Equity for an integrated water resources management of irrigation systems in the Mediterranean: the case study of South Lebanon

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Abstract

To achieve sustainable management in irrigation projects, equity represents the major social challenge and the primary objective at all water management levels. However, this topic has drawn limited attention from the scientific community, and the equity concept remains ambiguous and often undefined. This paper deals with the equity among users of an irrigation system in a semi-arid Mediterranean climate. A non-linear, stochastic, static mathematical programming model has been used to maximise farmers' utility. It takes into consideration several conditions and is subject to a specific set of constraints. Two scenarios have been selected, both of them of the on-demand water distribution: an area-based water allocation system associated with a binomial water tariff (SC1); and a farm-based water allocation system (SC2). Based on the field visits and the understanding of the case study, SC2 is believed to increase equity among farmers. Results calculated farmers' income in both scenarios and showed that the economic cost of a socially equitable policy in the study area could be around 5% decrease in farmers' income. Such a policy could have effects on the total volume of irrigation water between 2% and 4% less in SC2 than in SC1, while the change in the irrigated surface is insignificant. The implementation of such scenarios would improve the governance of water policies in Lebanon generating a sustainable development for the agricultural sector.

Keywords: *irrigation project, equity among users, Litani River System, Lebanon, Stochastic Mathematical Programming, Non-linear model.*

Résumé

Dans le cadre d'une gestion durable des projets d'irrigation, l'équité représente le principal défi social et l'objectif prioritaire à tous les niveaux de gestion de l'eau. Toutefois, cette question n'a pas reçu l'attention nécessaire de la part de la communauté scientifique et de ce fait, le concept d'équité s'avère être encore ambigu et souvent flou. Dans cet article, nous allons aborder le thème de l'équité entre les usagers d'un système d'irrigation en milieu méditerranéen semi-aride. Un modèle de programmation mathématique non–linéaire, stochastique et statique a été utilisé afin de maximiser l'utilité des exploitants, en intégrant de nombreuses conditions et des contraintes spécifiques. Deux scénarios ont été retenus du côté de la distribution de l'eau à la demande : un système d'allocation de l'eau à l'échelle territoriale et associé à un tarif binomial (SC1) et un système d'allocation de l'eau à la parcelle (SC2). Sur la base des observations sur le terrain et de l'étude de cas, le système SC2 semble assurer une plus grande équité entre les exploitants. Les résultats ont pris en compte le revenu des exploitants dans les deux scenarios et ont montré que le coût économique d'une politique socialement équitable dans la zone cible pourrait correspondre à une réduction d'environ 5% du revenu des exploitants. Une telle politique pourrait avoir des effets de réduction du volume total de l'eau d'irrigation de 2% à 4% pour le système SC2 par rapport au système SC1, alors qu'il n'y aurait pas de différence significative en termes de surface irriguée. La réalisation des scenarios évoqués permettrait d'améliorer la gouvernance des politiques de l'eau au Liban, favorisant ainsi un développement durable du secteur agricole.

Mots-clés: Projet d'irrigation, équité entre les usagers, système du canal du Litani, Liban, programmation mathématique stochastique, modèle non-linéaire.

1. Introduction

Irrigation is generally considered an effective way of increasing agricultural production, reducing poverty in developing countries and, ultimately, of meeting the international Millennium Development Goals (MDGs). Therefore, many governments and donors are investing in new irrigation projects or in the rehabilitation of the existing ones (Kikuchi *et al*., 2003; Inocencio *et al*., 2007). Large-scale investment and research have been involved in understanding and improving performance and efficiency in the very complex matter of irrigation systems (Heermann *et al*., 1990; Smith, 1990; Inocencio *et al*., 2007). However, the resulting technical and engineering improvements do not seem to be enough to achieve sustainable management without considering socio-economic issues (Miller, 2004; Sghaier *et al*., 2006; Hamdy, 2008; Montana *et al*., 2009) in a particular way an equitable social dimension basically linked to the principles of Integrated Water Resources Management (IWRM). Hence, water allocation systems and arrangements are of great importance in determining the equitable use of water resources for different users and uses.

