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Optimum allocation of Hirmand river water in Sistan area

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Abstract

One of the biggest planning problems in less developed countries is insufficient recognition of potentials and nonoptimal application of the production factors. This research is a case study of Shibab district located in Sistan region of Iran.The necessary data were collected from a random sampling of 105 farmers during 1998-1999 through questionnaires. Three different cropping patterns suitable to temporal allocation of water i.e. 247, 336, and 185 mm^3 per year were selected. Linear Programming model was used for finding the optimal patterns. Technical coefficients were calculated by means of farmers sampling. Results indicated that the most important restriction in agricultural activities of this area was water scarcity in summer season. Shadow prices of water in June & July with 247mm^3 annual water capacity was 228 and 54.6 Rials respectively ($=1750Rials). On the other hand in drought which water volume was between 136-202 mm^3, shadow price was about 174.5 Rials. Estimation of normative demand function for water implied that quantity of water demanded had negative relationship with its price and demand curve would be stepwise. Shadow price for >= 274 mm^3 water volume was zero and point elasticity for 127 mm^3water capacity was equal to one(0.9999). There was land constraint only in situation of 335 mm^3 available water capacity and shadow price of one hectare was estimated around 940110 Rials. Furthermore, with increasing in water quantity, limitation of fertilizer was observed. Ignoring the effect of self-sufficiency constraint from model were considered and the results showed that by remove of these restrictions, total net revenue can be increased. In this paper outcomes about water allocation for different activities in agricultural sector of study area were analyzed and some suggestions are given for optimum allocation & utilization of water resources.

Introduction

Water is the most precious matter of life and an important input of agricultural sector. Most countries in the world are facing water shortage and production of food stuffs in the countries requires the implementation of more irrigation development projects. Utilizing water resources efficiently has changed into a pivotal discussion in designing economic, social, industrial, and agricultural projects and it is here that a proper water resources management plays an important role in improving and enhancing economic development[1]. The importance and value of water is felt more in eastern Iran particularly in Sistan and Baluchestan province that is situated in an arid and semi – arid zone suffering from a rainfall shortage .

In this province water is a scarce and valuable commodity necessary for cultivation. So suitable plans and programs are needed to optimize its usage. Although planning plays an important role in decreasing agricultural uncertainties but itself is effected by many unforeseen factors including water supply which is determined by nature and on the other hand its demand is influenced by utilization methods. This investigation is a case study of Shibab district in Sistan region. Hirmand river is the only source of water providing potable, agricultural, and industrial water requirements in the study area. The Hirmand upon arriving in Iran is divided into two branches one called Sistan river that irrigates central Sistan and the other is called Paryan river forming part of Iran and Afghanistan border and irrigating eastern Sistan boundary and Miankangi region. The Hirmand's annual average flow is $78m^3$/sec that is 2459 mm^3/year[2].

Several studies of this type have been previously done. A study carried out by Yaron and Diner in 1982 for allocation of water in specific farms. Another study done by Sankhyan and Romast in 1990 to determine optimal agrcultural pattern. Koohpaiey in 1996 applied the same model on the optimal allocation of water in Sarakhs. Another study carried out by Soltani in 1993 on the optimal allocation of water in the lands irrigated by Fars Province dams.

The main objective of this study is to determine optimal allocation of production factors, especially that of water. Shadow prices of water and other production inputs will also be considered . Demand function of water in the region will be estimated. In the mean time total income , total cost, and output of various crops and required investment will be calculated. These objectives were based on the hypotheses such as water is the most limiting factor in the agriculture sector, existing cultivation pattern is not optimal and desirable, water accessibility & distribution is homogenous , agricultural machinery application method is the same , region possesses high potentials in agriculture, and linear programming model is applicable in the region.

Methods & materials

Required data were collected in a specific period (agricultural year of 1998 – 1999) in Shibab district through 105 questionnaires in 30 villages interview with farmers, those responsible for water distribution, agricultural experts in Jihad Keshavarsi adminstrations and those offices involved in water affairs. The questionnaires were completed randomly in two stages and technical coefficients as well as coefficients of objective function were calculated by Excel software and then results after being modeled were analyzed by QSB software.

