SHORT AND LONG-TERM SOCIO-ECONOMIC IMPACTS OF USING WATER STORAGE POOLS FOR AGRICULTURE OF GORGANRUD WATERBASIN

IMPACTS SOCIO-ECONOMIQUES A COURT ET LONG TERMES DE L'UTILISATION DES ETANGS DE STOCKAGE D'EAU EN AGRICULTURE DU BASSIN VERSANT DE GORGANRUD

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ABSTRACT

Short and long term impacts of off-river ponds and their interactions with the river and among them on agriculture stakeholders' socio-economic indices will be a supplementary factor in optimum pond design. To account for pond-river system operation in assessment of socio-economic impacts of ponds construction, a model capable of integrated modeling of pond and river system is necessary. By modeling of pond-river system, especially, for long term analysis with a model, optimum operation of pond-river system for best achievement in water supply can be determined. Then according to water supply, cultivated land area and other dependent socio-economic indices, like; production and net income can be estimated and used for ponds' socio-economic impacts assessment.

In this research, a real world case in north east of Iran, Siyahjuy river and its ponds, are analyzed by this methodology for socio-economic impacts assessment. A 10 year analysis of these river-pond systems shows that by changing from rain-fed to irrigated agriculture by using the water stored in ponds, meaningful improvements can be achieved in the system. This improvement in terms of production per unit cultivated area is 90% and the net income per unit cultivated area is 21% in upstream region of Siyahjuy in comparison with current state. Besides, WEAP analysis shows, in dry years when river flow decreases up to 25%, pond-river system can be managed in a manner to limit the reduction in net income and production to 15%.

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Key words: *Ponds, Socio-economic indices, Water Supply, Agriculture, Gorganrud.*

RESUME

L'étude des impacts à court et à long terme des étangs de la rivière et leurs interactions avec la rivière et entre eux sur les indices socio-économiques des parties prenantes de l'agriculture sera un facteur supplémentaire dans la conception optimale des étangs. Il est nécessaire d'avoir un modèle capable de modélisation intégrée du système rivière-étang pour évaluer les impacts socio-économiques de la construction des étangs. Par la modélisation du système rivière-étang, il est possible de déterminer le meilleur résultat de l'exploitation optimale du système rivière-étang pour une analyse à long terme. Puis, selon les indices tels que l'approvisionnement en eau, la superficie cultivée et d'autres indices socio-économiques, il est facile à calculer la production et le revenu net pour utiliser cette information dans l'évaluation des impacts socio-économiques des étangs.

Un cas réel a été analysé par cette méthode sur la rivière Siyahjuy et ses étangs au nord-est de l'Iran. Une analyse de 10 ans de ces systèmes rivière-étang montre qu'en changeant le système agricole pluvial au système agricole irrigué en utilisant l'eau stockée dans des étangs, il est possible d'améliorer le système de manière significative. Cette amélioration en termes de production par unité de surface cultivée est de 90% et le bénéfice net par unité de surface cultivée est de 21% en amont de la région de Siyahjuy par rapport à l'état actuel. En outre, l'analyse WEAP montre que dans les années sèches lorsque le débit de la rivière diminue de 25%, le système rivière-étang peut être géré pour limiter à 15% la baisse en bénéfice net et production.

Mots clés : *Etangs, indices socio-économiques, approvisionnement en eau, agriculture, Gorganrud.*

1. INTRODUCTION

The Gorganrud waterbasin is agriculture dominated. The farmers with the aid of government construct off-river ponds to store the surplus water in rivers and floodways. The stored water is meant for use in high demand seasons. Off-river ponds in comparison with larger structures; like, dams have many benefits, such as; low cost and high speed of construction, operation safety and simplicity, longer life due to affordable maintenance cost, few social problems as there is no land property right problems, no conflict between stakeholders due to allocation of each pond to a village and water intake in high flow months when rights to river water do not exist, better participation of stakeholders in construction and operation.

Currently these ponds are designed and constructed based on farmers request, target cultivated land area (or water demand volume) and government financial position. In design and construction of these ponds their short and long term socio-economic impacts on agriculture and farmers and their hydrologic impacts on river flow regime, flood control and groundwater recharge are not taken into account. It is felt that consideration of the above factors would lead to a set of better criteria for pond design.