Although it represents the major objective on all water management levels and plays an important role in conflict resolution and prevention (UN, 1992), equity is one of the topics that has acquired limited currency when compared to other themes like poverty (Montana *et al*., 2009). The equity concept seems to include a lot of ambiguity and is often undefined as Wegerich (2007) argues. For instance, Phansalkar (2006) defines several equity strands: social, spatial, gender and intergenerational; while Moyo (2005) and Wilder and Lankao (2006) focus solely on the intergenerational aspect. Furthermore, the equity issue could be considered across economic sectors (agriculture vs. industry), among users within the same sector (e.g. farmers vs. peasants), among countries or regions which share a common source, or among urban and rural users, etc. (Cremers *et al*., 2005; Gaur *et al*., 2008). However, scientists within the professional water debate could not agree on a unique and exact definition of equity in the water management

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context or on how it could be implemented in practice (Wegerich, 2007).

The focus of this paper will be on equity among users of the irrigation system designed and studied within the hydro-agricultural project in the rural Marjeyoun area in south Lebanon. The case study covers a pilot area within a larger project developed to irrigate around 35,000 ha from the Litani River System (LRS), managed by the Litani River Authority (LRA). The equity notion in this case was perceived as the opportunity for all farmers to have equally irrigable land, regardless of farm size and the paper will specifically calculate, in terms of income, the effect of the irrigated project on the study area with and without the implementation of an equitable distribution scheme among farmers.

The adopted methodology is based on the mathematical programming of a farm model widely applied in economic-agricultural analysis and in irrigated agriculture analysis (Gómez-Limón and Berbel, 2000; Blanco Fonseca *et al*., 2003; Borresh *et al*., 2003; Janssen and Van Ittersum, 2007; Saraiva and Pinheiro, 2007; Scardigno and Viaggi, 2007; Marchand *et al*., 2008; Chemak and Dhehibi, 2010; El Chami *et al*., 2011a, 2011b). The farm model is a non-linear optimisation model encoded in GAMS (General Algebraic Modelling System), designed and run to evaluate the trade-offs between economic and social aspects occurring in irrigated agricultural ecosystems.

Finally, introducing the equity concept in the study at this level may be an incentive for future studies to include the social perspectives that could reduce conflicts between farmers. This is especially so on issues related to irrigation, particularly in this specific Mediterranean zone, classified as being between subtropical and arid, where water scarcity has always been a limiting factor (Wolf, 1996).

2. Materials and methods

Lebanon is located on the east side of the Mediterranean Sea which characterises its climate. More than 70% of the average yearly precipitation of the country is lost by runoff leaving only around 2,000 MCM of exploitable water (El Fadel, 2002) to be divided between different sectors of the national economy.

The present Lebanese policies on the water sector have many shortcomings and deficiencies, which are affecting the national agricultural system 50% of which relies on irrigation for high value crop production (MoA/FAO, 2012), and threatening *i)* the agro-diversity in the region (El Moujabber *et al*., 2006), *ii)* the sustainability of the rural societies, and *iii)* the governance of the national waters (El Chami and Karaa, 2012).

The study area groups five local villages (Blat, Ebl El Saki, Jdeidet Marjeyoun, Dibbine and Borghoz) in Marjeyoun district (Caza), part of the Nabatyeh governorate (Mohafazaat), in southern Lebanon. It has a total area of 3,090 ha, with a total population of 45,000.

The Litani River forms the administrative boundary to the west of Berghoz and Blat districts for a distance of 8.5 km. The minimum elevation of the pilot area is 340 m and the maximum elevation is 800 m.

According to the land use/cover report prepared by the United Nations Development Programme (UNDP), 37% of the total study area is occupied by agricultural land and a further 42% is covered by grassland. In the project area, agriculture is a prevailing economic activity. The three most cultivated crops in the total cultivated area are field crops, occupying around 62.6%, followed by olives at 36.8% and 0.5% fruit trees.

The study carried out examining the situation of agriculture in the study area (Karaa *et al*.,2011), showed that farms are of two types: full-time farming representing about 62.79% of the total area of farms, and part-time farming corresponding to 37.21% of the total area. Farm size varies for each typology (Table 1) with a difference of more than 30% in their Useful Agricultural Area (UAA). The respective values are 58.18% of the total area of part-time farms and 87.60% of the total area of the full-time farms. Furthermore, the proportion of irrigated land in part-time farming (15.21%) is higher than that of full-time farming (6.45%).