With respect to the objectives study was continued by related research methodology & theoretical principles.By considering linear programming model for the activities and present conditions of the region, the mathematical model of the problem was prepared in which the objective function was maximizing the net profit of each activity without deducting water costs. The prices have been calculated based on the value of the crops in the year studied. In this model more than 30 constraints are introduced including , land, fertilizer, water, self-sufficiency and the constraints of maximum and minimum cultivation for about 13 agricultural activities in the region . some of the main constraints are : 1- land 2- The consumed water needed for each crop depends on its needs in different months of a cultural period and the constraint of water resource is demonstrated in 3 forms as follows:

A)general constraint of water, that means the water used in the proposed pattern does not exceed the allocated quantity i.e

$$\sum_{j=1}^{12}\sum_{i=1}^{13} NW_{ij}X_i - W_y \le 0 \qquad (1)$$

In this constrain NW_{ij} is the water needs of the ith crop in the jth month and Wi is the total quantity of water allocated to agricultural activities.

B) constraint of maximum annual water consumption, based on which the total annual water consumption should not exceed the total accessible water. B_i is the amount of accessible water in the jth month, as indicated

$$\sum_{i=1}^{12} NW_{ij}X_i \le \sum_{i=1}^{12} B_i \qquad (2)$$

C) Monthly water constraint, while the needs of crops to water differs in different months so for each month a water constraint is introduced in which the technical coefficient of the activities are the water needs of the jth month for each activity i.e.

$$\sum_{j=1}^{13} NW_{ij}X_i \le \sum_{j=1}^{13} B_j \qquad (3)$$

3- Labor force constraint, labor for each activity e.g. for land leveling and preparing, rowing, protecting crops against pests and diseases, cultivation, irrigation, harvesting, threshing, packing, and transportation have been considered 4–Fertilizer constraint, including chemical fertilizers and manure 5- The farmer's domestic consumption, while traditional farmers try to provide their foodstuff requirements regardless of the economic aspects and they are risk-

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aversion 6- Cash capital, that includes the farmer's savings, loans and personal earning 7- the constraint of maximum and minimum, for some crops like Tobacco there is a maximum acreage of cultivationthat is dictated by the related authorities. The main activities in the study area which are considered in research model were as: wheat, barely, fodder,alfalfa,clover,lentil, sorghum, saffron,onion ,turnip,tobacco, caraway, and greenery(melon , watermelon…)

Results & discussions

The findings of the study are illustrated by tables, figures and related discussions are briefly explained below. Technical coefficient, costs & income of 13 activities are demonstrated in table 1-2. Meanwhile water requirements for various crops were considered as shown in table3-4.

Table 1: Technical coefficients & data obtained in the region.

No	Activity	Land (hec.)	Labor		Chemical fertilizer		used seeds (kg)	seeds Value (Rail)
			Irr.	total	ne.	Pht		
1	Wheat	1	3.4	17.4	46.5	31	140	645
2	Barely	1	3.4	26.4	51.5	36.5	149	649
3	Fodder	1	3.5	12.8	0	29	181	620
4	Alfalfa	1	22	121	26	74	21	1400
5	Clover	1	15	58.2	15	64	53	3550
6	Sorghum	1	10	54	96	72	8.4	6500
7	Onion	1	7.5	100.5	50	87	7.35	9235
8	Greenery	1	6.1	49.5	55	46.5	1.78	42478
9	Tobacco	1	13	100	78	171	7.5	7050
10	Lentil	1	8	43	50	100	31	2620
11	Caraway	1	4	59	50	100	40	10000
12	Saffron	1	4	144	49	25	2667	2000
13	Turnip	1	4.6	16	0	42	3	3150

Source: Field Survey

Table 2: Costs & incomes of linear programming model activities.

