CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

INTER-SECTORAL WATER ALLOCATION USING AN INPUT-OUTPUT MODEL

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Abstract: An input-output model allows the interaction between the supply and demand sides of an economy to be examined. It can also provide decision makers with information on the total production of sectors as well as required resources. In this paper, we used an input-output model to manage water use and estimate the total water use for various economic sectors in Iran's North Khorasan Province (INKP). Initially, the province's economy was disaggregated into 19 sectors and the regional input-output table was estimated using the Cross-hauling Adjusted Regionalization Method. Then, using linear programming, the basic input-output model was transformed into an improved input-output model having the ability to choose among alternative technologies for allocating water to sectors. To compensate for the water shortage by selecting alternative technologies and assessing their impact on the total cost of the system as well as the production, three scenarios for managing the supply side and one scenario for reducing the final demand of the most water-consuming sector (managing the demand side) were analyzed. The results showed that the agriculture sector is always required to use less water-consuming and more expensive technology to compensate for about 161 million cubic meters of water to keep the total production unchanged.

1 INTRODUCTION

As a primary input, water plays a major role in attaining sustainable growth and development. Economic activities are dependent on this critical resource, making effective management one of the main concerns of decision-makers. While developing countries generally suffer from obstacles in capital investment and education to improve water efficiency, they usually encounter significant water shortages. In this case, to supply water, an intense competition may occur among economic sectors that may lead to serious conflicts. Economic tools facilitate the optimal management of resources (Pulido-Velazquez et al., 2016), and several optimization models have been developed to help decision-makers with optimal water resources allocation.

Input-output (IO) models are based on the general equilibrium theory. These models can depict the relationships between flows of good and services and the resources necessary to produce them in an economy. This can facilitate sustainable water management and the appropriate allocation of resources among economic sectors. Another advantage of these models is to provide the possibility of managing both supply and demand sides. Several studies have been conducted to assess the supply-demand interaction as well as water consumption in global and regional scales using IO models (Alabi et al., 2016). Estimating direct and indirect water consumption of economic sectors, water allocation to economic sectors based on their estimated water values, and analyzing various water management scenarios (e.g. imposing taxes on water consumption) are some of the most popular problems that input-output models were used to analyze (Zhang et al., 2015; Lenzen et al., 2013; Cazcarro et al., 2013; Hubacek and Sun, 2005). The majority of IO models were developed based on the Leontief IO model (Velazquez, 2006). This model helps distinguish flows of good and services as intermediate and final demands. As a result, it allows various dimensions to be evaluated for a managerial decision. López-Morales and Duchin (2015) developed a rectangular IO model which provides economic sectors with the ability to choose between technologies (Duchin and Levine, 2011) to investigate water consumption by economic sectors in Mexico. The model accounts for both surface and ground water as separate resources supplying water with different prices as well as resource capacity constraints.

IO tables are usually calculated at the national level and it may be difficult to convert them into regional tables because of structural and computational complexities. There are several methods to estimate regional tables. Statistical methods calculate the regional table by gathering extensive regional data for each economic sector (Kronenberg, 2009), but substantial effort and cost can be required to use these methods with acceptable accuracy (Hewings, 1985). On the other hand, to cut cost and time, some researchers proposed non-statistical methods to convert national IO tables into regional tables. Non-statistical methods have been used by many researchers in the 1980s, but they have been criticized due to errors and inherent uncertainty of these methods as well as a lack of the required accuracy (Tohmo, 2004). To overcome such challenges, researches proposed hybrid methods. As the hybrid methods have an acceptable accuracy in assessing regional tables in exchange for a reasonable cost, they can bridge the existing gap.

Given that in the IO model, the total demand is comprised of the intermediate and the final demand, managerial scenarios can affect different components on both supply and demand sides. As a result, we first introduce the basic Leontief IO model and estimate the regional IO model of INKP based on Iran's national IO table. Then, by transforming the basic model into an improved rectangular model, we solve an optimization problem to analyze various water management scenarios.

2 Methodology

2.1 Input-output table

The information contained in the IO table shows flows of goods and services among economic sectors in an economy. This table provides a statistical representation of the regional economy in a specific year. IO tables usually have monetary units. Generally, for an economy with n sectors, the IO table is presented as shown in Table 1.

