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Abstract

This study addresses the problem of water-use efficiency in agriculture via the optimization of water use for and the external trade patterns of agricultural products in Iran. Towards this end, some major issues on agricultural water use and trade patterns are first discussed. Then, the underlying concepts and principles of agricultural water use and trade patterns are presented. Finally, a comparative analysis of virtual water trade among MENA countries is conducted. The findings indicate that cropping patterns and external trade of agricultural products in Iran are hardly consistent with the notion of comparative advantage and the country's water resources. While some MENA countries are consciously adopting cropping and agricultural trade policies for enhancing water-use efficiency and increasing the economic value of irrigation water, cropping and agricultural trade patterns in Iran have not aimed at enhancing water-use efficiency in agriculture.

JEL Classification: Q 25, C61, F18

Keywords: Water-use efficiency, Iran, Virtual water trade, Water demand management, Policy Analysis Matrix, Mathematical programming

ملخص

تتناول هذه الدراسة مشكلة كفاءة استخدام المياه في الزراعة عن طريق الاستفادة المثلى من استخدام المياه لأنماط التجارة الخارجية للمنتجات الزراعية في إيران. وتحقيقا لهذه الغاية، تناقش بعض القضايا الرئيسية على استخدام المياه الزراعية وأنماط التجارة الأولى. ثم، يتم عرض المفاهيم الأساسية ومبادئ استخدام المياه الزراعية وأنماط التجارة. وأخيرا، يتم إجراء تحليل مقارن لتجارة المياه الافتراضية بين بلدان المنطقة. وتشير النتائج إلى أن أنماط المحاصيل والتجارة الخارجية للمنتجات الزراعية في إيران لا تكاد تتفق مع مفهوم الميزة النسبية والموارد المائية في البلاد. في حين أن بعض بلدان المنطقة وبوعي اعتماد زراعة المحاصيل وسياسات التجارة الزراعية لتعزيز كفاءة استخدام المياه وزيادة القيمة الاقتصادية للمياه والري، وزراعة المحاصيل وأنماط التجارة الزراعية في إيران لم تهدف إلى تعزيز كفاءة استخدام المياه في الزراعة.

1. Introduction

The main source of water in Iran, which is located in an arid and semi-arid region is precipitation in the form of rainfall and snow. Precipitation is estimated to at $429\times10^9 m^3$ out of the $96\times10^9 m^3$ of water available from surface and groundwater sources. About $88\times10^9 m^3$ is allocated to the agricultural sector, $5.7\times10^9 m^3$ to the domestic and $2.0 \times 10^9 m^3$ for industrial purposes. The former fraction is used to irrigate 7.6 million hectares of land per year (Sabuhi 2006). The drive for food security for a rapidly growing population, encouraged by low irrigation water prices, has placed heavy pressure on the quantity and quality of water resources in Iran. Both the inefficient patterns of water use in irrigation and the insufficient attention to the problem of water allocation have contributed to the low performance of water development projects. As municipal and industrial water demand increases and per capita water availability declines with population growth, the agricultural sector will face increasing competition for fresh water resources, given the higher value added and willingness to pay per unit of water in the municipal and industrial sectors. Hence, policies influencing the efficient use of irrigation water are extremely important. Irrigation water in many parts of Iran is mainly used for low-value products and consequently water users are neither willing nor able to pay tariffs that would cover the supply cost of irrigation water as willingness and ability to pay are positively related to high-value cropping patterns.

Agricultural trade policy is also not designed to reduce pressure on the country's water resources. While the underlying foundation of agricultural trade is the notion of comparative advantage, the motivation for agricultural trade is hardly a pursuit of this comparative advantage; it is initially to fill the domestic gap of food supply and maintain social and political stability. In any economy where water is as scarce as it is in Iran, one would expect dependency on export products which contain small quantities of high- value water in exchange for products which are embedded with large quantities of low-value water (or in other words importing virtual water) to enhance water-use efficiency. However, Iran's agricultural structure in terms of water use is exactly the opposite of this. Iran's agriculture uses large quantities of water to produce low-value products, which consequently implies that water in Iran is relatively inexpensive and abundant. Moreover, in recent years, Iran has been pursuing a deliberate policy of self-sufficiency through substantial investment in irrigation infrastructure. This policy has intensified pressure on water resources.

