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Optimal Groundwater Irrigation Allocation of Al-Wajid Aquifer in the Kingdom of Saudi Arabia

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Abstract: Groundwater is the primary water source in the Kingdom of Saudi Arabia. As result of lack of basic knowledge on irrigation practices, massive abstractions of groundwater occurred in 1980's. A Decision Support Linear Goal Programming (LGP) model was developed to determine optimal groundwater irrigation levels, to assess the implications for water management policies, and to estimate welfare impact on producer surplus. Due to the reductions of groundwater in 1980's, the Al-Wajid aquifer water levels have dropped in agricultural areas by more than 200 m. Results from this study estimate that the total groundwater of the Al-Wajid aquifer that can be saved is equal to 66 MCM for the first scenario, 147 MCM for the second scenario, and 229 MCM for the third scenario. Regarding the welfare analysis impacts, it is clear that the total gross margin is decreasing up to 7.7% at the end of the year of scenario III. Therefore, the third scenario with a water saving increase to 18.1% is recommended as a directive for agricultural policy formation in the future.

Keywords: Agricultural policy, groundwater, Al-Wajid aquifer, abstraction, irrigation, welfare analysis.

1. Introduction

The Kingdom of Saudi Arabia is ranked as an arid land, with limited natural water resources. As result of rapid growth and comprehensive development in all economic sectors, water demand for domestic, agricultural and industrial purposes has dramatically increased. Agricultural is the major water consumption which consumes about 85% of total national water use [1]. Groundwater is considered a nonrenewable, stock resource that is mined by water users over time, although groundwater stocks are clearly rechargeable by both natural and artificial means, the potential benefit of recharge in use decisions tends to be small relative to aquifer capacity [2]. The sedimentary deep aquifers are the main sources of irrigation water for Saudi Agriculture, there are ten principal and five secondary aquifers, based on their real extent, groundwater volume, water quality and development potential [1]. The abstraction and use of groundwater in arid land is the same as a mining operation [3]. Since groundwater is the primary source of water for irrigation, and massive abstractions occurred in 1980's, a signal was released by the government of Kingdom of Saudi Arabia in 1993 and 1994 to make the use of groundwater resources more sustainable and to prevent massive groundwater consumption [4, 5].

The policy challenge is predictable groundwater resources for the purpose of assuring continued availability in the future. The success of the policy depends on the ability to accurately value the water resources being used. Developing the institutions for this valuation process, and determining the impact of changing valuation on allocation of water to various users, is the primary role the economics profession plays in the creation of water policy [6].

Al-Wajid aquifer is one of the principal aquifer in

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the Kingdom of Saudi Arabia, which suffered from massive irrigation abstractions. Wadi AD Dawasir and Najran regions are the major irrigation water abstraction from Al-Wajid aquifer. The total volume of groundwater abstracted for irrigation in this relatively small region has increased from 23 MCM in 1973 to 2,051 MCM in 2006, while the annual recharge does not exceed 10% [6]. In fact, most economic research has treated groundwater recharge as either invariant with respect to the current stock of groundwater or variable only as the aquifer approaches maximum capacity [7-10]. The annual irrigation abstraction of Al-Wajid is in the range of total annual residential water consumption of the entire Kingdom of Saudi Arabia, and 10 times of two regions in Al-Wajid area which estimated to be 200 MCM/a [11]. This case study can serve as a pattern for other aquifers.

The objectives of this study are to determine optimal groundwater irrigation levels for Al-Wajid aquifer through the optimal allocation concept, and to assess the impact of agricultural policy reforms on farm income and groundwater resources use.

2. Geographical Overview

Al-Wajid area encompasses a variety of geomorphologic units that are characteristic for the southwestern part of the Kingdom of Saudi Arabia. From east to west the main units are: the Rub' Al-Khali desert, the Tuwayq Escarpment, the Wajid Plateau, the Hijaz Plateau and the Najd Peneplain on the Arabian Shield, and the Asir Highlands [7].