Production				Costs						Crop
Net inco	Total income	price	Perfo manc	Total cost	Other	Labor	Seed Used	Fertilize	Prepar-ation	
240735	900639	666.7	1287	659904	130125	278400	90300	23033	138046	Wheat
29045	664052	600	1079	634987	46500	343200	89400	26151	126736	Barly
1569	422000	*	*	1139712	28298	792000	75271	30154	213989	Grenary
650902	2589750	450	5755	440431	6127	192000	112220	8584	121500	Fodder
54523	1063750	250	4255	1938847	25321	1815000	29400	29652	39474	Alfalfa
362766	1448200	200	7241	1009227	15116	882000	18815	23414	69884	Clover
69688	1210200	300	4034	1085434	19231	810000	54600	49920	15683	Sorghum
2067016	4355950	400	1089C	2288934	366038	1608000	67877	40652	206367	Onion
96702	2121000	1400	1519	1928298	13438	1600000	52875	73860	188125	Tobacco
1041857	2025000	5000	405	3591486	100000	2240000	1168774	4500	38212	Saffron
1901500	3600000	9000	400	1698500	135000	944000	400000	44500	175000	Caraway
1806098	5397584	30000	*	983143	15000	688000	81220	22000	176923	Lentil
-16988	371250	450	825	388238	5556	256000	9450	12432	120000	Turnip

Source: Field Survey

Table 3 : Water requirements of Autumn crops based on Belani Craddle method (FAO) m^3 / hectar.

Crop	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Yearly
Wheat	804	868	702	654	837	1186	1531	6482
Barely	804	868	702	654	837	1186	1531	6482
Turnip	888	1137	924	663	693	-	-	4305
Saffron	804	768	702	654	837	1186	-	4951
Caraway	-	768	702	654	837	1186	1531	5678
Clover	-	757	924	663	765	1085	1739	-
Fodder	804	768	702	654	837	-	-	3765
Alfalfa	2061	1303	747	600	693	980	April	-
Lentil	-	650	750	-	-	March	1531	7497

Source: [3]

Table 4: Water requirements of spring crops based on Belani Craddle method (FAO) m^3 / hectar.

Crop	April	May	June	July	August	Septum	Yearly
Greenery	676	2031	3370	3853	3168	-	13098
Tobacco	645	2613	4235	4399	2446	-	14338
Onion	729	2976	4052	4073	-	-	11830
Clover	1739	3190	3275	2682	-	-	15080
Sorghum	694	2288	3850	4185	2466	-	13483
Alfalfa	1333	2886	3866	4278	4077	3279	26102
Pulses	794	2693	2590	-	-	-	7497

Source: [3]

As the main point was considering water resources utilization and distribution therefore 3 situations were proposed based on the quantity of water used yearly and monthly in agriculture sector[4].Initially the Hirmand's water supply was studied for last 50 years (1948-98) and it was found that the river underwent an intense slump in its water volume every 10 years[2&3] as depicted in fig.1,that means in every decate the region has experienced an intense drought like that of the year 2000 – 2001.

Based on findings , situations were divided into 3 groups (table5-8):

I situation : The amount of accessible water was 247.67 mm^3 in study year.
II situation : The average accessible water in last 18 years was 335.98 mm^3/year.
III situation : The average in 5 water deficient years was 185.1 mm^3/year.

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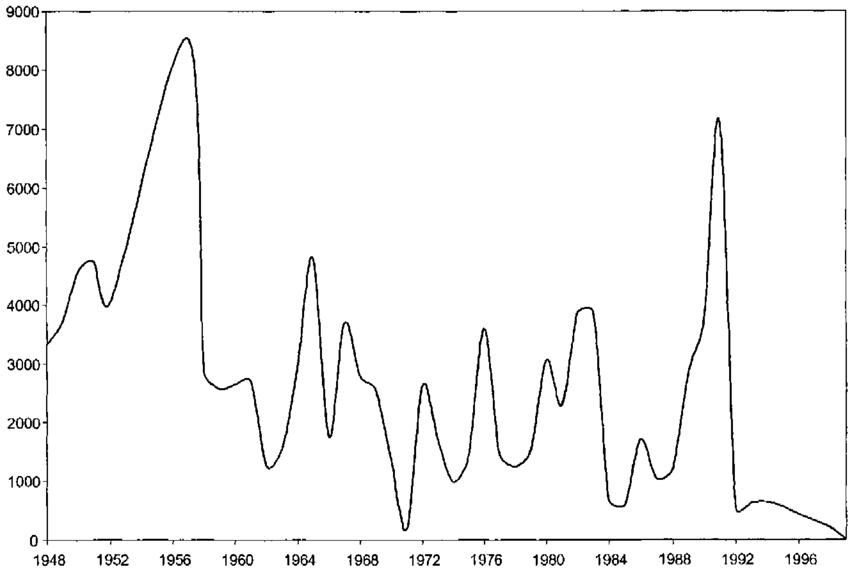

Figure 1: Hirmand river water supply in Iran (1948-98).