Supply management policies are confronted by increasing cost of implementation and budgetary restrictions. Consequently, more consideration should be given to water demand management measures, which have historically been ignored in water development schemes. Demand management seeks to encourage a more efficient use of the available water and since the agricultural sector is the largest user of water in Iran. (over 90 percent of total water withdrawn), irrigation management is particularly important (Soltani 2005).

Agricultural water-use efficiency studies in Iran have mainly focused on a local scale (farm or project) without considering and linking those with basin and global efficiency levels (Shajari ,etal 2008; Alizadeh 2005; Sabuhi 2006). This study moves beyond the traditional practice of analyzing the agricultural water-use efficiency by considering and linking together three levels: local, basin and global, including the possibility of virtual water import and export in the form of food trade in the region. Hence, it is an innovative study which brings cross cutting disciplines into a coherent framework of analysis.

The rest of the paper is structured as follows. Section 2 discusses the underlying concept of water-use efficiency in an arid environment which is re-interpreted by viewing three levels of analysis: local, basin and global. Section 3 describes the research methodology and the identifies the equations for analyses. Section 4 provides a discussion of the results. Section 5 presents policy recommendations and the implications of the study for the MENA region.

2. Conceptualization of Water-Use Efficiency

Agricultural water-use efficiency can be viewed on three levels: local, basin and global. Water-use efficiency at the local (farm) level can be raised through demand management methods. At the basin level, the value of water in alternative use is involved and is more affected by macro-policies. At the global level, water-use efficiency can be increased through "virtual water" trade between water abundant and water stressed regions (Hoekstra and Hung 2005).

It is to be noted that the classical concept of technical water-use efficiency is concerned with local efficiency or the volume of water diverted and consumed in a project or irrigation district. Although this concept is the basis for the water account, it ignores the potential for return flows and recycling (Perry 2007). Considering the scale of this analysis it is also important to conceptualize the idea of water balance at the basin level. The basin approach discounts the need for paying much attention to individual water use but instead focuses on determining how much of the water that enters a basin is ultimately being recovered and reused, as a measure of the overall "basin efficiency". At the basin level, all losses are assumed to be recaptured and reused somewhere else downstream. Seckler (1996) calls attention to the importance of evaluating return flows, measuring both basin and field (farm) efficiencies. He argues that in closed basins all water is ultimately used beneficially or productively even if there are field inefficiencies. This argument implies that there is a connection between field and basin efficiencies. At the global level in the long term, evaporation from water bodies and evapotranspiration from land and vegetation must equal precipitation. However, as soon as the framework of reference is spatially or temporary narrowed, flows across borders become of vital concern (Perry 2007). Only where river flows are sufficient to meet demands, can water-use efficiency be examined in isolation (as in the classical efficiency concept). Thus, given the intensified sectoral water use (consumption) under conditions of severely limited supply, it becomes increasingly important to conceptualize water-use efficiency at the basin or global level. From this perspective, distinction must be made between consumptive use which removes water from the current hydrological cycle and non-consumptive use which returns water for potential re-use. Moreover, changing the scale takes us from the issue of the cost-effectiveness of water saving technologies to bigger issues like water allocation, rights to extract water and regulation of its use (Molle and Turral 2004; Gleick et al. 2011).

3. Methodology

A Policy Analysis Matrix (PAM) is used to reveal the comparative advantage of various basins and regions in the production of crops (Monke and Pearson 1989).This method is a product of two accounting identities. The first defines profitability as the difference between revenues and costs and the second measures the effects of divergences (distorting policies) as the difference between observed parameters and parameters that would exist if the divergences were removed (Monke and Pearson 1989). To determine private profitability, observed revenues and costs reflecting actual market prices received or paid by farmers are used. However, in measuring the comparative advantage in an agricultural commodity system, social prices need to be used. Description of the methods used to determine social inputs and outputs values (shadow prices) are outside the scope of this paper.