Since there are multi-pond systems on a river, a model that considers their interaction from upstream to downstream must be used. WEAP is widely used for water planning evaluation in more than 56 different projects from east Asian to north and south American countries. Water resources evaluation, sustainable development, water allocation and conjunctive water use are studied successfully by WEAP software (ACRES, 2004). CALSIM-II is hydro-system operation modeling toolbar developed by California Water Authority and USBR for water allocation and hydro-system operation study in the California Bay Delta Region. This model considers influence of upstream operation on downstream withdrawals and operates the hydro-system in a manner that least negative impacts in terms of slacks in water supply occur in the system (Cai et al, 2003). Other software modeling systems include; AQUARIUS, ARSP, MIKEBASIN and MODSIM, that consider upstream-to-downstream impacts in their analyses and minimize these impacts (Close, et al, 2003; DHI, 2003, Dudu and Chumi , 2008 and Diaz, et al, 2005.

Another important aspect of pond systems analysis is their socio-economic impacts, which are not included in the software tools mentioned above. These impacts are elsewhere modeled and integrated with hydro-system modeling for water basin management (Krol, et al, 2006; Labadie, et al, 2000; Roe, et al, 2005 and Stockholm Environment Institute, 2005).

However, in this research an analysis method based on hydro-system modeling of pond and river systems by WEAP is introduced and used in conjunction with a secondary (de-coupled) assessment of socio-economic indices. These indices are presented as production and income of farmers, which are defined in terms of supplied water and cultivated land area. Therefore, socio-economic impacts of pond construction can be estimated by hydro-system analysis of the pond-river system in short and long term runs. Normal, wet and dry flow regimes are used for assessment of different river flow conditions on the dimensions of socio-economic impacts.

Modeling and problem formulation is introduced first, and then by applying the modeling to a real world case in the north-east of Iran (Siyahjuy river, Gorganrud Water basin) impacts of construction of small ponds is compared to the construction of a dam on the river.

2. MATERIALS AND METHODS

For being able to assess the short and long term hydrologic and socio-economic impacts of construction of ponds on river, a two stage analysis method is introduced. In the first stage, a hydro-system analysis is performed to determine deliverable water to meet agricultural water demands. In the second stage, based on the amount of water demand supplied, cultivated land area will be determined. Then according to the relationship between cultivated land area and socio-economic indices, like; production and income, socio-economic indices will be estimated. Figure (1) shows the algorithm for assessment of socio-economic impacts of ponds construction and operation.