Table 1- the input-output table

	Intermediate demand					Final demand						
	Sector 1	Sector 2	…	Sector n	TID[a]	H[b]	G[c]	C[d]	GIA[e]	Export	TFD[f]	Total Output
Sector 1	x_{11}	x_{12}	…	x_{1n}	x_{10}	c_1	g_1	i_1	iv_1	e_1	f_1	z_1
Sector 2	x_{21}	x_{22}	…	x_{2n}	x_{20}	c_2	g_2	i_2	iv_2	e_2	f_2	z_2
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
Sector n	x_{n1}	x_{n2}	…	x_{nn}	x_{n0}	c_n	g_n	i_n	iv_n	e_n	f_n	z_n
Total intermediate	x_{01}	x_{02}	…	x_{0n}	x_{00}	c	g	i	Iv	e	f	Z
Value- added	v_1	v_2	…	v_n	V							
Total Gross input	x_1	x_2	…	x_n	X							
Imports	m_1	m_2	…	m_n	M							
Total Input	z_1	z_2	…	z_n	Z							

[a] Total intermediate demand
[b] Households
[c] Government purchases
[d] Capital
[e] Gross inventory accumulation
[f] Total final demand

The core of the table indicates intermediate goods and services that are exchanged among economic sectors (matrix T). Rows present the distribution of products among economic sectors. For example, the first row shows that the total output of sector 1 is z_1 units including x_1 units for manufacturing sectors (intermediate demand) and f_1 units for final consumers (final demand). Thus, the sum of each row of matrix T is equal to the total intermediate demand for product i (equation 1). X^D is defined as the vector of intermediate demands (equation 1).

$$[1]\quad x_i^D=\sum_{j=1}^{n} x_{ij}, \qquad x^D=(x_1^D,....,x_n^D)$$

Final demand (f_i) includes the households (ci), government purchases (g_i), capital investment (i_i), exports (e_i), and gross inventory accumulation (iv_i). To facilitate the process, final demand is expressed as the internal demand (d_i) (includes households, government purchases, capital investment, gross inventory accumulation) and exports.

[2] $f_i=c_i+g_i+i_i+e_i+iv_i=d_i+e_i$

As the rows in Table 1 show the products of sectors, the summation of intermediate and final demands in each sector is called output (zi). Thus, the total demand vector (z) can be calculated as follows:

[3] $z=f+x^D=d+e+x^D$

Columns of Table 1 show purchases or demands of sector j from sectors i. In other words, it shows intermediate inputs required to produce sector j's product. Vector x^u represents total inputs necessary for each sector (equation 4).

[4] $x_j^U=\sum_{i=1}^{n}x_{ij}, \quad x^U=(x_1^U,....,x_n^U)$

Also, each sector purchases or uses primary inputs (including labor, capital, etc.) which are components of value added (v_j). The vertical summation of intermediate demands and value-added is equal to the total gross input for each sector ($x=v+x^u$). Regarding the import (m_j), one can calculate the total input (z_j) for each sector. Equation 5 presents the total input vector including value added, total gross input, and imports.

[5] $z=v+x^U+m$

It must be noted that imports are considered indirectly in the table. According to Walras' law, total supply and demand for each sector should be in equilibrium ($Z_i=Z_j$). Net export (b) or product balance for each sector can be obtained by subtracting imports from exports (b=e-m). Leontief used the inter-sectoral transactions matrix (T) and the total production matrix (X) to calculate technical coefficient matrix (A) (equation 6).

[6] $A=TX^{-1}$

Thus, technical coefficients (a_{ij}) that show the required product of sector i that must be used to produce a unit of product of sector j is calculated by dividing x_{ij} (the purchase of sector j from sector i to produce x_j) by x_j.

[7] $a_{ij}=\frac{x_{ij}}{x_j}$

The IO table can be used to estimate the total production of economic sectors. Equation 8 illustrates how the total outputs of economic sectors can be calculated using the technical coefficient matrix and the final demand vector. Rewriting equation 8, we obtain equation 9, where I is the nxn identity matrix.

[8] $x=Ax+y \quad ; \quad y=f-m$

[9] $x=(I-A)^{-1}y$

2.2 Value-added and resources

Generally, the value added is considered as the money paid for using labor and capital (which can be measured physically). To substitute monetary units with quantities, Duchin and Levine (2015) added production factors (including land, minerals, and water) to elements of value-added. Equation 9 shows the basic IO model. With this interpretation of value-added and considering primary inputs along with labor and capital as the components of value-added, factor inputs matrix F_{kxn} can be defined. In this matrix, k denotes number of factor inputs and n is the number of sectors. Each element has the unit of the factor input per the unit of the product. Multiplying this matrix and the unit price vector for each input (π_k), the value-added vector of each sector for producing a unit of its product is deduced (equation 10). Besides, total consumed inputs (φ_k) in the economy can be found by multiplying matrix F_{kxn} and vector x_n (total production) (equation 11).