Table 1 - *Farm size with respect to the typologies.*

Farm size	<5 ha	5 – 10 ha	>10 ha
Full-time farming	21.62%	14.87%	12.16%
Part-time farming	43.24%	6.76%	1.35%

2.1. Data collection

Weather data has been collected using the available historical series as well as the Food and Agriculture Organization (FAO) libraries for Marjeyoun area. The historical weather data measured at the Marjeyoun meteorological station covers a period of 27 years. Additionally, the average, monthly Marjeyoun station weather data available in the FAO database were collected. These data include: precipitation, minimum and maximum air temperature, relative humidity, wind speed, sunshine hours, and incoming solar radiation.

Reference evapotranspiration, crop water requirements (crop evapotranspiration) and irrigation requirements have been estimated using CROPWAT, a software developed by the FAO (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979; Smith, 1992; Allen *et al*., 1998). Climatic conditions and soil properties define the set of all the crops that can be cultivated in the area, while technical and agronomic considerations allow the definition of possible combinations among crops (C), irrigation techniques (T), and irrigation methods (I). Hence, for a given crop, technique or method, ‘1’ stands for feasible and ‘0’ for not feasible.

Two irrigation methods (drip and sprinkler) with different field application efficiencies and four irrigation techniques (dry, complementary, partial and full irrigation) were considered. Here, full irrigation is relative to the full satisfaction of the crop water requirements; partial irrigation is relative to the satisfaction of 75-85% of the total crop water requirements; and complementary irrigation is relative to the satisfaction of 45-55% of the total crop water requirements. For each crop, the gross irrigation requirements were estimated by dividing the net irrigation requirements by the field efficiency of each method of irrigation used (sprinkler 85% and drip 90%).

In addition, several different crops sown throughout the year according to their planting and harvesting dates and yields per crop and per irrigation technique were estimated and included in the model. Prices and costs of the different crops were also collected and integrated in the model.

Variable costs correspond to the summation of specific crop expenses with costs for temporary labour and mechanisation. Specific crop expenses include the costs for seeds, fertilizers and pesticides, hire charges and so forth (fuel, insurance, electricity). Labour costs exclusively include the costs for waged labour and not implicit costs relative to the family work.

The prices used were collected from records of the wholesale local market, and were integrated to generate the "endogenous prices" of different crops. To elaborate, the equilibrium price of a good in a supply and demand model is endogenous because it is set by a producer in response to consumer demand. Therefore, an "endogenous prices" formula, taking into consideration the elasticity of crop price for any change in the demand, has been considered.

The cost of irrigation water is not included in the variable costs as it is an endogenous variable. It consists of three different components: *i*) "the cost of the water" given by the volume of water used multiplied by the price of water per cubic meter; *ii*) the depreciation of irrigation equipment, and *iii*) the labour required for operating the irrigation systems.

2.2. The socio-economic model

A constrained optimisation model, written in GAMS (General Algebraic Modelling System) language and integrating climatic and pedo-agronomic data with socio-economic variables in an objective function maximizing farmer's income, was developed. It aims to identify the optimal cropping pattern of the study area and to calculate the relative water demand in the peak period upon which the irrigation network will be dimensioned.

The model is a non-linear, stochastic, single-year, static, mathematical programming model maximizing farmers' utility taking into consideration several conditions, such as climatic conditions and soil properties, irrigation requirements and management techniques, monthly and total water availability/supply, prices of the products, agricultural input cost and water tariffs.

Agricultural farms in the five villages of the study area do not show any significant variability in their structural specifications – average size, capital and labour availability – or in their socio-economic features. Further, both climatic conditions and soil properties are quite homogenous over all of the study area. Therefore, the optimisation model used is a block aggregated model that represents the whole area, where each block is referred to as a macro farm representing the group of farms of the same type present in the area (Dono *et al.*, 2008).

The model includes a macro level component that corresponds to all of the farms located in the area that will be served by the new irrigation water distribution system, and a micro level component that corresponds to the blocks of the different types of farms present in the area (indicated by index f), i.e. part-time and full-time farms.

The adopted approach allows the analysis of the macro area highlighting though the differences and at the micro level (the farm level). The analysis of the agricultural system is performed by pursuing total economic efficiency, which leads to identification of the optimal solution for the system as a whole.

The model maximizes the total agricultural income of the area which is equal to the summation of the net farm income Z_f of the considered types of farm (Equation 1):

$$MaxU = \sum_f Z_f \quad (1)$$

The farm model represents the micro component of the territorial model. Each model can be expressed in a compact analytical form by an income function and by a set of constraints.