Patterns of agricultural trade are determined by using mathematical programming. When water supply is scare and stochastic, water trade—both actual and virtual—reduces both parties' risk exposure and increases water-use efficiency (Calatrava and Garrido 2005; Sabuhi 2006). It is expected that, with external trade, Iran may specialize in products in which it is specially adapted and may trade the surplus of these products for imported ones. As indicated before, agricultural (virtual water) trade can be simulated by applying mathematical programming models. The approach used in this study aims at enhancing water-use efficiency by directing cropping patterns to maximize net virtual import (Sabuhi 2006). A programming model is applied for optimizing cropping patterns at the basin level considering the virtual water trade, the comparative advantage of the basin for producing crops, and the basin's water resource potential for producing farm products. Cropping patterns, in which net virtual water use is optimized, are determined using a combination of basin model and nearly optimal programming techniques. This is implemented by changing the level of imported and exported products aimed at maximizing social profits. In estimating virtual water, it is important to distinguish between the quantity of irrigation water applied and the amount of water consumed by a crop. Virtual water is the amount of water embedded in the crops produced irrespective of the efficiency with which it was applied. Obviously, as irrigation efficiency (water application efficiency) increases, the gap between the two quantities declines. As indicated above in the construction of the basin model, social (real) rather than market prices are used for factors and products. In other words, the model is implemented in the absence of market failure and government distorting policies. Moreover, sample crops were subjected to various degrees of water stress in their growth stages and net virtual water is considered as an additional source of irrigation water in the region[1]. The structure of original basin model is as follows:

Max:

$$NSB = \sum_{c=1}^{n}\sum_{d=1}^{m}[ya_{cd}(sp_c - sc_c) - w_{cd} \times pw)x_{cd}$$

Subject to:

$$\sum_{c=1}^{n}\sum_{d=1}^{m} x_{cd} = \bar{\chi}$$

$$\sum_{d=1}^{m} x_{cd} \le \bar{\chi}_c \qquad \forall_c$$

$$\sum_{c=1}^{n}\sum_{d=1}^{m} w_{cd}x_{cd} \le w + NVWI - Z_a\sigma_w$$

$$X_{cd} \ge 0$$

Where, NSB is the net social benefits from all crops considered, ya_{cd} is actual yield per hectare of crop c with deficit irrigation d, sp_c is the social unit price (shadow price) of crop c in the region and sc_c is the social cost of production per unit of crop c in the region excluding the cost of irrigation water. x_{cd} is the level of activity c with deficit irrigation d. $\bar{\chi}$ = total cropped area. $\bar{\chi}_c$ = maximum acreage of crop c. W_{cd}= water requirement of crop c in the region, calculated assuming various water stress and irrigation efficiency levels at various growth stages of the crop. NVWI = net virtual water import per hectare in the year studied. Irrigation water constraint is considered as a random (stochastic) variable. $\bar{w}$ = average irrigation water supply calculated per hectare. Value of Z_a is estimated assuming normal distribution. Maximum cropped area was assumed to be equal to the existing crop area in the sample on 1 hectare basis. For each crop in the model, 45 activities were used according to the number of deficit irrigation considered. Due to the random nature of irrigation water supply, the level of risk in water supply was set at 80, 85, 87.5 and 95% for Z_a in the model. Estimating water supply per hectare was based on the average irrigation water at 45% irrigation efficiency for sample crops plus net virtual water imports per hectare. The amount of water supply—which is bound to decline as uncertainty (risk) increases the social cost of

[1] - The region is in Khorasan province located in the north-east of Iran.

production per kg of crops—was determined by PAM, from which the cost of water supply was deducted.

3.1 Modification of the Basin Model

After solving Model 1, the objective functions were added to the constraint of the model in order to provide for the maximum (optimal) use of virtual water. Then, the new model was solved for minimizing the production of imported crops (wheat and barley separately and jointly: objectives 1 to 3) and exported crops (tomato, potato and onion: objective 4) and determining cropping patterns to maximize social benefits and the use of net virtual water import. Accordingly, the modified model is written as follows[2]:

Minimize

$$\sum_{d}^{m} x_{wheat,d} \qquad \text{scenario 1}$$

$$\sum_{d}^{m} x_{barely,d} \qquad \text{scenario 2}$$

$$\sum_{d}^{m} x_{wheat,d} + \sum_{d}^{m} x_{barely,d} \qquad \text{scenario 3}$$

$$\sum_{d}^{m} x_{potato,d} + \sum_{d}^{m} x_{tomato,d} + \sum_{d}^{m} x_{onion,d} \qquad \text{scenario 4}$$