[10] $v=F'\pi$

[11] $\varphi=Fx$

2.3 Input-output model using several technologies

In the basic form of the IO model, it is supposed that each sector uses a single constant technology and technical coefficients do not change over a year. To improve the model, a rectangular matrix is introduced by López-Morales and Duchin (2015). If the sector i has options among t_i technologies, all technologies in the economy, t, is equal to the summation of all sectors' technologies. Adding a column for every technology in each sector causes the technical coefficient matrix, the identity matrix, the factor input matrix, and the total production vector to be changed and equations 9 and 11 are rewritten as follows.

[12] $x^*=(I^*-A^*)^{-1}y$

[13] $\varphi=F^*x^*$

In this case, vector x* has dimension tx1, matrices I* and A* have dimension nxt, and F* is a kxt matrix. Meanwhile, the final demand matrix remains intact. In the new identity vector, the ith row is expanded to the number of technologies with 1 for a specific sector. After changing the structure of the technical coefficient matrix and the governing equations, we need to define specific selection criteria allowing the best option for meeting final demand to be determined. When no constraint exists for resource consumption, the model chooses technologies with the lowest cost to minimize the objective function and satisfy the final demand regardless of resource consumption. In fact, to tackle this challenge, we use the carrying capacity vector (c) and add it as a resource constraint to the model (Duchin and Levine, 2015).

$$\text{Min } Z=\pi' F^*x^*$$

[14] $$\text{s.t. } (I^*-A^*)x^* \geq y$$

$$F^*x^* \leq c$$

In this equation, all variables (except carrying capacity vector with dimension kx1) remain unchanged. According to equation 15, if the resources become scarce, it is possible for sectors to use one or more technologies to satisfy the constraints.

2.4 Non-statistical methods

In Iran, there are five national IO tables with monetary units developed in 2001, 2006, 2011 and 2012 by various organizations. As it is not possible to provide the physical inter-sectoral data to use the IO table at the required level (except for country level), two key modifications are necessary. At first, we need to transform the national IO table into a regional one. Then, we have to define a new objective function to minimize resource consumption. We use non-statistical methods to convert the national table into the regional one. We used Cross-hauling Adjusted Regionalization Method (CHARM), developed based on the commodity balance (detailed information is provided by Tohmo (2004)). As the net regional export (b^R) or commodity balance for each sector is calculated by subtracting regional export from regional import ($b^R=e^R-m^R$), and substituting equation 3 and x=v+xu we have:

[15] $b^R=z^R-(x^{DR}+d^R)$

To calculate commodity balance coefficients, we need to gain information about the total regional output for each sector (including intermediate and final demand except export). Regional values can be estimated using the regional employment rate. Therefore, total regional production in sector i (x_i^R) is:

[16] $$x_i^R=\frac{L_i^R}{L_i^N}x_i^N$$

Supposing each sector uses the same technologies at regional and national scales, inter-sectoral regional transaction coefficients and the regional intermediate demand matrix T^R are calculated as (equation 18):

[17] $x_{ij}^R=a_{ij}x_j^R$; $T^R=A(X^R)^{-1}$

Eventually, the final regional demand is given as:

[18] $$d^R=\frac{L^R}{L^N}d^N$$

Equations 16, 17, and 18 provide information needed to solve equation 14. By estimating net export, we can complete a regional IO table. In commodity balance method if the value of b^R is positive for sector i, regional import for the sector (m_i^R) is zero and the export is the net export. Meanwhile, for negative b_i^R, this value is equal to imports from sector i (Moore and Petersen, 1955). This assumption is not true everywhere, because export and import for a sector can be done simultaneously. Simultaneous export and import in an economic sector is called cross-hauling (Kronenberg, 2009) and usually occurs due to non-homogeneity of products (Kronenberg, 2009). Non-homogeneity in products of a sector can violate one of the key assumptions of IO models (i.e., homogeneity of products in a sector) (Harris and Liu, 1998). This problem can be solved by segregating economic sectors in smaller entities (Flegg et al., 1995). It is assumed that cross-hauling is a function of non-homogeneity, domestic production, and intermediated and final demands (equation 19).