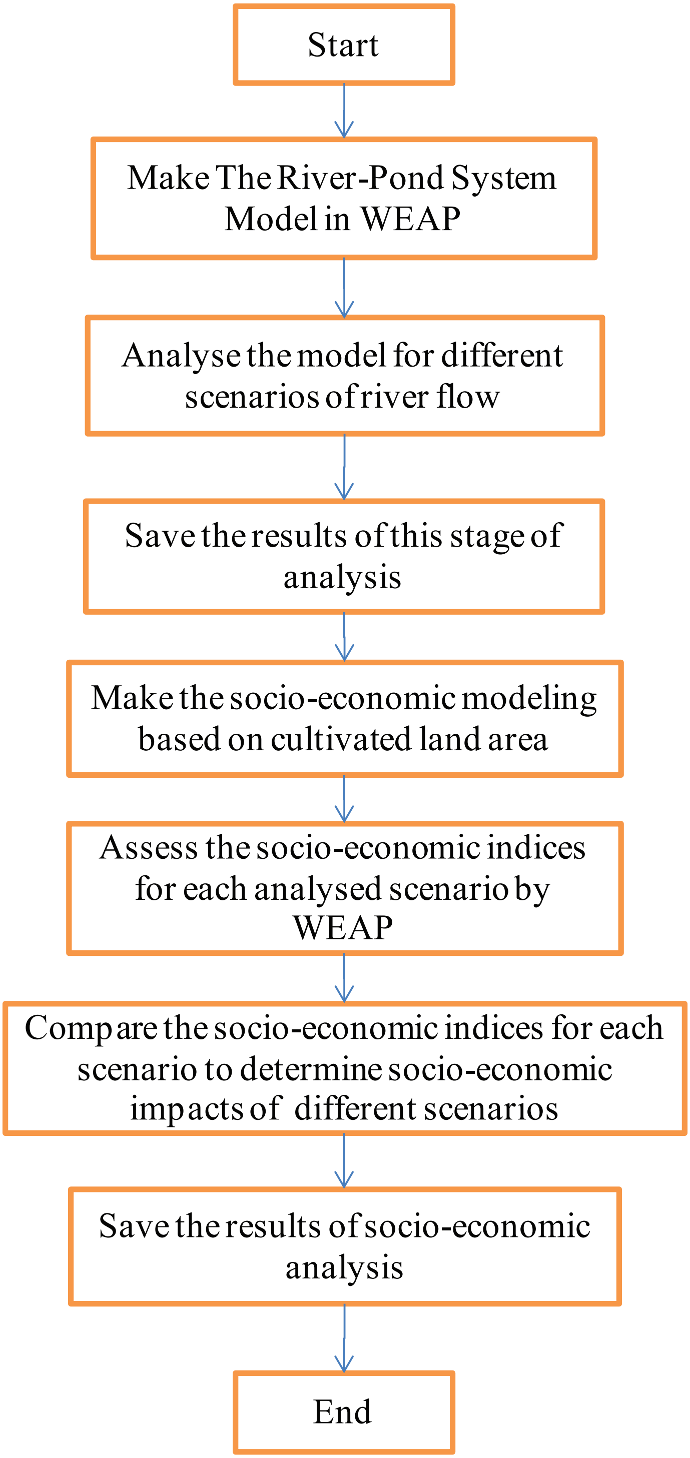

Fig.1. Algorithm for assessing the impacts of pond construction on agriculture stakeholders

WEAP is a single period optimization model, which uses linear programming to determine best operation of hydro-systems in a river basin. It uses water balance equations in nodes and arcs to determine water movement and allocation at different points of a river basin. In this software most of the hydro-structures, like; dams and diversions, hydro-plants, return flows and groundwater system can be modeled and analyzed.

WEAP, which is an object-oriented model, is used for modeling the river-pond system in this research. Inflows, water demands, ponds specifications are provided through forms. Amount of supplied water to agricultural demands are determined by WEAP model. However, impacts of water supply to agriculture demand can be assessed by socio-economic modeling. This modeling is based on crop-yield modeling and cost-benefit analysis. Since it is assumed that water is supplied fully to the agricultural demand, agricultural production can be modeled as:

$$AP^{y} = \sum_{j} CY_{j}^{y} \cdot CA_{j}^{y} \tag{1}$$

where, AP is yearly agricultural production, CY is crop-yield coefficient in terms of kg per ha and CA is cultivated area of crop j in year y. Net income can be computed based on gross income minus production costs as shown in Eq (2)

$$NI^{y} = \sum_{j} NIC_{j}^{y} \cdot CY_{j}^{y} \cdot CA_{j}^{y} \tag{2}$$

where, NI is net income (Rials), NIC is net income per production of crop j (Rials/kg).

By Eqs (1) and (2), socio-economic indices of water supply in the river-pond system on agriculture stakeholders can be estimated. Comparison of these socio-economic indices in different analysis conditions in each scenario shows the socio-economic impacts of different scenarios in the river basin.

Cultivated area is computed based on the ratio of supplied water to target water demand. This ratio shows the per cent of target land area than can be irrigated. Based on irrigated area production, the net income is estimated and used for socio-economic indices. This methodology is used for assessment of socio-economic influences of the ponds on farmers' net income and agricultural production.

3. RESULTS AND DISCUSSION

Gorganrud waterbasin is a good example of an agriculture dominated hydro-system with many off-river ponds in north east of Iran. Figure (2) shows the Gorganrud waterbasin and its location in Iran.