The climate in the study area ranges from hyper-arid in Rub' Al-Khali desert to semi-arid in the Asir Highlands. About 80% of the study area receives less than 100 mm/a, mostly during the spring months. The area of Wadi Ad Dawasir, situated at an altitude of around 650 m.a.s.l., is characterized by very hot summers, average monthly maximum/minimum in July: 43.9 °C/27.7 °C, and mild winters, average monthly maximum/ minimum in January: 24.7 °C/9.8 °C. The calculated annual potential evapo-transpiration ET_0, Penman-Monteith approach [12] for Wadi Ad Dawasir is 2,643 mm/a. Najran, at an altitude of around 1,250 m.a.s.l., does not suffer the extreme heat of the summer, average monthly maximum/ minimum in July: 39.2 °C/24.8 °C, and mild winters, average monthly maximum/ minimum in January: 25.2 °C/8.7 °C. ,which also reduces the annual potential rate of evapo-transpiration to 2,168 mm/a [1].

Most of the study area is covered by typical desert soils, which are pedogenetically underdeveloped and were formed mainly by mechanical weathering rather than chemical alteration. The parent material of those soils consists of the metamorphic and granitic rocks of the Arabian Shield. As would be expected for desert soils, they have a low field capacity and cation exchange capacity due to the rather coarse texture and lack of organic and inorganic colloidal complexes. Also, these soils are rather alkaline due to elevated calcium- carbonate content in the upper layer that at some places develop into a caliche horizon.

Before the beginning of the agricultural expansion in early 1980s, the agricultural activities in the study area were confined to areas where more abundant annual precipitation allowed rain-fed crops to be cultivated or where shallow groundwater for irrigation was easily accessible by traditional means. The crops of these wadi oases were mainly date palms, followed by winter and summer cereals, alfalfa and vegetables. The agricultural production during that time was largely in equilibrium with available water resources and the output was sufficient to meet the needs of the population living in the area. With the advent of modern large-scale (center pivots) irrigation schemes during the 1980s, supplied by deep wells mainly tapping the Wajid aquifer, the agricultural land use within the study area increased significantly. Today’s agriculture in Wadi Ad-Dawasir area consists of technically highly developed farm enterprises that operate modern center pivot irrigation system. The size of center pivot range from 30 ha to 60 ha with farms managing up to 100 of them with the corresponding number of wells. The main crop grown in winter is wheat and occasionally potatoes, tomatoes, or melons. All year fodder consists of alfalfa, which is cut up to ten times a year for hay. Typical summer crops for fodder are sorghum and Rhodes grass, which is perennial, but dormant in winter. The shallow alluvial aquifers could not sustain the high groundwater abstraction rates for a long time and groundwater level declined dramatically in most areas (Figs. 1-2).

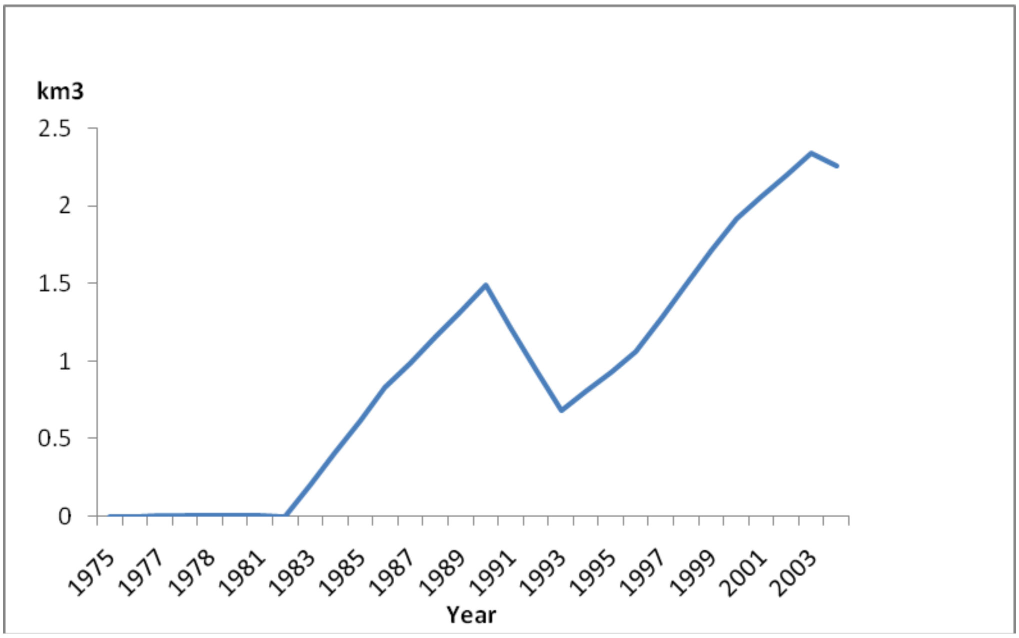

Fig. 1 Groundwater abstractions of Al-Wajed aquifer.