Table 5: Quantity of accessible water for 3 main situations (mm^3).

Situation	Various months					
	April	may	June	July	August	Sep
I	44.9	30	21.3	10.6	6.6	4.1
II	48.48	59.54	32.77	14.17	9.68	10.25
III	12.4	15.4	15	20.6	19	10.7

Source : Study Findings

Table 6: Quantity of accessible water for 3 main situations (mm^3).

Situation	Various months						
	Oct.	Nov.	Dec.	Jan.	Feb.	March	Yearly
I	25.4	33.9	15.9	99	23	22.3	248.67
II	19.25	24.12	18.54	30.09	36.59	32.8	335.98
III	20.6	24.7	15.6	9.8	11.3	9.8	185.1

Source : Study Findings

Being a flat plain and lack of dams in sistan region the only source of reserving Hirmand's water is natural reservoirs of Chahnimeh. So in order to optimize water utilization the reserving and transferring possibility of water from one month to anther one has been taken into consideration. After studying the effect of water reserving on the 3 situations the effect of removing the self-

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sufficiency constraint from the pattern was considered. According to the results obtained from the 3 situations it was found clearly that water is the most limiting factor.

In the first situation, the amount of water in Jan , June and July is highly restricted and water shadow price is exceedingly high being 2905.5 , 290,and 218 Rials respectively.

Table 7: Water shadow prices during constrain months (Rial).

Situation	Condition	Water constraint during various months						Land
		Dec.	Jan.	Mar.	April	June	July	
I	1	0	2905	0	0	290	218	0
	2	0	0	0	0	288	54.6	0
II	1	1253	0	0	0	0	516.8	0
	2	0	0	0	0	0	276	940110
III	1	0	0	1602	0	363	145.7	0
	2	0	0	0	156.25	315	165.4	0

Source: Field Survey

The figure 2095.5 indicates that an increase in water supply as many as one cubic meter in Jan cause the farmers income to increase 2905 Rials. The reason for the increase of water prices is the suitability of climatic conditions and water requirements of crops like wheat, barely, fodder, lentil and cultivation restriction of the most profitable crop of the season (caraway). In June and July the water shadow prices increased as many as 288 and 54.6 Rials respectively and also the model's efficiency improved significantly.

Table 8: Cultivation area of different crops in four patterns(hec.)

Pattern	Wheat	Barely	Greenery	Fodder	Onion	Lentil	Tobacco	Caraway	Saffron	Turnip
Current	15502	3387	1222	2023	171	171	56	0	0	23
I	13653	3387	0	2039	2937	4065	0	4275	725	0
II	10481	3387	0	2039	8338	2939	0	5000	0	0
III	9763	2500	0	2072	1955	2899	0	0	2360	0

Source: Field Survey

In the second situation we face water constraint in Dec. and July that the constraint was obviated through reserving extra water. In this situation labor constraint emerged in the harvesting season of caraway. In second stage the most important restricting factor was land whose shadow price was 940110 Rials.

In the third situation, in March, June, and July water was restricting factor with the shadow prices of 1602 ,363, and 145.7 Rials respectively and in other months where there was surplus water the shadow price was zero and it must be mentioned that the remaining surplus water was considered as wastage .

The numeral value of each activity indicates that if a farmer decides to cultivate one hectare greenery he has to ignor 1752648 Rials in his total income, as indicated in tablea .

Table 9: Opportunity cost of the optimal model activities.

Activity	First pattern	Second pattern	Third pattern
Greenery	1752648	1936603	1737773
Tobacco	1462427	1521846	1516155
Caraway	0	0	143990
Saffron	0	92234	0
Turnip	206254	955101	17991

Source: Field Survey

In all the patterns investigated above, a number of constraints including wheat, barely, and fodder self–sufficiency production have been considered. Now this question is posed that what would happen to the net income and region's activities level if uncertainties are removed and the self–sufficiency requirements are omitted from the model ? (table10-12)

Table 10: Comparing the proposed & current patterns' incomes in different conditions (million Rials).