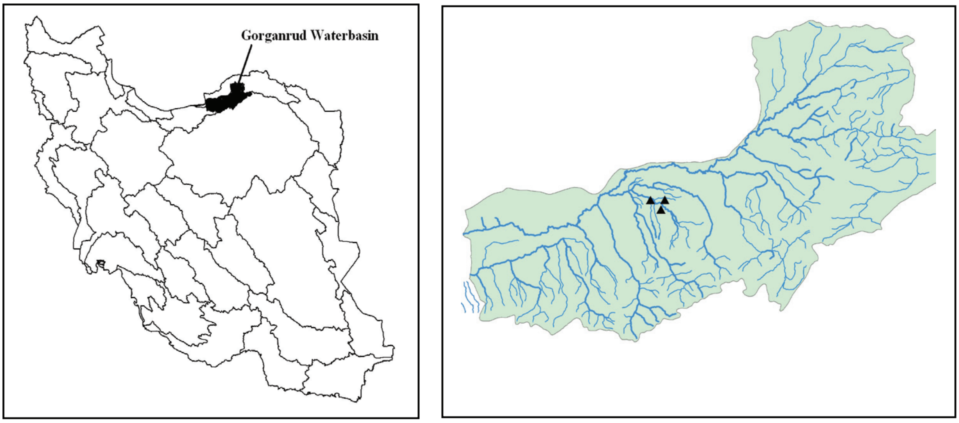

Fig. 2. Location of Gorganrud Waterbasin and off-river ponds on Siyahjuy river

The case study is with respect to the Siyahjuy river and its three ponds; Kuchakplang, Shahid-Mohajeri and Haj-Allahyar-Imer. These ponds are going to provide water for irrigation of lands that belong to villages with the same name as the ponds. Target cultivated land area, water demand, socio-economic coefficients and river flow are shown in Tables 1 and 2.

Table 1. River flow, agriculture water demands

Months	River Headflow	Kuchakplang_AWD	Sh.Mohajeri_AWD	IMER_AWD
OCT	0.096	0.434	0.213	0.091
NO	0.274	0.277	0.140	0.184
DEC	0.323	0.000	0.001	0.001
JAN	0.391	0.000	0.004	0.006
FEB	0.605	0.070	0.040	0.059
MAR	0.879	0.176	0.100	0.147
APR	0.935	0.347	0.189	0.278
MAY	0.436	0.651	0.330	0.486
JUN	0.172	0.560	0.269	0.395
JUL	0.203	0.668	0.310	0.113
AUG	0.065	0.945	0.459	0.189
SEP	0.258	0.878	0.428	0.178

Table 2. Demand and Socio-economic Parameters

Region	Target Land Area (ha)			
	Wheat	Barley	Cotton	Soya
Kuchakplang	250	0	0	250
Sh. Mohjaeri	120	10	20	110
Imer	176.25	15	30	33
	Net Income (Rials/kg per ha)			
Kuchakplang	7907450	0	0	2938580
Sh. Mohjaeri	6257450	3228260	2749040	2938580
Imer	10547450	6528260	2749040	4788580
	Unit Production Coefficient (kg/ha)			
Kuchakplang	3200	0	0	2000
Sh. Mohjaeri	3300	3300	5400	3700
Imer	4000	2500	2000	2500

Siyahjuy pond-river system is shown in Figure 3. This hydro-system is modeled in WEAP and analyzed for river flow scenarios as shown in Table 3. Figure 4 gives the schematic representation of the pond-river system in WEAP and Table 4 gives the pond specifications.