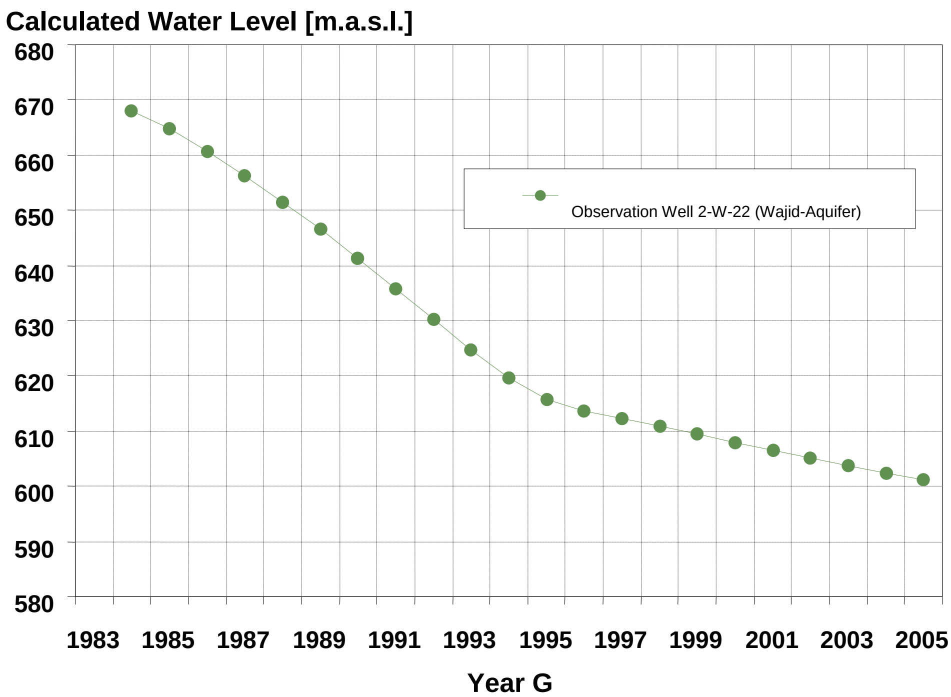

Fig. 2 Al-Wajid aquifer water level.

3. Methodology and Data Source

The problem of evaluating irrigation water demand and management, and water regulations assessment are not recent and has become a growing field of research in the last few years [13], two approaches on irrigation water demand and management estimation exist. If data relating to observed water consumption exist then econometric models are used [14, 15], while if the data imprecise on consumptions then standard mathematical techniques such as linear programming [16, 17] or quadratic programming are applied [18, 19]. However, the programming methods are based on the mathematical formulation of the farmer's behavior to maximize his gross margin, thus, for variations in water prices induce different levels of optimal water quantities [13]. The weaknesses of these models are due to formalization the farmer’s program and to the necessarily simplifying assumptions. Also, most of the previous studies are based on the unrealistic assumption that the farmers are risk-neutral, while it is recognized in the literature that farmers are risk adverse [20]. The studies based on maximizing the objective function of farmers gross margin are in the short run and at production unit level, therefore, risk factor is related to farmers gross margin not to water sustainability.

In fact, all previous studies in Saudi Arabia such as Refs. [21, 22] which used linear programming technique for irrigation water management through maximizing farmer’s gross margins, assuming that the average amount of water used in a certain period available, accessible, stable, and sustainable. Of course, these assumptions are not valid. In reality, there are remarkable signs of serious decline in aquifers water levels in the Kingdom of Saudi Arabia.

This study tries to overcome the weaknesses of previous studies (maximizing problems) by using linear goal programming through the rationing water use in the context of policy constraint. Because water resource is the most scarce important and limited factor for sustainable agriculture development. Therefore, the method of this study is considered more objective in dealing with the development of non-renewable groundwater in Saudi Arabia. It is based on water efficiency oriented rather than production efficiency of all production factors, and it relies on the intensification of available items such as capital and reduces scarce factors such as water.