[19] $q_i = q_i(x_i, x_i^d, d_i, h_i) \Rightarrow q_i = h_i(x_i + x_i^d + d_i)$

In this equation q_i is the amount of cross-hauling and the degree of non-homogeneity is denoted by h_i. This parameter is defined so that for completely homogeneous products, it becomes zero and for non-homogenous ones, it approaches infinity. The degree of non-homogeneity can be estimated by solving equation 19 based on h_i. Knowing that the total trade v_i is equal to the summation of imports and exports (e_i+m_i) and the trade balance b_i is the difference between them (e_i-m_i), we can write both as shown below. The trade volume (v_i) can be written based on trade balance and cross-hauling.

[20] $m_i = (v_i - b_i)/2, \quad e_i = (v_i + b_i)/2, \quad v_i = |b_i| + q_i$

If there is no cross-hauling in a region, it means that it only either exports or imports products. To calculate the degree of non-homogeneity, a function must account for two assumptions. First, for zero degree of non-homogeneity, cross-hauling must be zero. Also, the more production and consumption a region has, the higher cross-hauling and simultaneous export and import must be expected. The degree of non-homogeneity from the following equation:

[21] $h_i = \dfrac{v_i - |b_i|}{(x_i + x_i^d + d_i)}$

The national IO table provides all the required data on the right hand side of equation 21 that can be used to calculate the degree of non-homogeneity for each sector. As the degree of non-homogeneity depends on products regardless of their geographical areas, we can suppose that this factor is the same for both regional and national scales ($h_{Ri} = h_{Ni}$).

2.5 Study area

Irans' North Khorasan Province (INKP) is segregated into 11 study areas (Figure 1). Potential renewable surface water in INKP is calculated by subtracting total inflow from total outflow. The potential surface water and the renewable groundwater are about 1103 MCM and 270 MCM for an average year, respectively. Therefore, the total available water is 1373 MCM.

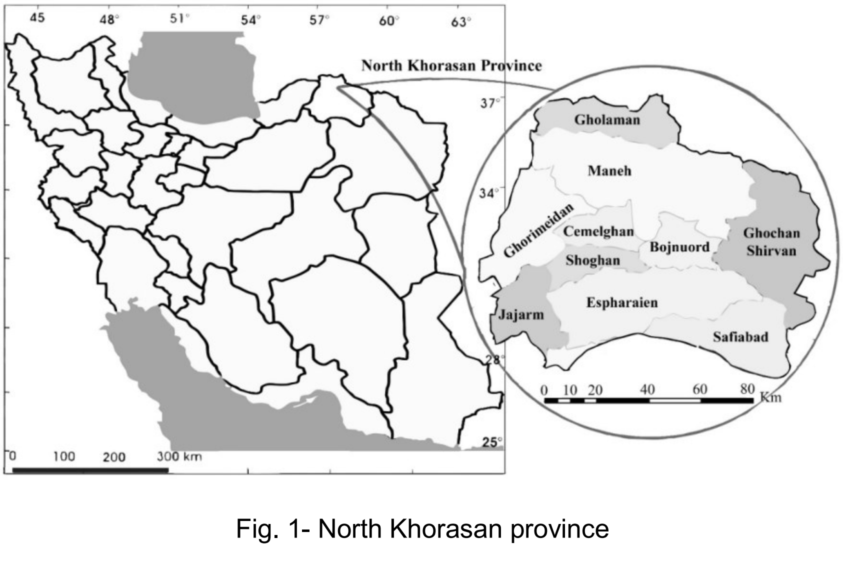

Fig. 1- North Khorasan province

2.6 *Scenarios*

Scenario 1: Agriculture is the sector which consumes the highest amount of water per unit of its total value. This scenario accounts for decreasing water use in this sector. It is supposed that the sector can use two technologies with the second one (technology 2) reducing water consumption per unit of total value by 15% (about 38 m^3/Rial). Also, technology increases the price of water by 20%. In this scenario, the total available water as a resource constraint (C) is about 1373 MCM.

Scenario 2: Here we assume that the first six most water-consuming economic sectors per unit of their output including Agriculture, Textile, Paper and paper products, Fabricated metal products, Chemical substance and products, and Food products and beverages can reduce water consumption per unit of their products by 10% as a result of new technologies. Similar to the first scenario, the price of water increases by 20%. In this scenario, we ignore sectors having far lower total outputs (meaning that their total water consumption is negligible) including Manufacture of paper and paper products, and Manufacture of fabricated metal products.