Subject: $$\left(\sum_{c=1}^{n}\sum_{d=1}^{m}[ya_{cd}(sp_c - sc_c) - w_{cd} * pw] * x_{cd}\right) \geq (1 - .03) * NSB$$

$$\sum_{c}^{n}\sum_{d=1}^{m} x_{cd} = \bar{x}$$

$$\sum_{d}^{m} x_{cd} \leq \bar{x}_c \qquad \forall c$$

$$\sum_{c}^{n}\sum_{d}^{m} w_{cd} x_{cd} \leq \bar{w} + NVWI - Z_a \sigma_w$$

$x_{cd} \geq 0$

Obviously, since Iran is short on water supplies, it should concentrate on producing agricultural products that generate a high level of income per unit of scare water. To focus on the demand side of the problem, demand management instruments should be selected to achieve this objective. Water requirements per unit value of agricultural output produced is used to determine the manner in which agricultural trade can mitigate domestic water supply restraints. The country's water trade position is shown by the difference between exports and imports of embedded water. The country may export or import water on a net basis, or its water trade may be balanced, depending on the cropping or water use patterns prevalent in the agricultural sector. Hence, water requirements for the production of a unit value of each crop are calculated and used as the basis for determining agricultural trade patterns.

[2] - In the new constraint, the optimum solution of the original model was reduced by 3%.

The terms of water exchange is the average trade price of embedded water exported (in 10000 Rials) divided by the average trade price of embedded water imported. A rise in the terms of water exchange means that, the region (country) may import a large quantity of embedded water for each unit of embedded water exported resulting in an increase in economic advantage, at least for a water scare region (country). Hence, optimization of agricultural water-use and trade patterns within a region (country) requires pursuing policies to encourage growth of cropping patterns in which water generates high value per unit of water, among other measures.

It should be noted that, agricultural trade between and within countries can be seen as a less costly and more environment friendly alternative to inter-basin water transfers especially since trade in real water between water rich and water poor regions is generally costly due to the long distances, bulkiness and associated costs.

The virtual water hypothesis predicts a specialization pattern based on exports of water intensive agricultural products from the water-abundant to water-deficient countries. However, it does not provide an answer to the problem of inefficient water use and trade patterns in the latter countries. Solutions to the problem of water shortage in the water-deficient countries are not created by just importing water-intensive agricultural products (virtual water), or by just addressing the water supply issues, but often, and even more importantly, they are realized by addressing the demand for water through demand management measures and water policies that encourage and even aid the change in the countries' agriculture structure and patterns of water use, and the external trade of agricultural products. In other words, while the virtual water hypothesis is intended to reveal the comparative advantage of water-deficient countries in the production of commodities, it does not address the problem of inefficient water use and the choice of appropriate demand management instruments.

The main purpose of this study is to examine the alternative of adopting a conscious agricultural trade policy designed to maximize social returns to scarce water resource by adopting agricultural trade patterns consistent with the country's or the basin's water resources. Obviously, this approach requires managing irrigation water in order to maximize the economic returns by accessing markets to generate the means for financing the import of food deficit. These markets need not necessarily be global but could be regional.

4. Results and Discussion

4.1 Empirical Analysis of Agricultural Trade Patterns of Iran

Iran's major agricultural imports include wheat, barley, rice, maize and sugar. Total cereal imports have declined during the last decade from 6,383,000 tons in 1995 to 3,972,153 tons in 2004 (FAO 2004). However, during the same period imports of barley, soybeans, banana and maize have increased while imports of wheat, rice and sugar beet have decreased. Declining imports of these commodities is the result of the government's self-sufficiency policy in the so-called strategic crops. It is worth mentioning that rice, sugar beet and sugar cane are water-intensive crops, the increased production of which applies heavy pressure on the country's scarce water resources. Analyzing the exports of agricultural commodities during the same period indicates that agricultural production and trade patterns are changing in favor of water-intensive crops which is considered unsustainable from the water resources point of view.

Iran enjoys considerable potential comparative advantage in the production of various agricultural products such as pistachios, almonds, walnuts, figs, saffron, garlic, dates, grapes and many horticultural crops. These corps are less water demanding than many of the imported commodities. Moreover, they produce higher income per hectare than many other commodities produced. Hence, production and export of these crops earn higher returns per unit of scarce water and should be considered for optimizing agricultural trade patterns, since adopting such trade patterns is consistent with the country's water endowments.