Linear goal programming (LGP) approach is applied for only two regions that rely on water abstraction from Al-Wajid aquifer namely (Wadi Ad-Dawasir and Najran; Mj, j = 1,2). The study include 17 commodities (Ni; I =1, 2,….., 17). These commodities were classified into four groups (cereals, fodder, vegetables, and fruits, I = 4). Farmers implement two types of irrigation schemes (modern (center pivot) and traditional (flood) schemes, k = 1, 2). The LGP model has been stated as follows:

The objective function:

$$Max\ Z = \sum_{i=1}^{N}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} GM_{ikj} \quad ...(1)$$

Subject to:

$$\sum_{i=1}^{N}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} Y_{ikj} < TW \quad ...(2)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} W_{ikj} \geq YB \quad ...(3)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} < BLH(j) \quad ...(4)$$

$$\forall_j ;\ j = 1,2 \qquad i = 1,2,...,M$$

$$\sum_{i=1}^{In}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} < BCA(j,i) \quad ...(5)$$

$$\sum_{i=1}^{In}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} * C_{ikj} \quad < TC(j,i) \quad ...(6)$$

$$\sum_{i=1}^{In}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} * F_{ikj} \quad < TF(j,i) \quad ...(7)$$

$$\sum_{i=1}^{In}\sum_{k=1}^{L}\sum_{j=1}^{M} X_{ikl} * L_{ikj} \quad < TL(j,i) \quad ...(8)$$

$$Barea1(i) = \sum_{j=1}^{M} X_{i1j} \quad ...(9)$$

$$Barea2(i) = \sum_{j=1}^{M} X_{i2j} \quad ...(10)$$

$$Barea2(i) > Barae1(i) * R(i) ....(11)$$

$$X_{i2j} \geq 0$$

where:

X_{ikj} is decision variables and G_{Mikj} is the gross margin, W_{ikj} , C_{ikj}, F_{ikj}, L_{ikj} are water, capital, fertilizer, and labor requirements, respectively (technical coefficients), Y is the productivity per hectare, YB is the production quantity, BLH is the total cultivated area, TC is total cost, TF is total fertilizer, TL is total labor force. The separability among commodity groups is assumed, this assumption allow competitions among commodities in each group based on water efficiency, therefore equations 1-4 are added to the LP model. Eqs. (9) and (10) represent the sum of traditional and modern irrigation in region (M_j), respectively. For high water efficiency use, Eq. (11) is used to ensure that traditional water use should not exceed actual water use for LGP solution, and R is ratio between modern and traditional irrigation.

Water requirement, land, production level data were obtained from Ministry of Agriculture [23]. Other data such as labor, fertilizer, operating costs were obtained from Agricultural strategy survey, 2005 [24].

4. Results

Table 1 illustrates the basic data for LGP model. The highest total operating cost among all products in Wadi Ad-Dawasir was the squash (10,440 SR/ha), while among grains was the wheat (7,050 SR/ha) for modern irrigation. The large amount of water requirement is for palm dates which equal to 32.5 (29.2) thousand m^3 for modern and traditional irrigation, respectively. Wheat is the largest amount of water requirement among grain group. The current water use according to area production and water requirements in both regions and for all commodities (N_i ; i = 1,2,……..n) for 2008 year was 1.3 billion m^3.

Table 1 Water requirements and total operating costs in Wadi Ad-Dawasir and Najran regions.

Commodity	Water requirements (m^3/ha)				Total water use (1,000 m^3)	Total operating costs (SR/ha)			
	T1	T2	M1	M2		T1	T2	M1	M2
Wheat	7,309	9,514	7,258	7,419	45,321	10,390	2,830	11,770	7,050
Barley	6,614	8,610	6,568	6,714	365	10,390	1,860	11,770	7,980
Other grain	6,961	9,038	6,613	7,408	56	10,390	4,800	11,770	3,520
Alfalfa	20,373	23,550	20,106	19,053	432,212	10,390	5,480	11,770	4,120
Other fodder	24,935	24,452	23,707	19,053	398,132	13,280	14,950	5,610	5,610
Tomato	8,128	8,337	7,315	7,503	8,582	13,280	14,950	4,290	4,290
Squash	5,553	5,953	4,998	5,358	1,778	13,280	14,950	7,940	7,940
Eggplant	8,298	7,625	7,468	6,863	1,734	16,370	6,230	13,280	8,340
Potato	9,194	10,583	8,275	9,525	6,675	16,720	5,810	8,350	10,440
Onion	7,565	9,852	6,809	8,867	1,716	16,550	6,510	10,820	7,370
Mellon	9,676	5,454	8,708	4,909	9,242	16,550	7,500	10,820	3,330
Water melon	9,676	5,572	8,708	5,015	6,252	16,550	5,210	10,820	8,970
Other veg.	8,298	7,625	7,468	6,863	9,987	16,550	4,100	10,820	6,310
Dates	32,470	25,160	29,220	22,644	233,607	16,550	4,100	10,820	6,310
Citrus	37,318	34,756	33,586	31,280	61,768	16,550	5,640	10,820	7,300
Grapes	31,283	23,992	28,155	21,593	1,674	9,040	6,220	12,030	4,050
Other Fruits	32,251	25,672	29,026	23,105	42,403	12,440	6,060	12,030	2,330
Total					1,261,504				