Scenario 3: Here we assume that all sectors can reduce water use by 10% for producing 1 million Rials of their products. The price of water increases by 20% for alternative scenarios.

Scenario 4: commodity balance that there is no change in technologies, the less production economic sectors have, the less water they consume. Adjusting the level of final demand leads to a reduction in total production and controls resources consumption (Equation 9). Also, changing the final demand of a certain sector can affect the production of other sectors according to inter-sectoral economic relationships. In this scenario, to compensate for the water scarcity, we suppose that the final demand of Agriculture (as the largest water consumer) is reduced by 15% (587.948 million Rials).

2.7 *The objective function and research problem*

Because equations 14 and 15 are developed for a physical IO model, we modify the objective function and constraints in which water use is minimized (equation 24).

$$
\begin{aligned}
& \text{Min } Z=\pi' w^{*} x^{*} \\
[24]\quad & \text{s.t. } (I^{*}-A^{*})x^{*} \geq y \\
& w^{*} x^{*} \leq c
\end{aligned}
$$

In this equation, x^{*}_{tx1} is the total production vector (million Rials), I^{*}_{nxt} and A^{*}_{nxt} (dimensionless) are rectangular identity and technical coefficient matrices, respectively. w^{*}_{1xt} is water use per unit of output for each sector (m^3 per million Rials), π_{1xt} is water price (Rial/m^3), and C denotes the total available water (m^3). The main difference between equations 24 and 15 is the presence of the water use (w) and water price (π) vectors. Because it is difficult to determine water price for some economic sectors (e.g., Agriculture; based on the law, farmers do not pay anything to the government except for the water right which is negligible and mostly granted in the past) the main goal of this study is to highlight the water consumption differences made by implementing the scenarios and not just to focus on the value of the objective function. As a result, we suppose that the unit price of water is equal to 1 for all sectors as the status quo. Water price changes by applying new technologies in scenarios.

3 *Discussion and results*

In this study, the first step is to estimate the regional IO table. Based on the International Standard Industrial Classification of All Economic Activities (ISIC), Iran's economy is subdivided into 71 sectors (two-digit divisions). Because there are no reliable data to monitor water use in all sectors, we recognized 19 sectors consuming a considerable amount of water to produce one unit of their products in INKP and gathered the required data including the total output and total water use from the Regional Water Company, the Jihad Agriculture Organization, and the Industry, Mine and Trade Organization. Afterward, the 71-sector national IO table in 2012 was regionalized to the 19-sector IO table using the CHARM method. As can be seen in Table 2, final demands for some sectors are negative. This shows that net export in these sectors is negative, which indicates INKP imports these products to satisfy its intermediate demands. The highest output in INKP belongs to the Non-domestic services sector that includes eight other activities (Wholesale and retail trade and repair of motor vehicles and motorcycles, Hotel and dormitory, Post and communication, Bank, Other financial intermediates, Insurance, and Residential and non-residential services). As a result, Construction and Agriculture have the highest levels of total outputs which is confirmed by economic changes in 2012 (due to economic crisis, the price of houses approximately doubled over six months). The most water-consuming sectors are Agriculture (1514.218 MCM), Manufacture of chemicals and chemical products (6.7 MCM), Manufacture of food products and beverages (3.15 MCM), Manufacture of textiles (1.95 MCM), Non-domestic services (1.26 MCM) and Public administration (1.19 MCM), respectively. Table 3 presents total output, total water use, and water use ratio. Water use per the value of a unit of the product is another criteria to measure the water productivity for each sector. Table 3 shows that Agriculture needs over 257 m^3 of water to produce 1 million Rials of its products. Similarly, Textile, Paper and paper product, Manufacture of fabricated metal products, Chemicals and chemical products, Food products and beverages, Other non-metal products, and General affairs and civil services consume most water to produce 1 million Rials of products, respectively. The total amount of water consumed by economic sectors is 1534 MCM. As the total available water is 1373 MCM, the province encounters an annual deficit of 161 MCM. This can result in raising competition among economic sectors to satisfy their water demands.