In general, agricultural production and trade patterns of Iran are hardly consistent with the notion of comparative advantage, but are rather designed to fill the domestic food gap and maintain social stability. In other words, it is mainly the imperative (preventing the rise in food prices) rather than comparative advantage that drives agricultural production and trade patterns in Iran. Increasing oil revenue as a result of the increase in its price has enabled the government to pursue such a lavish import policy in recent years. It is to be noted that since the country is now subject to sanctions and is in a situation of conflict, food security issues assume new critical roles.

A relevant aspect of agricultural trade patterns is its effects on the country's net virtual water import. Table 1, shows the effects of agricultural external trade patterns on the net virtual water import of Iran from 1995 to 2004. Based on the net annual import of agricultural commodities including sugar imports, virtual water imports in the two 5-year periods amount to 5.82 and 5.5 billion cubic meters per annum respectively. This indicates that the net virtual water imports of Iran have declined due to changing agricultural production and trade patterns.

Table 2, shows some indicators of virtual water relative to agricultural trade in Iran. As shown in the last row, net virtual water import per hectare (NVWI) that plays a vital role in the mathematical programming model is 765.75 cubic meters per annum.

4.2 Results of agricultural trade simulation using mathematical programming model

Irrigation water requirements and values per ton of exported and imported crops at the three levels of irrigation efficiency considered are shown in table 3. As shown, the price (cost) of irrigation water used in producing one ton of exported and imported crops is different. As expected, the social cost of producing crops increases with decreasing irrigation efficiency. Moreover, water requirements for producing one ton of exported crops are lower than imported crops. Considering border prices for the sample crops, returns per cubic meter of irrigation water used are shown in the last row of table 3. Estimated returns show the relative advantages of sample crops in external trade.

Optimal cropping patterns at 45% irrigation efficiency are shown in table 4. As indicated, social profits and irrigation water used with and without virtual water are different. When considering virtual water in the model, social profits and irrigation water requirements do increase. However, the irrigation water used is still less than the water supply. By minimizing barley production as an import crop, the model has a solution only with the 80% water supply reliability. In this case, the production of wheat, tomato and potato increases by 838,1172 and 943 kilograms respectively and the production of barley decreases by 1,487 kilograms.

By minimizing the production of both wheat and barley, the model has a solution with the 80 % irrigation water supply reliability. In this case, barley and wheat production decreases by 942 and 604 kilogram respectively but tomato and potato production increases by 506 and 2,626 kilogram respectively. With respect to virtual water use, the optimal cropping pattern is not in a better place than the reference pattern. However, the minimization of export crops production (onion, potato and tomato) results in a more efficient cropping pattern than the reference cropping pattern relative to the use of virtual water.

In summary, the findings showed that it is possible to direct optimal cropping patterns at the basin level to maximize social profit, water-use efficiency and net virtual water import simultaneously. However, in order to derive a definite conclusion, more data on the quantity of water embedded in each crop exported from and imported to each country is needed.

Moreover, it is necessary to design a suitable export-import plan to be used as a target for directing cropping patterns. The approach used in this study can be considered as a first step in this direction.

4.3 Comparative analysis of agricultural trade patterns of Iran and MENA region

The significance of agricultural and food (virtual water) imports to MENA countries is evident in the overall structure of trade. According to The World Bank (2001), food imports in MENA region have averaged about 20 percent of the total merchandised imports since the mid-1970s and have been increasing ever since. Unsurprisingly, the Middle East has been characterized as one of the least self-sufficient regions of the world. Based on Allen's view (Hakimian 2003), such a global trading system instead of posting threat has provided an opportunity for countries of the region to solve their serious and deteriorating water scarcity.

Despite the general food (virtual water) dependency of MENA countries, there is a significant variation in the degree of dependency among the countries of the region.

The ratio of net virtual water import to total volume of available water resources in MENA countries is shown in table 5. Countries like Jordan, Libya, Israel, Algeria and Tunisia are more dependent on virtual water import than Iran, Lebanon, Syria, Morocco and Egypt (Yang and Zehdner 2002).