T_j: stands for traditional irrigation, T_1 for wadi Ad-Dawasir region and T_2 for Najran region, M_j: stands for modern irrigation, M_1 for wadi Ad-Dawasir region and M_2 for Najran region, ha: Hectare.
Source: MOA, 2008.

The LGP feasible solution for minimizing water use is 1.23 billion m^3 which save about 70 million m^3.

Table 2 illustrates the optimal solution for the area production for both types of irrigation systems. The columns (5, 6, 7 and 8) show the reduced cost, which indicates at increasing one hectare from n commodity will result in decreasing the total gross margin by the value corresponding to the n commodity. For example at increasing one hectare of barley cultivation will decrease the total gross margin by 136 SR, however, the highest value of decreasing the total gross margin is occurred at increasing melon cultivation by one hectare at Najran region for both irrigation system. The last column in Table 2 shows the least change in total gross margin due to change in one unit of crop production.

Table 3 shows the slack area that not used which equal to 64.4 ha for Wadi Ad Dawasir and 953 ha for Najran. In Wadi Ad Dawasir region, the grain, fodder, dates and fruits areas have been used so that the slack area equal to zero, so that at increasing grain area by one hectare will result in increasing total gross margin by 811 SR, 1,650 SR, and 3,320 SR respectively. Thus AD Dawasir region has comparative advantages of growing grains, fodder, and dates and fruits over Najran region.

The efficiency of available total capital, this can be seen from adding capital constraints. The result shows that at increasing one thousand Riyals, this impact is only for fodder and vegetables which will increase total gross margin by 116,000 SR and 81,000 SR respectively, other commodity groups will not be affected.

4.1 Policy Implications

Water resource problems in many cases are primarily the result of inefficient policy and institutions [25-26]. Bernardo and Whittlesey [28] use a mathematical programming model to show that farmers in Washington State substitute water with labor, by switching to more water efficient mode of operation of their irrigation technology. Consequently, under restricted water supply, water use can be reduced up to 35% for surface irrigation and 25% under center pivot schemes, without greatly affecting farmer income. Oyt and Paul [29] reached similar

Table 2 LP optimal solution in Wadi-Aldawasser and Najran regions.

Commodity	Area (ha)				Reduced cost				Current demand (ton)	Change in gross margin SR/ton
	T1	T2	M1	M2	T1	T2	M1	M2		
Wheat	571.5	8,929	50,354	0	0	0	0	-1	29,895	-1,061
Barley	50.8	0	269	0	0	-136	0	-356	207	-962
Other grain	26.5	0	28	112	0	-54	0	0	29	0
Alfalfa	0	0	190,885	20,782	-183	0	0	0	404,033	-269
Other fodder	7,539	0	152,977	7,202	0	0	0	0	303,312	-418
Tomato	824	0	25	11,901	0	-1	0	0	23,375	0
Squash	0	0	0	3,161	-1,372	0	-1,372	0	4,739	-671
Eggplant	0	0	1,677	0	-109	-1,933	0	-1,933	2,743	-2,128
Potato	0	1,649	4,345	1,098	-189	0	0	0	17,937	-957
Onion	576	0	1,899	0	0	-421	0	-418	6,474	-1,499
Mellon	2,468	0	8,145	0	0	-6,362	0	-6,393	20,345	-2,829
Watermellon	1,668	0	5,504	0	0	-4,945	0	-4,876	13,785	-2,817
Other veg.	0	0	12,604	0	-23	-1,649	0	-1,649	26,179	1,545
Dates	0	40,199	36,308	3,891	-43	0	0	0	47,912	0
Citrus	0	0	14,892	9,468	-10	-6	0	0	23,430	-490
Grapes	0	349	0	349	-458	0	-468	0	1,024	0
Other Fruits	0	5,777	0	5,777	-1,229	0	-1,238	0	20,405	-966