Where:

f = 1,…, F farm type

$$Z_f = \sum_{c,t,i} (m_{c,t,i,f} \times X_{c,t,i,f}) \; \forall f \quad (2)$$

$$\sum_h a_{f MaxU = \sum_f [\sum_{c,t,i} (m_{c,t,i,f} \times X_{c,t,i,f})]_{c,k}} \leq b_{f,k} \; \forall f \quad (3)$$

$$\boldsymbol{X_{f,h} \leq 0} \quad \mathbf{(4)}$$

h = 1,…, C crops

k = 1,…, K production factors

Net farm income (Equation 5) is defined as the difference between the gross margins and fixed and variable costs, except for the cost of the irrigation water (Blanco Fonseca, 2007). It is given by the following equation:

$$Z_f = \sum_{c,t,i} [(Y_{c,t} \times \mathrm{Pr.end_c} - \mathrm{VC_c}) \times \mathrm{X_{c,t,i,f}} \times \mathrm{FTI_{c,t,i}}] - \sum_{c,t,m,ii} [GIR_{c,t,m,ii} \times \mathrm{X_{c,t,i,f}} \times \mathrm{FTI_{c,t,i}}]$$
$$- \sum_m [ext.wat_{m,f} \times mwt] - fwt \times tirriland_f - \sum_{c,t,i} [X_{c,t,i,f} \times FTI_{c,t,i} \times Irricost_{c,i}]$$
$$- \sum_m [(ext.wat_{m,f} \times pr.ext.wat) - ext.lab_f \times lab.tar] \quad (5)$$

Where:

$Y_{c,t}$: *Crop Yield*
$Pr.end_c$: *Endogenous Price*
VC_c: *Variable Costs*
$FTI_{c,t,i}$: *Feasible Techniques (technical set)*
$GIR_{c,t,m,ii}$: *Gross Irrigation Requirements*
$X_{c,t,ii,f}$: *Surface of Crop Activity*
mwt: *Volumetric Water Tariff*
fwt: *Flat Water Tariff*
$tirriland_f$: *Total Irrigable Land*
$irricost_{ii}$: *Irrigation Costs*
$ext.lab_f$: *External Labor Requirement*
$lab.tar$: *Labor Tariff by Hour*
$ext.wat_{f,m}$: *External Labor Requirement*
$pr.ext.wat$: *Price of External Water*

The net farm income function (Equation 2) includes the economic data (cost and price of crops) relative to each of the possible production processes as coefficients – vector m –, and the corresponding levels – vector X – representing the surface for each on-farm activity or production process as unknown variables.

The Z_f variable represents the net farm income, equal to the summation of the incomes resulting from different farm activities. The value of production refers to the product sold for final consumption or processing. Variable costs are given by the specific cropping expenses. The expenses for water are instead kept apart so analyses considering variation in water cost can be undertaken.

Two different water sources were considered; in addition to the water supplied by the LRA through the Canal 800 project, the possibility of self-supply through wells was also taken into consideration.

A binomial water tariff consisting of a fixed fee per hectare of irrigable land and a volumetric fee depending on consumption was considered for the public water source. A main condition for applying such a water pricing scheme, is to equip the distribution network with measurement devices - a condition easy to fulfil in pressurised systems. The cost for the private water follows a similar structure, with the cost of extraction rising with quantity due to higher pumping costs for the progressive lowering of the water table level.

The obtained income (Z_f) is the remuneration of factors of production to the family, i.e. land property, labour and capital.

At farm level, income is quantified in view of the quantity constraints (Equation 3) imposing two main conditions: the total consumption of each of the resources (matrix A) is less or equal to the total availability of factors i.e. total land, irrigable land, and labour (vector b); the non-negativity of the activity levels of the variables (Equation 4).

A further agronomic constraint is also considered in order to ensure that crop rotations incorporate good practice rules for preserving soil fertility. Such constraints ensure that certain crops or groups of crops do not exceed particular levels and are not repeated on the same plots until an adequate number of years has elapsed (ex. biannual rotation imposed among tomatoes and cereals).

Finally, on the basis of a statistical analysis of the study area's meteorological data, four water availability scenarios –average, medium dry and very dry –have been identified and their probability of occurrence has been estimated. Availability of water represents the stochastic feature of model. Risk associated with unreliable water supply is taken into account in the constraints part of the model and considered as a technical risk (Mejías *et al*., 2003) and a probabilistic availability of irrigation water was considered as shown in Table 2.