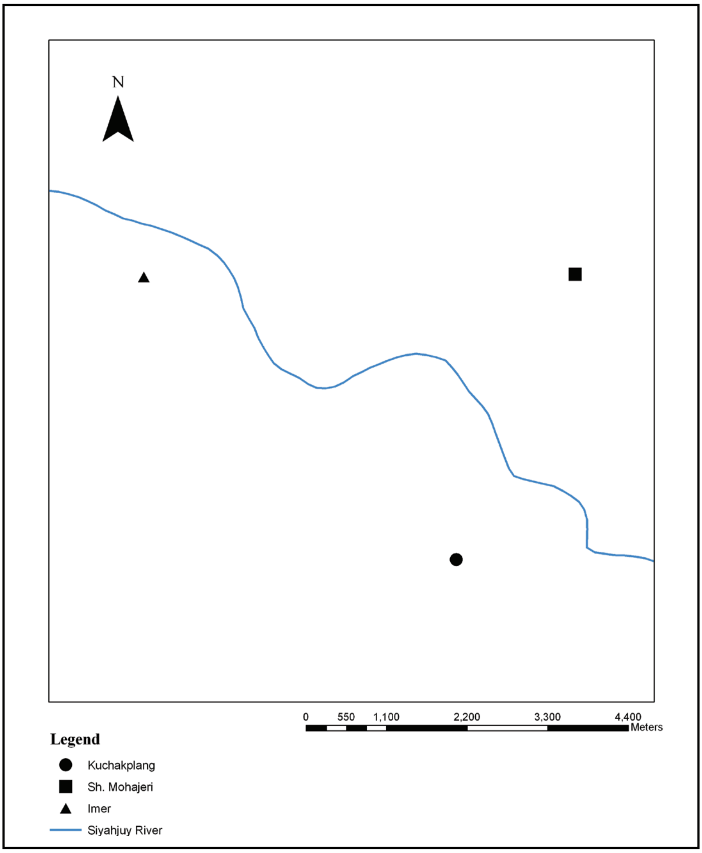

Fig. 3. Location of ponds around the Siyahjuy River

Table 3. River flow scenarios for normal, dry and wet year

Months	Normal	Dry=0.75*Normal	Wet=1.25*Normal
OCT	0.096	0.072	0.120
NO	0.274	0.205	0.342
DEC	0.323	0.242	0.403
JAN	0.391	0.293	0.489
FEB	0.605	0.454	0.757
MAR	0.879	0.659	1.099
APR	0.935	0.701	1.169
MAY	0.436	0.327	0.546
JUN	0.172	0.129	0.216
JUL	0.203	0.152	0.254
AUG	0.065	0.049	0.082
SEP	0.258	0.193	0.322

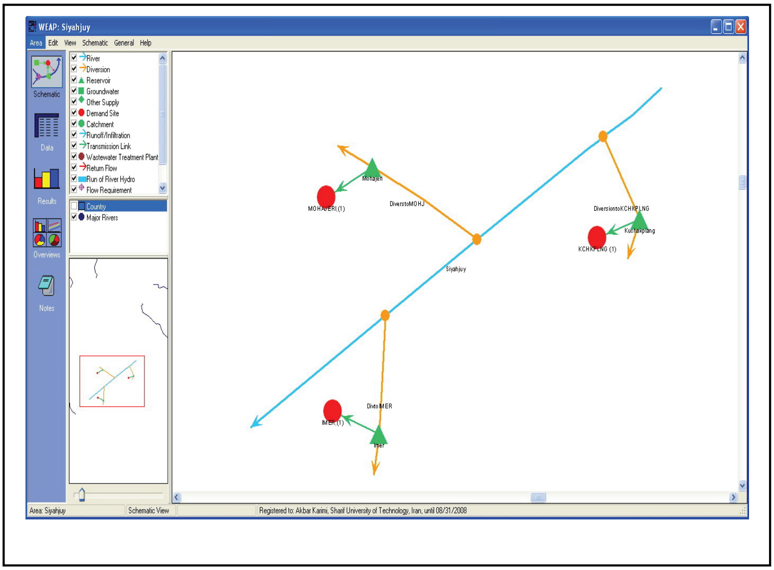

Fig 4. Siyahjuy Pond-River System Model Schematic in WEAP

Table 4. Ponds specifications and operation conditions

Pond Name	Normal Vol. (MCM)	Initial Storage (MCM)	Min. Operation Vol. (MCM)
Kuchakplang	0.75	0	0
Sh. Mohjaeri	0.7	0	0
Imer	0.425	0	0

Results of this hydro-system long-term analysis by WEAP for a 10-year period are shown in Figures 5, 6 and 7. Since scenarios are for normal and dry years, they show the expected level and lower limit of the hydro-system activities. Analysis for normal condition is considered as short-term, since the flow regime does not change. Analysis for dry conditions is considered the worse side of long-term period when river flow reduces up to 25% of normal year values (still drier conditions are ignored). WEAP analysis shows that the system can be operated in a manner that on 25% reduction in river flow, just 2 months in a year agriculture water demands are not met (16.7% of the times, compared to normal condition). Table 5 gives the agricultural water demand based on 10-year mean values in different conditions. Figure 5 shows ponds full during November to January and empty from May to September.

Though ponds are filled during November to January (Fig. 5), in other months diversion is necessary to meet water demand through the ponds. Filled ponds have water in reserve for low flow and high demand months from May to September. As could be seen, in high demand months (Fig. 6) the ponds are emptying (Fig. 4), while diversion to ponds is also increased (Fig. 5) for normal year scenario. Table 6 shows that in normal conditions just 60%, 70% and 75% of cultivated area in Kuchakplang, Sh. Mohajeri and Imer regions can be irrigated fully in normal years (this corresponds to 100% in Table 5). Besides, in dry years, just 50%, 60% and 75% of the target cultivated land area can be irrigated.