T_j: stands for traditional irrigation, T_1 for wadi- Aldawasser region and T_2 for Najran region, M_j: stands for modern irrigation, M_1 for wadi- Aldawasser region and M_2 for Najran region.
Source: Lp results.

Table 3 Area and capital cost impacts in Wadi-Aldawasser and Najran regions.

Region	Crop groups	Region area impact			Crops area impact			Capital cost impact		
		Current area	Slack area	SR/ha	Current area	Slack area	SR/ha	Current cost	Slack cost	Water (m^3/ha)
Wadi-Aldawasser		493,700	64.4	0						
Najran		121,600	953	0						
Wadi-Aldawasser	Grains				51,300	0	811	36,150	238	0
	Fodder				351,400	0	1,650	239,820	0	116
	Vegetable				39,800	65	0	24,730	0	81
	Dates and fruits				51,200	0	3,320	30,570	10,951	0
Najran	Grains				9,100	58	0	9,420	10	0
	Fodder				28,000	0	0	35,890	18,512	0
	Vegetable				18,600	790	0	25,650	3,287	0
	Dates and fruits				65,900	89	0	70,575	3,173	0

Source: Lp results.

conclusions on farmer response to increasing pumping cost as result of declining aquifer levels in Texas, USA. His modeling results imply that if water supply restricted by 20%, farmers profit will not be affected significantly. Increased water extraction costs and crop prices have no significant impact on the efficiency of water use [30]. However, due to the inelastic demand for irrigation water, reliance on price mechanisms to conserve water has limited impact in the short run [31]. Only if prices increase dramatically, capital investments in more efficient irrigation technology become viable at considerable profit loss to farmers [32]. There are a wide range of irrigation technologies available for irrigation. Using techniques available today, farmers could cut their water demands by 10%-50% [33]. However, both technology diffusion and water allocation efficiency improvement have not been easy without appropriate policy and economic instruments [34, 35].

A result of the expansion of agricultural policies in the early eighties, which aims to increase self-sufficiency of strategic crops such as wheat, this expansion has led to an increase in wheat production in excess of local market and then export in some years. It was from within the agricultural policy incentive is to buy grain silos full of wheat production and pay prices higher than world prices for a long period of time. This was undoubtedly at the expense of depletion of non-renewable groundwater resources and largely. A result, the Government issued Decree No. 335 in 2008 aims to reduce water consumption in the agricultural sector through the reduction of bonds to buy wheat from traditional farmers and agricultural companies, by 12.5% per year for eight years. Of course, the resolution will have a direct impact on reducing the cultivation of wheat due to the adoption of the producers to ensure full production of the silos as well as the inability to compete with imported wheat. One of the main pillars which conservation policies are built is water laws. Legislation can help to improve groundwater management plans, facilitate the use and protection of the resources and provide guidelines for future conduct [36].

In addition to Decree No. 335 in the context of maintaining the non-renewable groundwater resources, government has encouraged farmers by linking subsidies and direct and indirect loans, using modern irrigation techniques in the style of modern irrigation in order to raise the efficiency of water use. Also that the fodder is water consumption crop, therefore, the government is currently studying reducing the area devoted to grow fodder as well as to ensure that wheat producers, especially agricultural enterprises, have not to shift to the cultivation of fodder, which accessible could be marketed to the dairy farms. Based on the foregoing views of the government in the rationalization of water consumption in the agricultural sector and to assess the impact of the new policy on rationalize water consumption and farm incomes, thus three alternative scenarios has been prepared based on a fundamental solution to linear goal programming as follows:

Scenario I: is to assess the effect of the Resolution No. 335 in reducing the purchase of wheat by 12.5% for eight years to conserve the consumption of non-renewable groundwater resources. Table 4 shows the impacts of Decree No. 335 on the total gross margin, water saving, and the water value average product. Total gross margin has decreased from 1,190.7 million SR at the year 2009 to 1,181 million SR at year 2015. Water supply will increase through increasing water saving as shown in table 4, water saving increases from 2.5% in year 2009 to 5.2% in year 2015. The value of average product of water increases from 0.979 SR/m^3 in 2009 to 1.002 SR/m^3 in 2015. The value of marginal product of water is equal to 1.094 which indicates the low value of water comparing with other sectors in the Kingdom of Saudi Arabia.