The Constant Relative Risk Aversion coefficient was also used for calibration using the mean standard deviation approach. The model was run for different values of the coefficient in a range between 0 and 1.65 and the simulated results compared with the observed data. To validate the model, the percentage absolute deviation (PAD) parameter between observed and predicted values (Equation 6) was used.

Table 2 - *On-farm annual irrigation water availability.*

	Probability (%)	Volume (m^3 ha^{-1})
Average	50	7,000
Medium dry	30	6,300
Very dry	20	4,900

$$PAD = \sum_{i=i}^{n} |X_i^O - X_i^P| \div \sum_{i=i}^{n} X_i^O \quad (6)$$

Where X_i^0 is the observed value of the variable and X_i^p the predicted value.

The value of risk aversion that gives the lower PAD value was used for scenario testing (Janssen *et al*., 2010).

2.3. Simulated scenarios

Alongside the actual situation of the study area that was run with the actual irrigated area, several scenarios were simulated in order to take into account different water pricing schemes, two different water distribution regimes – on demand and rotation (restricted demand) – and two different water allocation rules – area-based and farm-based. Combining these three factors, two scenarios have been selected:

- SC1: An area-based water allocation system and an on-demand water distribution are associated with a binomial water tariff (flat + volumetric tariffs) with a flat tariff of 10 \$ ha^{-1} and three different rate levels of volumetric tariff equal to 0.05 \$ m^{-3} (SC1a), 0.10 \$ m^{-3} (SC1b) and 0.15 \$ m^{-3} (SC1c), respectively.
- SC2: A farm-based water allocation system and an on-demand water distribution are associated with a flat water tariff equal to 50 \$ ha^{-1} and three different rate levels of volumetric tariff equal to 0.05 \$ m^{-3} (SC2a), 0.10 \$ m^{-3} (SC2b) and 0.15 \$ m^{-3} (SC2c), respectively. This scenario sets the irrigable land as equal for all farms regardless of their size. It has been set and run to calculate farmers' income generation as it is thought that it increases equity among them.

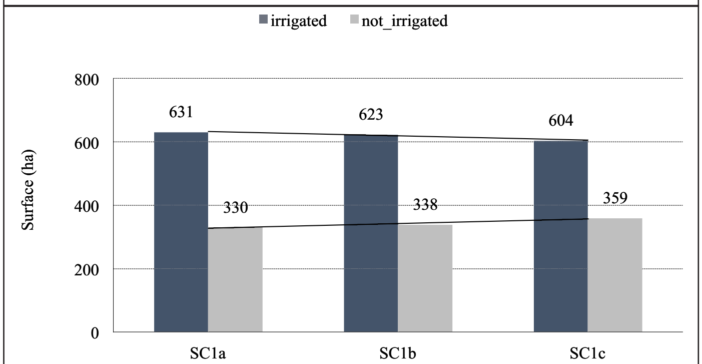
3. Results and discussion

All of the following factors have been considered in the simulated scenarios. Results presented by the scenario will include: total cultivated and irrigated land, cropping pattern, farmers' income, water demand – total per crop and per period – and cost of the irrigation water for the farmers and receipt of the Water Agency.

3.1. Scenario SC1

The total cultivated land is equal to 960.3, 961.3 and 962.4 ha in the three analysed scenarios (a, b and c) with a cropping intensity index equal to 1.29. The changes in irrigated land are not significant: 630.7, 622.9 and 603.7 ha in SC1a, SC1b and SC1c, respectively. Consequently the rainfed agriculture increases with the increase of the volumetric water tariff: 329.6 ha in SC1a, 338.3 ha in SC1b and 358.7 ha in SC1c (Figure 1).

Figure 1 - *Changes in irrigated vs. non-irrigated area in scenario (SC1).*



Water tariff also affects farmers' decisions about the cropping pattern: the main consequence of the increase in the price of water is the increase of the rainfed cultivation of cereals and forages only partly compensated by the increase in irrigated vegetables.

The optimal cropping pattern is very stable notwithstanding the increase in the volumetric water price:

- Forages cover 16% of the total land and are cultivated with an annual rotation scheme;
- Wheat and vegetables – such as tomato, cucumber, cauliflower and courgette, etc. – are cultivated in a bi-annual rotation.
- Among permanent crops there are: olives, apples, grapes and walnuts.