3.1 Scenario analysis

Table 4 shows the results of solving the linear optimization problem for the status quo (without water constraint) and under defined scenarios. As can be seen, the value of the objective function is equal to the volume of water use for the status quo due to similar water price for all sectors. Also, the estimated output for each sector is nearly equal to its observed data in table 1 (all figures in table 1 are rounded).

Scenario 1 indicates an increase of 1% in the value of objective function and as a result, the total cost of the system for a 10% reduction in total water use. Sector 1 uses a combination of technologies 1 and 2. It means that the system reaches the optimum condition for satisfying final demand and water use constraints via distributing the production between two technologies so that about 30% of final demand is fulfilled by technology 1 (cost-effective) while the remaining is satisfied by technology 2. The total outputs of other sectors remain intact.

Implementing scenario 2 reduces the share of Agriculture sector from 15% decrease in water consumption to 10% (it means that alternative technology can only reduce water consumption by 10% in contrast with the first scenario where the new technology saves 15% of water use), this sector requires to produce all of its products using the less water-consuming technology with higher price. As a result, this sector increases the value of objective function by 20% more than the status quo as well as 5% more than scenario 1. Sectors 4 and 5 are obliged to use technology 2 to compensate for water deficit. This change involves a 20% rise in costs. Also, Chemicals and chemical products sector must produce 70% of its output with technology 1. This leads to a 6% growth in its costs. Finally, under this scenario, the total cost increases by 6.1%.

Scenario 3 enables the model to arbitrarily determine which sectors must use the second technology or a combination of technologies to meet the water use constraint. According to Table 4, the Agriculture sector as the most water-consuming sector still needs to use less water-consuming technology (similar to Scenario 2). Similarly, the Textile sector uses technology 2. Sectors 7, 11, and 19 are required to use technology 2 to produce their outputs that result in a 20% increase in their costs. In this scenario, Chemicals and chemical products must produce 60% of its output using technology 2 which entails a 12% increase in its costs. The value of the objective function in this scenario is the same as its value in Scenario 2 due to the similar amount of saved water. As the reduction percentage of water consumption and the increase in the price of one unit of water are equal for all sectors, model supplies the water shortage by the same total cost in both scenarios.

To apply scenario 4, there is no need to solve the optimization problem, and it only suffices to resolve the IO model. However, to compare the difference, the value of its objective function is shown in Table 3. Also, similar to the status quo the output produced by technology 2 is zero. As can be seen, the value of the objective function and water use decreased by 10.6% in scenario 4 so that water use reduces to 1371 MCM that is less than the total available water. 15% reduction of final demand in sector 1 results in a 10.7% decrease in its output and 18% decrease in the output of sector 7. The saved water was about 162MCM of which 99% belongs to the Agriculture sector.

Table 2- The 19-sector input-output table for NKP (2012) (billion Rials).