Scenario II: the first scenario in addition to reducing the proportion of area devoted to growing fodder by 10%. Table 5 provides results of Scenario-II which shows a greater reduction in total gross margin up to 1,141.1 million SR in 2015, and more water saving which reaches up to 11.65% in 2015. The value of average product of water has increased to 1.048 SR/m^3 in 2015.

Scenario III: the second alternative scenario in addition to reducing the proportion of area devoted to growing fodder by 20%. Table 6 provides the results of this scenario, which showed the reduction in total gross margin and water saving in the last year of Resolution 335 (Figs. 3 and 4).

It is clear that the proportion of water can be saved in the last year of resolution 335 represents 5.2% and the total amount of water can be preserved during the years of the resolution is 66 million cubic meters.

Table 4 Total gross margin and the value of average product of water.

Scenario	Year	Total gross margin million SR	Water Saving %	AVP_W (SR/m^3)	MVP_W (SR/m^3)
Base solution	2008	1,192.3	2.04	0.965	1.094
I	2009	1,190.7	2.5	0.979	1.094
	2010	1,189.02	2.9	0.971	1.094
	2011	1,187.4	3.2	0.987	1.094
	2012	1,185.7	3.9	0.991	1.094
	2013	1,184.1	4.1	0.994	1.094
	2014	1,182.5	4.5	0.998	1.094
	2015	1,181.0	5.2	1.002	1.094

Source: Lp results.

Table 5 Total gross margin and the value of average product of water.

Scenario	Year	Total gross margin million SR	Water Saving %	AVP_W (SR/m^3)	MVP_W (SR/m^3)
Base solution	2008	1,192.3	2.04	0.965	1.094
II	2009	1,151.0	8.90	1.023	1.094
	2010	1,149.3	9.40	1.027	1.094
	2011	1,147.6	9.80	1.031	1.094
	2012	1,146.0	10.30	1.032	1.094
	2013	1,144.4	10.70	1.039	1.094
	2014	1,142.7	11.2	1.043	1.094
	2015	1,141.1	11.65	1.048	1.094

Source: Lp results.

Table 6 Total gross margin and the value of average product of water.

Scenario	Year	Total Gross Margin million SR	Water Saving %	AVP_W (SR/m^3)	MVP_W (SR/m^3)
Base solution	2008	1,192.3	2.04	0.965	1.094
III	2009	1,110.7	15.4	1.071	1.094
	2010	1,109.1	15.9	1.075	1.094
	2011	1,107.4	16.3	1.08	1.094
	2012	1,105.8	16.8	1.085	1.094
	2013	1,104.2	17.2	1.084	1.094
	2014	1,102.5	17.7	1.094	1.094
	2015	1,100.8	18.1	1.096	1.094

Source: Lp results.

While the second alternative, the total water quantities can be preserved by the amount 147 million cubic meters and up to 11.65% in the last year. The third scenario with total estimated quantity conservation is

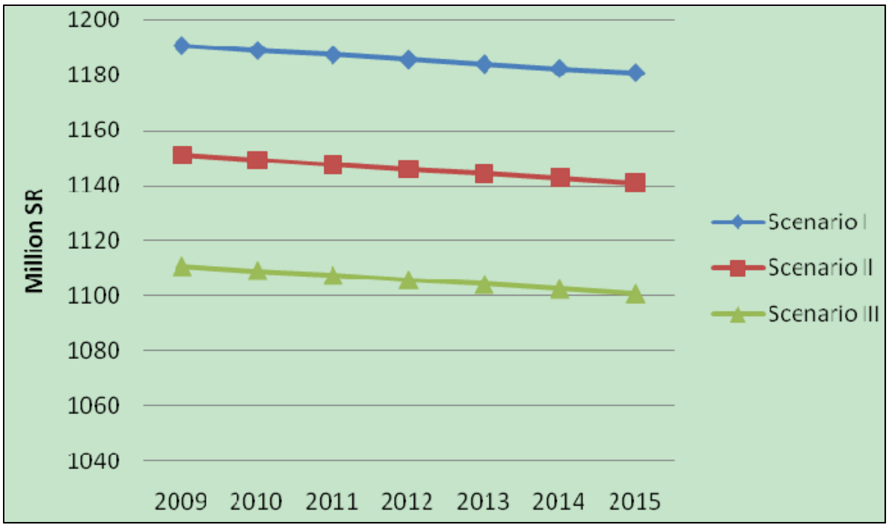

Fig. 3 Total gross margin under various scenarios for Alwjid aquifer.

