant 2001 prices) or $20.14 million US, so investment must grow by 25.5% relative to its base level or at an annual average rate of 7.9%.

Table1. The estimation results of fuzzy linear programming model for α=0.6

| Sector | Water necessary to satisfy the value added (mcm) | Water necessary to satisfy the final demands (mcm) | Investment necessary to satisfy the final demands (billion rials) |
|---|---|---|---|
| Agriculture | 7853.1 (89.9%) | 7723.5 (87.8%) | 918.37 |
| Industry/Mining | 296.6 (3.4%) | 491 (5.6%) | 5437.55 |
| Services | 595.3 (6.8%) | 581 (6.6%) | 28895.14 |
| Total Value added | | 107,460 (billion rials in constant 2001 prices) | |
| Minimum water requirements | | 8,795 (million cubic meters) | |
| Shadow price of water | | 10,400 (rials per cubic meter in constant 2001 prices) | |
| Minimum investment requirements | | 35,251 (billion rials in constant 2001 prices) | |

The total amount of water required for the agricultural sector is more than the amount of water that is required to satisfy final demands of the sector production (only 87.8% of the water is required for final demand in agriculture). Some of the water consumed in the agricultural sector is consumed indirectly by other sectors, so the agricultural sector transports water to other sectors as intermediate inputs. This reveals that there are important linkages among the sectors that must be considered for water issues. Neglecting these linkages with other sectors will distort water's true value.

The shadow price of water in Isfahan province is 10,400 rials per cubic meter ($5.94 US). Several studies have estimated the economic value of water, which were noted earlier. Chen (2000) found the shadow price of water was equivalent to about 6640 rials per cubic meter ($3.79 US) in Shanxi province (China), which is 3760 rials ($2.15 US) less than the present study. This difference is justifiable due to the relative scarcity of water in Iran. Liu et al. (2007) found the average value of water for productive and industrial water was similar to the present study. The four basins studied had shadow prices for water between 10,480 and 14,670 rials (in 1999 prices) per cubic meter ($5.98 and $8.38 US, respectively). The estimates from the present study are closer to the estimates from China than they are to estimates from studies performed in Iran. Including intersectoral linkages in calculating water's value is the likely reason.

The Zayanderood River accounts for 13.6% of the value added in the province, given the estimated value of water and the river's current flow. This is a tremendously large percentage, showing the river's important role in supplying vitally important water for the agricultural sector in the Zayanderood basin. The river is essential for the province because of water's wide effects on production. Because Isfahan province's economy is the third most important in Iran, the river is certainly important nationally too. Inappropriate management of the river, through non-compliance with environmental regulations or other inappropriate exploitation of the river, could damage the whole economy.

The model with α equal to 0.7 calls for 8,880 million cubic meters of water to meet the goals of the 4th development plan; this is 85 million cubic meters more than with α equal to 0.6. Table 2 indicates the estimation results of the model for α=0.7.

The estimated total value added for the province is 106,058 million rials (constant 2001 prices) or $60.6 million US. There would need to be 35,780 million rials (constant 2001 prices), or $20.44 million US, invested to meet the goals of the 4th development plan, 531 million rials ($303,000 US) more than with α equal to 0.6. Investment would need to grow by 27.4% from 2009 or 8.4% annually. Agriculture uses 89.9% of the water in this case, with industry/mining and service sectors using 3.3% and 6.8%, respectively. The shadow price of water increases to 15,300 rials per cubic meter ($8.74 US). The share value added from the Zayanderood River increases to 20.2% in this case.

Table2. The estimation results of fuzzy linear programming for α=0.7

| Sector | Water necessary to satisfy the value added (mcm) | Water necessary to satisfy the final demands (mcm) | Investment necessary to satisfy the final demands (billion rials) |
|---|---|---|---|
| Agriculture | 7892.3 (89.9%) | 7804.8 (87.89%) | 929.11 |
| Industry/Mining | 287.1 (3.27%) | 485.5 (5.47%) | 5689.47 |
| Services | 598.1 (6.81%) | 589.5 (6.64%) | 29161.51 |
| Total Value added | | 106,058 (billion rials in constant 2001 prices) | |
| Minimum water requirements | | 8,879.8 (million cubic meters) | |
| shadow price of water | | 15,300 (rials per cubic meter in constant 2001 prices) | |
| Minimum investment requirements | | 35,780 (billion rials in constant 2001 prices) | |

Moving from 40% risk of not meeting the constraints to 30% risk requires increased investment in water supply capacity. If the necessary resources can be found, the possibility of meeting the goals of the 4th development plan will increase. The model finds that reducing the risk to 20% is not possible even if there is enough water available and investments are made. The economic structure of the province and the production capacity of sectors are not flexible enough to have an 80% probability that the goals of the 4th development plan will be met. Structural problems in the economy make it impossible for further risk reduction.

**Conclusions**

This study finds that water is a fundamental aspect of the economy in Isfahan province. Water resource management and increased investments are the two important factors for improving the present economic structure for Isfahan province. Therefore, providing the proper incentives to increase these two key variables in the province must be considered as a strategic policy of the government.

Water from the Zayanderood River alone is estimated to contribute 13.6% of the value added in Isfahan. The indirect impact of water on various production sectors provides a more realistic estimate of its importance so it is recommended that direct and indirect uses be included in future water studies. Therefore, proper planning and decision-making to protect this vital river is crucial to the development of Isfahan province. A key factor in protecting this river is the valuation of water and the preservation of that value through maintaining its natural ecosystem. The study also finds that major investment is required in order to increase economic activity concomitant with the goals of the 4th development plan. The minimum annual investment growth for the province is 7.9% in order to have a 60% chance of meeting the goals.

It is instructive that this study revealed that decreasing the risk in not meeting the production constraints to 20 percent is not possible in the present economic structure of Isfahan province. Thus, it is clearly necessary to either improve the economic structure or adjust the goals of the 4th development plan. Otherwise, there is a good chance that the province's long-run targets will not be met and the strategy will fail.

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