Facing severe water shortage, Israel, Tunisia, and Jordan are trying hard to save irrigation water by investing in water saving technologies and changing cropping patterns towards less water demanding crops. Also, they are consciously adopting trade policies that are consistent with their water resources (i.e. reducing export of water intensive products and increasing exports of high value products, mainly fruits and vegetables).

While, groundwater extraction and surface water development were possible in the past, easy access to freshwater resources to achieve food self-sufficiency has been increasingly curtailed in most countries of the region.

As a result, many countries have become increasingly dependent on food (virtual water) imports. Based on FAO estimates, between 1990-1995 nearly 86 billion cubic meters of irrigation water were used for producing food products imported to MENA countries. Iran imported 3.53, 6.16 and 6.58 million tons of wheat in 1989, 1999 and 2000 respectively (FAO 2001). Having had to produce wheat domestically, some 20 billion cubic meters of irrigation water had been required. This amount was more than the total volume of water stored in large dams in the country. In years when Iran became relatively self-sufficient in wheat production (2006-7) it was mainly achieved by over-extraction of groundwater and over-use of surface water. Excessive extraction of ground water has created external costs in the form of water salinity and increased pumping costs due to declining water tables. While water resources per capita in Iran are more than those of many other MENA countries, the cost of water is rapidly increasing and the available water resources are approaching their limits. Hence, reliance on virtual water import is likely to increase in the near future. It is to be noted that virtual water import for Iran and other MENA countries is beneficial for two main reasons: 1) The main agricultural imports for these countries are cereals (wheat, rice and corn). The production of these crops is mainly rain fed in temperate zone (i.e. they use green water instead of blue water, leaving the latter for more valuable uses. Hence, importing cereals from these temperate regions to save precious water for producing more valuable crops in MENA countries seems an appropriate agricultural trade policy. 2) Alternatively, they can use blue water for producing valuable export crops and use foreign exchange earnings to import needed cereals. The necessary conditions for successfully implementing the latter policy are easy access to export markets and meeting global food health and safety requirements. Despite the possible benefits of adopting such a policy, the problem is not as simple as it seems. First, agricultural products (virtual water) trade entails a number of economic, social, political and environmental consequences. Second, whether the benefits of reduced pressure on the country's water resources can offset the possible adverse effects of virtual water imports on the rural economy and food security is a question to be addressed.

Another problem is subsidizing agricultural exports in exporting countries and lowering import prices for importing countries. This could also result in an increased dependency of food importing countries. Hence, the continued food import of some water stressed countries in the region is not aimed at saving irrigation water but is due to the fact that they are unable to compete with the cheap imports.

Another factor which is against the adoption of comparative advantage based trade patterns is distorted prices used for determining the comparative advantage and competitive position of importing countries. In this case, it is difficult to determine the real value of virtual water.

In the foreseeable future, one could think of a possible environmental stress resulting in food (virtual water) exporting countries. This may lead to a future claim by agricultural exporting countries that they are not receiving adequate monetary compensation for the net flow of their managed water resources. Some researchers are now bringing this matter to the attention of policy makers in some exporting countries. For example, Lenzen and Foran (2001) suggest that the trade in virtual water could represent a loss for exporting countries of their land and water resources. Then, the prices exchanged in the international trade should cover the full environmental cost of the exchanged water embodied in the goods and services that are exported and imported. The possible development of international trading mechanisms whereby the full environmental and monetary costs of water use might be recognized and recompensed is likely to work against countries in the MENA region that are already stressed in water and food terms. In these countries, a more feasible policy option is to raise water-use efficiency via demand management measures. Assessing the impacts of surface water miss-management and groundwater overdraft in Iran, there appears to be a trade-off between meeting immediate population demand for food and the sustainability of irrigated agriculture. For a country like Iran, using foreign exchange earnings to save its vital water resources (particularly groundwater) may be considered a wise investment. However, as indicated for countries that lack the needed foreign exchange to pay for the food import bill, a more feasible policy option is to raise agricultural water-use efficiency through the demand management instruments mentioned before.

Theoretically, relying on virtual water import by water stressed countries is a win-win solution for both exporting and importing countries. But, as indicated there are some caveats in adopting such a policy in arid and semi-arid countries. Difficulties for accessing reliable markets, existing stringent food, health and safety requirements in the advanced countries, and uncertainty with regards to secure basic food supply are some of the major obstacles to be considered.