The total irrigation water demand for the whole area (Table 3) is equal to 3.8, 3.8 and 3.7 Mm^3 for SC1a, SC1b and SC1c, respectively which corresponds to average water consumption per irrigated hectare equal to 6,051.5, 6,042.2 and 6,174.0 m^3.

The most water demanding crops are walnuts, tomatoes, apples and grapes.

Table 3 - *Total irrigation water demand by crop in SC1.*

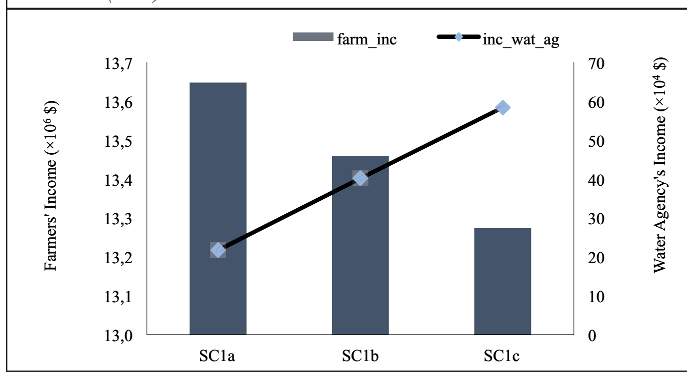
Water demand (m^3)			
CROPS	**SC1a**	**SC1b**	**SC1c**
Wheat	30,578	-	-
Maize_spring	41,200	27,637	-
Potatoes_spring	16,102	16,736	17,532
Tomatoes_spring	783,925	785,237	786,016
Cucumber_aut	94,770	97,558	100,970
Courgette	362,274	363,336	364,177
Cabbage	18,703	18,576	18,328
Cauliflower	71,193	71,644	72,197
Grape	711,813	714,350	716,892
Apple	579,865	574,077	567,366
Walnut	1,106,418	1,094,970	1,083,531
Total	**3,816,841**	**3,764,123**	**3,727,010**

When irrigated hectares per month are considered, the water consumed is per hectare per month. The maximum demand for irrigation water is in July when about 1,808 m^3 are consumed for each irrigated hectare. Water demand in November is very low and not essential for agricultural activity; however, it could be covered by a private source (well) that integrates LRA supply.

Agricultural income for all of the area achieves 18,347.4 $ per hectare per year in scenario SC1a and, as a consequence of water price increase, it decreases by 1.4 and 2.7% in scenarios SC1b and SC1c respectively, with respect to SC1.

Concerning the receipt of the Water Agency, it amounts to a total of 195,465 $ in SC1a and rapidly increases in SC1b to 375.3 $ and in SC1c up to 557.3 $ (Figure 2).

Figure 2 - *Changes in farmers' income and water agency receipt for scenario (SC1).*

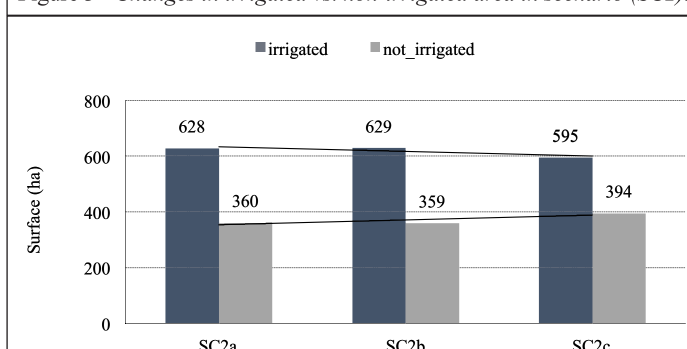


3.2. Scenario SC2

This scenario sets the irrigable land as equal for all farms regardless of their size. It has been studied as it is believed to increase equity among farmers.

The impacts of such a scenario on the study area are on irrigated land which increases by about 9% when compared to SC1 (Figure 3).