Table 6 shows the details of cultivated land area that can be fully irrigated, with net income and production per crop for farmers. WEAP model analysis reveals this important point that the system can be managed and operated in a way, that by 25% reduction in river flow as the main source of supply, just 16.6% and 14.3% reduction occur in socio-economic indices.

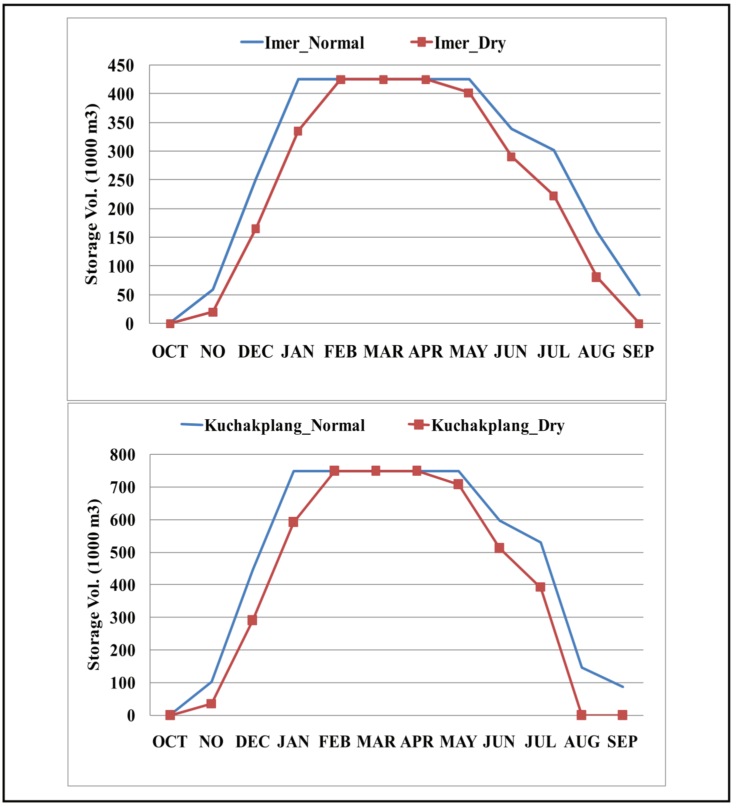

Fig. 5. Ponds monthly storage based on 10 year mean values

Table 5. Agricultural water demand coverage based on 10-year mean values in different conditions

	Months	Imer	Kuchakplang	Sh. Mohajeri
Demand Coverage in Normal Year	OCT	100	100	100
	NO	100	100	100
	DEC	100	100	100
	JAN	100	100	100
	FEB	100	100	100
	MAR	100	100	100
	APR	100	100	100
	MAY	100	100	100
	JUN	100	100	100
	JUL	100	100	100
	AUG	100	100	100
	SEP	100	100	100

	Months	Imer	Kuchakplang	Sh. Mohajeri
Demand Coverage in Dry Year	OCT	47.1	47.1	47.1
	NO	100	100	100
	DEC	100	100	100
	JAN	100	100	100
	FEB	100	100	100
	MAR	100	100	100
	APR	100	100	100
	MAY	100	100	100
	JUN	100	100	100
	JUL	100	100	100
	AUG	100	93.3	100
	SEP	67.5	67.5	67.5