Condition	First condition	Second condition	Changes %
Current activity net income	-	14695.675	-
First pattern net income	9992.176	23478.85	%134.98
Second Pattern net income	22265.35	32821.16	% 47.41
Third pattern net income	7370.845	14177.62	% 92.35

Source: Field Survey

Table 11: Beneficiaries income changing without self – sufficiency constraints (million Rails).

Net income	First pattern	Second pattern	Third pattern
Self-sufficiency Patterns	23479	32821	14177
Non self-sufficiency Patterns	26436	35791	16796
Change %	% 12.59	% 9	% 18.46

Source : Field Survey

Table 12: Cultivation area comparison of the pattern's activities with / without self-sufficiency constraint.

Activities	Under cultivation in the first optimum pattern			Under cultivation in the optimum pattern without self-sufficiency constraints		
	First	Second	Third	First	Second	Third
Wheat	13681	10480	6000	18720	14047	12867
Barely	3387	3387	1500	0	0	0
Fodder	2039	2039	6318	0	0	600
Onion	2936	5557	1169	4174	9575	3191.7
Caraway	4830	3757	347.4	3199	5000	0
Lentil	2940	6763	1756	4281	3553	3115
Saffron	169	0	0	1801	0	2360

Source : Field Survey

Finally in order to study the behaviors of water demand rate and its price, Fedcorick standard estimated water demand function was a step-like function with negative slope as demonstrated in fig. 2 which follows the general law of demand[5]. The changes ranges of the prices in the demand function are also presented in table 13.

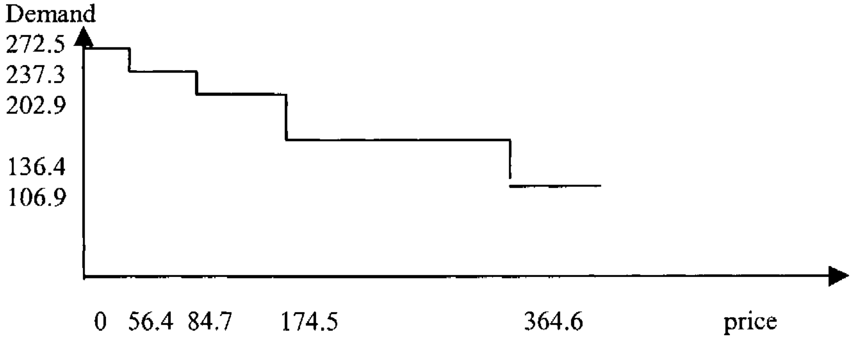

Figure 2 : Step-wise water demand curve

In order to estimate the effect of water price fluctuation level on water demand, point elasticity of water was considered and it was found that absolute quantity in the range of <127 m^3 was elastic and in a range of >127 m^3 it is inelastic. The point elasticity for 127 mm^3 capacity was equal to one (0.9999).

Table 13 : The changes range of the prices in relation to water demand

Lower range of demand	Price	Higher range of demand
+∞	0	27249908
27249908	56.424	23732046
237320.46	84.668	20298080
20298080	174.49	13649428
13649428	364.56	1068999

Source : study findings

Conclusion

Finding of the study show that serious problems exist in terms of water availability. Proper measures can reduce severity of the problem. Since the most restricting factor in the regions agricultural sector is water shortage in summer, it is necessary that appropriate plans be designed, to decrease water requirements. Water reserve is considered important in optimizing its usage. To this end, construction of appropriate reservoirs and irrigation systems can improve water retention and efficiency. In this regard construction of the fourth Chahnimeh is a desirable measure. Land fragmentation is another factor which reduces irrigation efficiency. Consolidation of lands could improve the situation tremendously. Cultivation patterns were not efficient. Therefore, it is recommended that authorities responsible for agricultural activities should change traditional methods through education and extension programs. Sistan suffers from drought most of the times and sometimes is stricken by floods. So investment to control water flood and water reserving projects is necessary to optimize usage of this vital matter of life. The existing patterns of utilizing the regions resources is not optimal. There are difficulties in providing seed, fuel, chemical fertilizers, and etc. Protective measures need to be taken to prevent agriculture inputs from being smuggled out to the neighboring countries, which in turn this would lead to higher efficiency.

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