There are two groups of options for enhancing agricultural water-use efficiency and food security in water scarce countries: policy options which are not directly linked to water resources such as population control and improved nutrition programs, and options directly linked with water resources. These policy options are not mutually exclusive and should be integrated. The focus of this paper is on the latter policy. Hence, the fundamental question raised is how the country can achieve sustainable food security via improved water management? Is the alternative of virtual water for Iran and other arid countries facing problems of financial stress possible given overseas market restriction and the increasing prices of cereals in the future a viable alternative? Water management can be enhanced by improving water-use patterns, and applying water saving technologies. However, many countries are not willing to design their external agricultural trade patterns based on water scarcity. For example, despite the possible benefits of virtual water mentioned above, only 20 to 25 percent of external cereal trade is from water abundant to water scarce countries. Yet, despite the difficulties of virtual water trade indicated above, there is an urgent need for an objective assessment of the impacts of virtual water trade. It is important because such an assessment can assist policy makers in making informed decisions when choosing it as a policy option in water management.

5. Conclusion and Policy Recommendations

Based on agricultural trade statistics, the current net virtual water import of Iran is about 5.8×10^9 m^3 per annum. However, a new government policy is aimed at expanding the domestic production of cereals and sugar which are water intensive products. Hence, changing cropping and agricultural trade patterns is likely to result in the reduction of the net virtual water import. A further expansion in the production of water-intensive farm products is expected to turn the country from a net importer to a net exporter of virtual water.

Based on the above discussion and analysis, the following policy recommendations are presented:

1-Iran can design and implement policies to reduce the export or the local production of water-intensive crops and replace them by the production of higher value crops to increase water-use efficiency. These are conscious choices made to relieve pressure on its domestic water resources. The net effects of agricultural trade on the country's water balance depends on the cropping or water use patterns prevalent in the agricultural sector.

2- In a country that is subject to sanctions and is in a conflict situation like Iran, food security issues assume critical roles. However, assuming a conflict free world, the optimization of irrigation water use is a meaningful objective. Hence, the introduction of virtual water in a water scarce country such as Iran should be a policy option to consider.

3- Agricultural external trade aimed at importing virtual water should be accompanied by the implementation of a conscious policy for raising water-use efficiency.

4- Demand management measures and policies encouraging and aiding changes in water use and trade patterns of agricultural products should be an integral part of the country's water policy.

5- Many fruit and nut crops in Iran have a high level of water efficiency; they require less water but give higher returns than grains such as wheat and rice. Hence, changing cropping patterns can facilitate virtual water trade and ease the pressure on water resources. However, the possible benefits of reduced pressure on the country's water resources should be compared with the possible adverse effects of agricultural product imports on the rural economy and food security if the country opts for virtual water imports to alleviate its water problem.

6- At present over 90 percent of available water is allocated to agriculture. Given the increased willingness to pay per unit of water in other sectors, water is over-allocated to the agricultural sector. Hence, broadening the analysis to look at the inter-industrial water allocation system makes sense.

6. Policy Implications of the Study for the MENA Region

Policies that encourage farmers to acknowledge the scarcity of the limited water supply in the region will gain importance in future, both to insure that water is used efficiently in domestic production and to motivate production of high-value crops for export. The gains that can be achieved by focusing on production activities for which the region has comparative advantage will increase with increasing resources scarcity. Farm level decisions regarding inputs and outputs will be consistent with national goals if the farm level prices or allotments of water and other resources reflect the relative scarcity of these resources.

Optimization of water use and trade patterns of agricultural commodities have the potential to mitigate water shortages and reduce the adverse effects of salinity on the productivity of land and water which are caused by the inappropriate patterns of water use in many countries of the region

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Table1: Agricultural Trade in Relation to Virtual Water Import

Period	Year 1995-1999	2000-2004
Annual import (tons)	8054076	7713016
Annual export(tons)	1092067	1014515
Net annual import	6962000	6698500
Annual sugar import	972211	624711
Net annual virtual water import (billion cubic meters)	5.82	5.5

Table 2: Some Indicators of Virtual Water Relative to Agricultural Trade in Iran (1995-1999)

Total virtual water import (billion cubic meter)	29.1
Population	62762116
Water extraction (billion cubic meter)	85.608
Available water resources (billion cubic meter)	117.5
Gross virtual water export per annum (billion cubic meter)	0.85
Gross virtual water import per annum (billion cubic meter)	6.623
Net annual virtual water import (billion cubic meter)	5.82
Water scarcity (%)	72.9
Irrigation areas (million hectares)	7.6
Net virtual water import per hectare (cubic meters per annum)	765.75

Source: Hoekstra and Hung (2002).