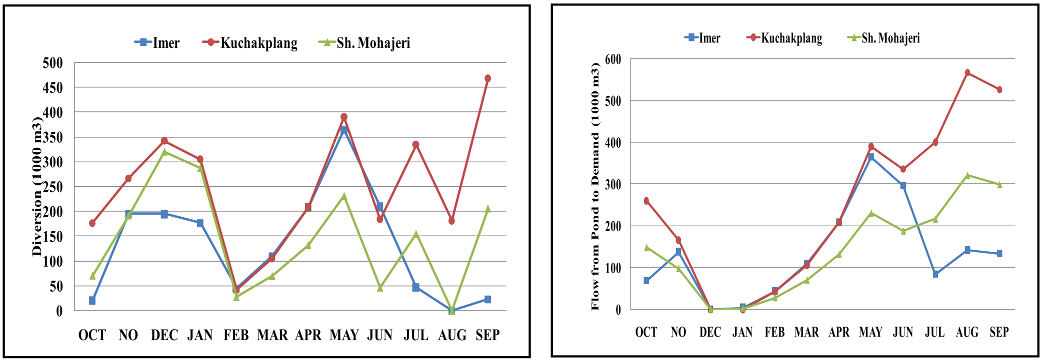

Fig. 6. Diversion from Siyahjuy to Ponds

Table 6. Land area irrigated, net income and production in different conditions

Region	Wheat	Barley	Cotton	Soya
	Irrigated Land Area in Normal Year (ha)			
Kuchakplang	150	0	0	150
Sh. Mohjaeri	84	7	14	77
Imer	132	11	23	25
	Net Income (Rials)			
Kuchakplang	1,186,117,500	0	0	440,787,000
Sh. Mohjaeri	525,625,800	22,597,820	38,486,560	226,270,660
Imer	1,394,241,047	73,442,925	61,853,400	118,517,355
	Production (kg)			
Kuchakplang	480000	0	0	300000
Sh. Mohjaeri	277200	23100	75600	284900
Imer	528750	28125	45000	61875

Region	Wheat	Barley	Cotton	Soya
	Irrigated Land Area in Dry Year (ha)			
Kuchakplang	125	0	0	125
Sh. Mohjaeri	72	6	12	66
Imer	132	11	23	25
	Net Income (Rials)			
Kuchakplang	988,431,250	0	0	367,322,500
Sh. Mohjaeri	450,536,400	19,369,560	32,988,480	193,946,280
Imer	1,394,241,047	73,442,925	61,853,400	118,517,355
	Production (kg)			
Kuchakplang	400000	0	0	250000
Sh. Mohjaeri	237600	19800	64800	244200
Imer	528750	28125	45000	61875

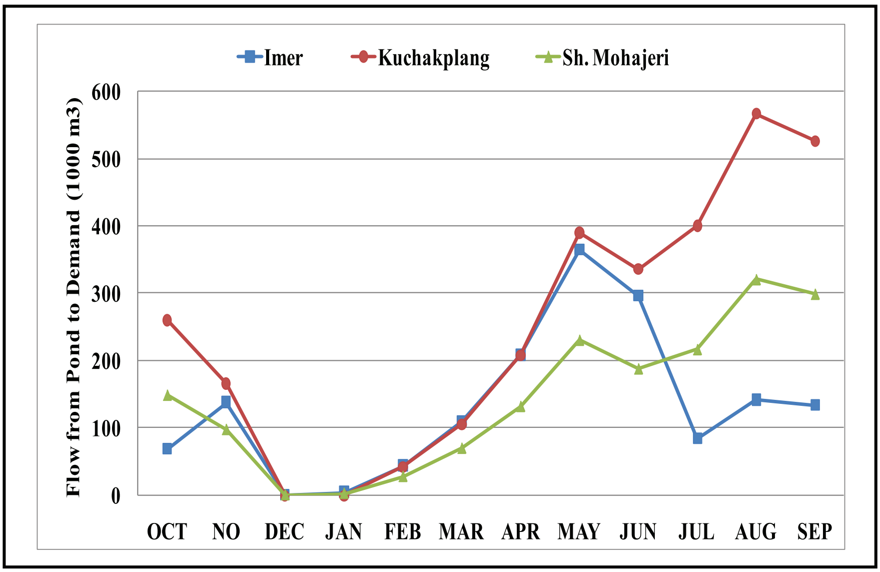

Fig. 7. Pond release for agricultural demand

Table 7. Socio-economic indices based on 10 year mean value

Region	Normal Year	Dry Year	% of Variation
	Land area (ha)		
Kuchakplang	150	125	16.67%
Sh. Mohjaeri	91	78	14.29%
Imer	132	132	0.00%
	Net Income ($)		
Kuchakplang	162690	135575	16.67%
Sh. Mohjaeri	81298	69684	14.29%
Imer	164805	164805	0.00%
	Production (Ton)		
Kuchakplang	780	650	16.67%
Sh. Mohjaeri	661	566	14.29%
Imer	664	664	0.00%

Table 7 shows the total socio-economic indices value in normal and dry conditions for the Siyahjuy river-pond system operation. In fact if diversion and withdrawal recommendations by WEAP model be adopted, on average 10% of impacts of dry conditions can be avoided in long-term operation of the ponds. However, analyses show that in dry conditions at least, on average, 15% reduction in socio-economic indices will occur. In Table 8, improvement in socio-economic conditions by construction of ponds are shown in terms of socio-economic indices and efficiencies in $/ha and Ton/ha.