Fig. 4 Water saving under various scenarios for Alwjid aquifer.

229 million cubic meters, accounting for 18.8% in the last year. The total quantities of water which possible saved in the third scenario greater than the amount of water used for municipal, industrial, in Al-Wajid area which was estimated at 200 million cubic meters per year (GTZ 2006).

4.2 Welfare Impacts of Various Scenarios

The welfare impact of various Scenarios is estimated as the changes in producer's surplus in both wadi-Al-Dowser and Najran areas. Gross margin of each crop was calculated based on total revenue and total operating cost. Farm gate prices, productivity of each irrigation techniques (traditional and modern), and total operating cost per area unit were assumed to be constant at the level of base period (2008). Table 7 presents producer surplus under various scenarios for Al-Wajid aquifer which is calculated by adding up the results of both Wadi Ad-Dawasir and Najran areas for simplicity.

It is concluded from data presented in Table 7 that total gross margin decreased from cropping pattern actually prevailing in the whole agricultural area depending on Al-Wajid aquifer (Wadi Ad-Dawasir and Najran) was amounted to 91.5 million Saudi Riyals in 2015 of scenario III. Producer surplus was distributed among Wadi Ad-Dawasir and Najran in ratios 66% and 34% respectively. It is also distributed

Table 7 Change in producer surplus under various Scenarios for Al-Wajid aquifer in Saudi Arabia.

Scenario	Year	Total gross margin (million SR)	Change in producer surplus (million SR)	Percent change in producer surplus (%)
I	2009	1,190.7	1.6	0.13
	2010	1,189.02	3.28	0.26
	2011	1,187.4	4.9	0.41
	2012	1,185.7	6.6	0.55
	2013	1,184.1	8.2	0.69
	2014	1,182.5	9.8	0.83
	2015	1,181.0	11.3	0.95
II	2009	1,151.0	41.3	3.5
	2010	1,149.3	43	3.6
	2011	1,147.6	44.7	3.7
	2012	1,146.0	46.3	3.9
	2013	1,144.4	47.9	4.0
	2014	1,142.7	49.6	4.2
	2015	1,141.1	51.2	4.3
III	2009	1,110.7	81.6	6.8
	2010	1,109.1	83.2	7.0
	2011	1,107.4	84.9	7.1
	2012	1,105.8	86.5	7.3
	2013	1,104.2	88.1	7.4
	2014	1,102.5	89.8	7.5
	2015	1,100.8	91.5	7.7

Source: Lp results.

among crop groups as shown in the table.

The first scenario would lead to 0.95% reduction in producer surplus. The second scenario would lead to 4.3% reduction in producer. The third scenario would result in 7.7% reduction in producer surplus. The percentage of reduction would be high in Wadi Ad-Dawasir (16.8%), and low (4.4%) in Najran areas.

5. Conclusion

The Kingdome of Saudi Arabia has implemented a series of policies since 1980 to boost agricultural production so as to ensure a higher level of food security and an improved rural standard of living. The problem is that most of the water used for irrigation is of a non-sustainable nature, both from the economical and environmental point of view. Due to massive abstractions occurred in 1980's, Al-Wajid aquifer water levels have dropped by more than 200 m. The total groundwater of Al-Wajid aquifer that can be saved is equal to 66 MCM for the first scenario, 147 MCM for the second scenario, and 229 MCM for the third scenario. Regarding to welfare analysis impact, it is clear that total gross margin is decreasing under the various scenarios so that producer surplus was reduced by 91.5 million Saudi Riyals in 2015 of third scenario, while water saving reached 18.1%. Therefore, the third scenario with a water saving increase to 18.1% is recommended as a directive for agricultural policy formation in the future.

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