Table 3: Water Requirements and Values of Exported and Imported Crops (cubic meters and Rials*)

Topic	**65% Irrigation Efficiency** **Export Crops**			**Import Crops**		
	Potato	**Onion**	**Tomato**	**Barley**		**Wheat**
Water requirements per ton	353	190	372	1073		935
Average water requirement		305			1003	
Irrigation water value (cost) per ton	1083900	584250	1141730	3295230		2872230
Average irrigation water value		1003510			3098240	
	45% Irrigation Efficiency					
Water requirements per ton	510	275	237	1549		1351
Average water requirement per ton		440			1550	
Irrigation water value	1566070	843920	1649160	4759780		4148780
Average irrigation value		1449690			4475230	
	35% Irrigation Efficiency					
	Potato	**Onion**	**Tomato**	**Barley**	**Import Crops**	**Wheat**
Water requirements per ton	655	354	690	1993		1737
Average water requirement		566			1865	
Irrigation water value	2012960	1086270	2118960	6123090		533696
Average irrigation water value		1863100			2756990	
Returns per cubic meter of water	3005	5766	3327	1366		1376

Notes: Official exchange rate is 12260 Rials per US Dollar

Table 4: Optimal Cropping Patterns Under Various Water Supply Risks with and without Virtual Water and Assuming Water Irrigation Efficiency 45% (Hectare, Kg)

Crop	Deficit irrigation	Yield (kg/Ha)	Optimal cropping patterns without virtual water under water supply risk (%)					Total output at alternative water supply risk				
			80	85	87.5	90	95	80	85	87.5	90	95
Wheat	14	4377	0	0.079	0.129	0.188	0.032	0	345.8	564.7	822.9	140.08
Wheat	40	4170	0	0	0	0	0.254	0	0	0	0	1059.38
Barley	17	3967	0.458	0.464	0.464	0.464		1817	1841	1841	1841	0
Barley	20	3133	0	0	0	0	0.464	0	0	0	0	1454
Tomato	8	3563	0	0	0	0	0.089	0	0	0	0	3171
Tomato	19	38686	0.382	0.296	0.247	0.188	0	14778	11451	9555	7272	0
Onion	6	59262	0.16	0.16	0.16	0.16	0.16	9481	9481	9481	9481	9481
Social profit (Rials)			5525644	5201735	5013457	4790990	41505950					
Irrigation water used			10608	9779	9299	8732	7118					
			Optimal cropping patterns with virtual water under water supply risk (%)					**Total output at alternative water supply risk**				
Wheat	14	4377	0	0.0002	0.05	0.109	0.27	0	0.979	218.8	477.15	1208.2
Wheat	40	4170	0	0	0	0	0	0	0	0	0	0
Barley	17	3967	0.375	0.464	0.464	0.464	0.464	1487	1487	1841	1841	1841
Barley	20	3133	0	0	0	0	0	0	0	0	0	0
Tomato	8	3563	0	0	0	0	0	0	0	0	0	0
Tomato	19	38686	0.464	0.375	0.326	0.267	0.1	17950	17950	12611	10329	3868
Onion	6	59262	0.16	0.16	0.16	0.16	0.16	9481	9481	9481	9481	9481
Social profit (Rials)			5810178	5502156	5313898	5091412	4458180					
Irrigation water used			11374	10545	10065	9498	7884					

Table 5: The Ratio of Net Virtual Water Import to Total Water Resources

Country	Ratio (percentage)
Algeria	79.2
Cyprus	67.4
Egypt	23.5
Israel	207.4
Jordan	195.7
Lebanon	28.7
Libya	557.0
Morocco	21.8
Syria	3.59
Tunisia	96.9
Iran	4.2

Source: Yang and Zehdner 2002