Table 8. Comparison of socio-economic indices in current and improved conditions

		Net Income		Production		Efficiency Measure			
		Current State	Improved State	Current State	Improved State	Current State	Improved State	Current State	Improved State
Region	Land Area*	Net Income	Net Income	Production	Production	$ per ha	$ per ha	Ton per ha	Ton per ha
Kuchakplang	250	200058	243346	665	1010	800	973	2.7	4.0
Sh. Mohjaeri	120	85132	90974	369	702.8	709	758	3.1	5.9
Imer	155	168924	187500	430	709.75	1090	1210	2.8	4.6

* Land area here is the total of rain-fed and irrigated areas. Consequently other parameters are summations for rain-fed and irrigated areas for current and improved agriculture system under normal condition.

4. CONCLUSIONS

In this research short and long term assessment of agriculture stakeholders' socio-economic indices by improving rain-fed agriculture to irrigated agriculture is done based on a 10 year analysis period. Improvement of agriculture system is achieved by off-river ponds to be constructed around Siyahjuy river in Gorganrud waterbasin in Iran. In fact the capability of these ponds on improvement of farmers socio-economic conditions is the main objective of this study. The river-pond system is modeled in WEAP and analyzed by considering the most preference for water supply to agriculture demands. Two scenarios are considered in analyses; normal and dry year conditions. Normal year scenario represents a short term view, since the there is no change in river flow values for the next 10 years. However, dry year conditions, which is considered to be prevailing for 10 years, is a representative of long term variation in river flow.

Analyses show that ponds have positive influences on socio-economic indices and agriculture efficiencies in terms of Net income and production. This improvement in terms of Net income per cultivated area reaches 21% in Kuchakplang region. Improvement in terms of production per cultivated area reaches to 90% in Sh. Mohajeri region. Besides, in dry years that river flow decreases up to 25%, pond-river system can be managed in a manner to limit the reduction in net income and production utmost 15%.

REFERENCES

ACRES, (2004), ACRES Reservoir Simulation Package User's Manual, ACRES Co. Ltd., Canada.

Cai, X., McKinney, D.C. and Lasdon, L.S. (2003), Integrated Hydrologic- Agronomic- Economic Model for River Basin Management, ASCE Journal of Water Resources Planning and Management, Vol. 129, No. 1.

Close, A., Haneman, W.M., Labadie, J.W., Loucks, D.P., Lund, J.R., McKinney D.C. and Stedinger, J.R. (2003), "A strategic review of CALSIM II and its use for water planning, management and operation in central California", California Bay Delta Authority Science Program, Association of Bay Governments, Oakland, California.

DHI, (2003), MIKE BASIN 2003, DHI Water & Environment, DK-2970 Horsholm, Denmark, http://www.dhisoftware.com/mikebasin.

Dudu H. and Chumi S. (2008), Economics of Irrigation Water Management: A Literature Survey with Focus on Partial and General Equilibrium Models, World Bank, Development Research Group, Sustainable Rural and Urban Development Team, Policy Research Working Paper 4556, March.

Diaz G.E., Brown T.C. and Sveinsson O. (2005), Aquarius: A modeling system for river basin water allocation, General Technical Report, RM-GTR-299, Fort Collins, U.S. Department of Agriculture

Krol, M., Jaeger, A., Bronstert, A. and Guntner, A. (2006), Integrated modeling of climate, water, soil, agricultural and socio-economic processes: A general introduction of the methodology and some exemplary results from the semi-arid north-east of Brazil, Journal of Hydrology, 328, 417-431.

Labadie J.W., Baldo M.L. and Larson R., (2000), MODSIM: Decision Support System for River Basin Management Documentation and User Manual, Department of Civil Engineering, Colorado State University, U.S Department of the Interior, Bureau of Reclamation, Pacific Northwest Region.

Roe, T Dinar, A Tsur, Y. and Diano, X. (2005), FEEDBACK LINKS BETWEEN ECONOMY-WIDE AND FARM-LEVEL POLICIES: Application to Irrigation Water Management in Morocco, World Bank Policy Research Working Paper 3550.

Stockholm Environment Institute, (2005), WEAP21: Water Evaluation and Planning System, 11 Arlington Street, Boston, MA 02116, USA, http://www.weap21.org.