Sectors	Intermediate demand																			Final demand	Output
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
1	380.7	708.7	0.17	808.4	4.11	0.01	0.04	4.90	0.96	0.77	0.17	0.29	1.17	28.19	7.40	4.10	1.43	4.79	2.77	3920	5879
2	55.22	405.2	0.00	454.6	0.40	0.00	0.00	0.05	0.08	0.07	0.01	0.00	0.35	5.02	0.77	2.89	0.07	0.22	0.40	3858	4784
3	44.78	6.26	2.49	2.51	0.06	0.00	0.06	20.73	185	246.9	0.61	0.01	158.7	12.15	1.59	0.04	0.80	0.99	1.00	-318	367
4	17.61	465	0.16	772.7	3.14	0.10	0.11	13.08	4.59	4.05	0.85	1.18	1.94	137.9	3.25	25.14	6.60	1.26	18.00	1742	3219
5	6.76	1.27	0.02	11.36	38.02	0.01	0.10	3.31	8.19	1.07	0.52	0.26	2.71	7.52	0.98	5.21	0.53	0.33	0.33	13	102
6	7.65	0.79	0.15	1.23	0.03	17.18	0.48	1.73	3.88	62.07	0.29	0.01	44.04	5.72	0.57	0.13	0.86	0.27	0.51	-108	40
7	4.66	11.77	0.03	81.03	0.54	0.89	4.79	15.39	21.92	1.77	2.04	0.75	0.84	41.61	7.16	2.60	8.54	1.87	0.86	-198	11
8	475.3	300.5	0.47	37.35	10.86	2.97	0.75	387.1	53.37	32.41	12.56	1.58	137.89	126.6	4.74	14.72	24.54	5.78	10.51	1508	3151
9	6.73	9.18	0.12	18.40	0.35	0.01	0.00	8.13	70.25	23.26	2.86	0.61	1037	80.13	0.99	0.37	2.43	0.56	5.36	1	1269
10	5.67	4.42	0.22	12.90	0.60	0.12	0.07	8.53	22.2	1028	115	1.67	1308.8	21.36	1.19	31.14	1.42	0.54	2.72	-107	2461
11	26.12	5.68	0.34	37.07	0.66	0.25	0.11	36.92	21.30	24.89	57.21	16.27	229.89	35.21	5.22	137.4	2.03	0.76	2.27	-278	368
12	19.33	7.44	0.33	19.18	1.70	0.44	0.21	22.76	60.31	62.76	2.08	116.9	2.87	153.2	9.97	3.06	14.71	11.59	6.40	257	787
13	5.21	13.63	1.62	4.30	0.10	0.05	0.03	7.67	6.39	7.63	0.69	19.13	439.4	347.9	6.33	2.93	22.06	3.09	10.38	8211	9116
14	231	544	6.68	49.54	2.22	0.46	0.25	54.60	28.42	26.6	8.06	27.77	998.8	913.8	85.8	158.4	70.35	39.73	27.83	10564	13861
15	0.60	0.56	0.44	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.01	14.13	5.99	9.47	0.13	1.13	0.65	0.47	1512	1545
16	0.15	0.14	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.01	0.02	2.13	76.51	0.00	0.14	0.35	0.16	1960	2040
17	0.08	0.17	0.01	0.00	0.00	0.00	0.00	0.10	0.04	0.02	0.05	1.16	0.11	5.41	0.91	34.57	0.15	0.29	2.68	2357	2403
18	4.25	0.53	0.00	1.99	0.01	0.00	0.00	0.29	0.65	2.75	0.15	0.15	6.65	28.42	9.18	0.49	6.34	22.68	2.45	393	480
19	0.61	0.36	0.00	0.01	0.00	0.00	0.00	0.03	0.17	0.08	0.00	0.30	0.76	7.04	0.22	0.17	1.72	1.40	16.29	334	363
Sum of inputs	1374	2491	14	2318	63	23	7	597	490	1528	203	191	4391	1983	243	425	169	98	114		
Value-added	4506	2292	353	901	39	17	4	2554	779	933	165	596	4725	11878	1302	1615	2234	381	249		
Input	5879	4784	367	3219	102	40	11	3151	1269	2461	368	787	9116	13861	1545	2040	2403	480	363		

Table 3- Economic activities, total outputs, total water use, and water use ratio.

Row	Economic Activities	Outputs (Million Rials)	Total water use (MCM)	Ratio of water consumption to output (m^3/ Million Rials)
1	Agriculture	5879245.5	1514.218	***257.5531***
2	Animal production	4783556.6	0.402	0.084038
3	Mining and quarrying	366812.03	0.024	0.065429
4	Manufacture of food products and beverages	3219414.5	3.15	***0.978439***
5	Manufacture of textiles	102124.4	1.958	***19.1727***
6	Manufacture of wood and of products of wood	39653.183	0.002	0.050437
7	Manufacture of paper and paper products	11331.167	***0.075***	***6.618912***
8	Manufacture of chemicals and chemical products	3151342	6.746	***2.140675***
9	Manufacture of other non-metallic mineral products	1268579.1	1.094	0.862382
10	Manufacture of basic metals	2461138.8	1.01	0.410379
11	Manufacture of fabricated metal products	367966.74	***0.881***	***2.394238***
12	Electricity	787230.82	0.415	0.527164
13	Construction	9116334.4	0.377784	0.04144
14	Non domestic services	13860888	1.262859	0.09111
15	Public administration	1545305.3	1.194975	0.773294
16	Public defence	2039739.8	0.231391	0.113441
17	Education	2402801.7	0.71753	0.298622
18	Arts, entertainment and recreation	479583.37	0.236392	0.492911
19	Religious and political	362703.73	0.179634	0.495264
	Total	52245751.38	1534.17	

Table 4- The status quo and scenario results.