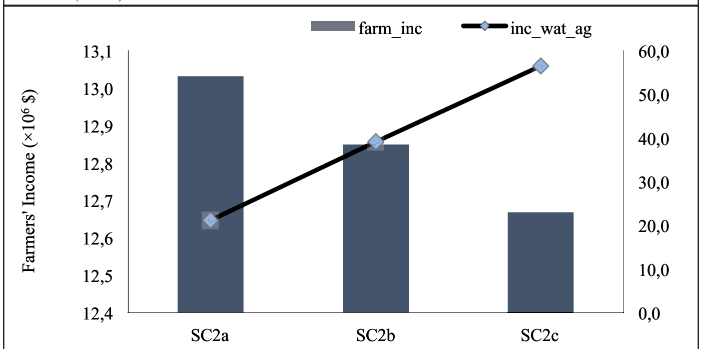
Figure 3 - *Changes in irrigated vs. non-irrigated area in scenario (SC2).*



Cropping pattern also varies generating a change in water demand that will decrease to 3.7 Mm^3, 3.6 Mm^3 and 3.6 Mm^3 respectively in SC2a, SC2b and SC2c. The monthly distribution of water volume decreased between 2% and 4% in comparison to the simulations of scenario SC1.

Subsequently, income of farmers slightly decreases while water agency receipt increases as a result of the increase in the fixed tariff (Figure 4).

Figure 4 - *Changes in farmers' income and the agency receipt in scenario (SC2).*



The main results of scenarios SC1 and SC2 have been summarised in a following table that compares differences between factors in scenarios that optimise the economic effects of irrigation in the study area, applying two different distribution schemes among users with and without implementing the equitable concept (Table 4).

Table 4 - *Results of the simulated scenarios.*

Scenario	Cropping pattern per cc; cf; cr_spring; cr_aut; cp*	Irrigated Surface	Total Irrigation Water Demand	Total Irrigation Water Demand	Water Demand in the Peak month	Farmers' Income	Farmers' Income	Water Agency Receipt
Unit	*% on total cultivated area*	*(ha)*	*(Mm^3)*	*(m^3 ha^{-1})*	*(m^3 ha^{-1})*	*(1000 \$ yr^{-1})*	*(\$ ha^{-1})*	*(\$ yr^{-1})*
SC1a	12; 16; 12; 17; 43	631	3.82	6,051.5	1,691.8	13,668	18,347	195,465
SC2a	15; 15; 15; 19; 36	628	3.70	5,896.2	1,670.7	13,031	17,492	210,831
SC1b	12; 16; 12; 17; 43	623	3.76	6,042.2	1,687.6	13,480	18,094	380,466
SC2b	15; 15; 15; 20; 36	629	3.65	5,799.3	1,637.7	12,848	17,246	389,915
SC1c	12; 15; 12; 18; 43	604	3.73	6,174.0	1,682.6	13,293	17,843	562,485
SC2c	15; 15; 15; 20; 36	595	3.59	6,041.8	1,634.2	12,668	17,004	563,743

gement option for the LRA and the WUA. The policy implications for the LRA would be the regulation of the irrigation water sector and the improvement of the governance of water policies in Lebanon generating for the WUA a sustainable development for the agricultural sector.

Flat water tariffs and volumetric charges can be shaped in order to take into account both capital and running costs of the network and the management of water demand in dry years. However, the rigidity of water demand response to volumetric water pricing could limit the Water Agency control over the total demand for irrigation water especially in drought periods when the agency has to limit the use of water.

Finally, the cost of a farm-based water allocation scheme can be assessed by comparing farmers' income and Water Agency receipt under SC2 and SC1. Although the social policy simulated in SC2 has an economic cost, this does not exceed a 5% decrease in the income.

To conclude, these results are primordial for the local policy makers in any irrigation system in implementation, to design and implement future irrigation systems in the area on equity basis, to improve farmers' social conditions and prevent future conflicts.

4. Conclusions

The main objective of this paper was to evaluate the economic effect at the farm level of the implementation of an irrigation system in Marjeyoun area considering an equitable distribution scheme among users. A socio-economic model representing the farming system of the area was developed, calibrated and run to optimise farmers' income.

Results showed that irrigation water supplied through the collective irrigation network will increase the area occupied with high value crops especially in the summer season. Compared with the current situation, the collective irrigation network will improve the income of farmers by around 235% (SC1). The income generated would be less if stakeholders decide to apply an equitable distribution scheme (SC2) that delivers irrigation water to all users regardless of the size of their farms.

From another viewpoint, the simulated binomial water tariff scheme demonstrated itself to be an appropriate management option for the LRA and the WUA.

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