Optimizations Scenarios	Status quo	Scenario 1	Scenario 2	Scenario 3	Scenario 4	difference between column 1 and 5 (Percentage)
Objective (Million Rials)	1533911	1550375	1645031	1371157	1533911	10.6
Total water use (MCM)	1533.911	1373	1373	1373	1371.157	10.6
Economic Sectors		Outputs				
Sector 1 (Technology 1)	5878.448	***1810.219***	0	0	***5247.269***	***10.74***
Sector 1 (Technology 2)	0	***4068.229***	5878.448	5878.448	0	
Sector 2 (Technology 1)	4783.364	4783.364	4783.364	4783.364	4776.214	0.15
Sector 2 (Technology 2)	0	0	0	0	0	
Sector 3 (Technology 1)	365.6409	365.6409	365.6409	365.6409	359.6509	1.64
Sector 3 (Technology 2)	0	0	0	0	0	
Sector 4 (Technology 1)	3218.279	3218.279	0	3218.279	3214.032	0.13
Sector 4 (Technology 2)	0	0	***3218.279***	0	0	
Sector 5 (Technology 1)	101.4652	101.4652	0	0	100.0965	1.35
Sector 5 (Technology 2)	0	0	***101.4652***	***101.4652***	0	
Sector 6 (Technology 1)	39.04711	39.04711	39.04711	39.04711	37.1391	4.89
Sector 6 (Technology 2)	0	0	0	0	0	
Sector 7 (Technology 1)	10.37253	10.37253	10.37253	0	8.440719	***18.62***
Sector 7 (Technology 2)	0	0	0	***10.37253***	0	
Sector 8 (Technology 1)	3146.889	3146.889	***2232.837***	***1281.943***	3086.997	1.9
Sector 8 (Technology 2)	0	0	***914.0515***	***1864.946***	0	
Sector 9 (Technology 1)	1266.44	1266.44	1266.44	1266.44	1264.985	0.11
Sector 9 (Technology 2)	0	0	0	0	0	
Sector 10 (Technology 1)	2454.213	2454.213	2454.213	2454.213	2449.778	0.18
Sector 10 (Technology 2)	0	0	0	0	0	
Sector 11 (Technology 1)	361.3738	361.3738	361.3738	0	356.7867	1.27
Sector 11 (Technology 2)	0	0	0	***361.3738***	0	
Sector 12 (Technology 1)	769.4624	769.4624	769.4624	769.4624	765.7262	0.49
Sector 12 (Technology 2)	0	0	0	0	0	
Sector 13 (Technology 1)	9108.236	9108.236	9108.236	9108.236	9106.52	0.02
Sector 13 (Technology 2)	0	0	0	0	0	
Sector 14 (Technology 1)	13837.82	13837.82	13837.82	13837.82	13808.39	0.21
Sector 14 (Technology 2)	0	0	0	0	0	
Sector 15 (Technology 1)	1537.899	1537.899	1537.899	1537.899	1537.781	0.01
Sector 15 (Technology 2)	0	0	0	0	0	
Sector 16 (Technology 1)	2063.59	2063.59	2063.59	2063.59	2063.569	0
Sector 16 (Technology 2)	0	0	0	0	0	
Sector 17 (Technology 1)	2423.35	2423.35	2423.35	2423.35	2423.329	0
Sector 17 (Technology 2)	0	0	0	0	0	
Sector 18 (Technology 1)	479.4575	479.4575	479.4575	479.4575	478.8961	0.12
Sector 18 (Technology 2)	0	0	0	0	0	
Sector 19 (Technology 1)	362.3691	362.3691	362.3691	0	362.2823	0.02
Sector 19 (Technology 2)	0	0	0	***362.3691***	0	***10.74***

4 Conclusion

In this research, the economy of INKP was disaggregated into 19 sectors and the regional IO table was estimated using the CHARM method for 2012. Using the Leontief input-output model, we calculate the total water use. As the total water use was more than the total available water, we defined four scenarios to assess how water shortage can be compensated and determined the optimal allocation plan. The results show that in scenarios 2 and 3 using less water-consuming technology in the Agriculture sector is essential to compensate for the shortage. Since the total industrial water demand is about 19 MCM compared to 160 MCM of water shortage, reducing or eliminating the water demand of these sectors has no significant effect on managing water scarcity. Results showed that scenario 1 produces the lowest final cost for the system and can be introduced as the most effective one. Scenario 4 focuses on managing the demand side of economy and indicates that while reducing the final demand of the Agriculture sector completely compensates for the water shortage and decreases the total cost of the system by about 10%, the total output is also reduced by about 2.2% that expresses shrinking the economy.

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