Groundwater use - assessment and options in a dry region of Syria

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ABSTRACT

The Khanasser Valley is a water-scarce region in northwest Syria. Sustainable pumping of groundwater for irrigation of winter and summer crops is of crucial importance in the region. The main objectives of this study were to estimate if current groundwater abstractions were sustainable and to compare alternative use options with respect to productivity and profitability. Groundwater abstractions were assessed by monitoring irrigation on multiple fields and during two consecutive seasons from 2002 to 2004. Domestic water use assessment was mostly based on population data and interviews. Agriculture accounted for about 75% of groundwater abstractions, domestic water-use for the remaining share. Total abstractions were equal to about 2.5% of the long-term rainfall average of 210 mm. Water in agriculture was used for supplemental irrigation of wheat (60%), barley (17.5%) and cumin (4.5%) from October to May. The rest (18%) was applied in summer, mainly to vegetables and olives. The irrigation benefit per unit of labour was highest for wheat while olives achieved the highest benefit per unit of water. During the observation period, farmers used an average of 1600 m³/ha/yr. It was concluded that this value was near the sustainability limit, as the water level remained largely unchanged over this period with near average rainfall.

KEY WORDS

Abstraction monitoring, sustainable groundwater use, water use efficiency, net irrigation benefit, dry areas

1 INTRODUCTION

In many parts of Syria, excessive pumping has caused a lowering of the water tables with negative effects on the irrigation economy due to higher energy and investment costs. The Syrian Government has ratified legislation to safeguard water resources and to stop or possibly reverse the depletion of aquifers. Cabinet Decision 11 of 5 July 2000 was issued at a national level to replace the traditional irrigation techniques with pressurized irrigation systems within 4 years and to support farmers with low interest loans for this purpose. Credit was extended also to farmers in Agricultural Stabilization Zone 4, provided they had a valid well license. Zone 4 receives 200-250 mm annual rainfall and covers about 10% of Syria's land.

The Khanasser Valley (Figure1) is located in Zone 4, approximately 80 km southeast of Aleppo. It stretches 20 km between the Jabboul salt lake in the north and the border of the Syrian steppe near Adami village in the south. Basalt plateaus of the Tertiary age border the valley in the east and west. The annual average long-term rainfall in Khanasser Valley is 209 mm (Bruggeman 2005). The deep calcareous soils in the valley have a silt loam to clay loam texture and basic infiltration rates of around 50 cm/d (Schweers et al. 2004a). Rearing sheep is the most important source of agricultural income and land-use is dominated by the barley-livestock system. Irrigation is used only on about 4% of the cropped area. Most of the irrigation wells have been installed in the early 90s. As a result of a "well boom," the groundwater tables had dropped. At least, this was indicated by the comparison of a few wells with earlier records (Schweers et al. 2003). In 2001, the prohibition of cotton irrigation from groundwater in Zone 4 was enforced. Since then, the area planted with olives has expanded and cumin was introduced as a cash crop alternative.

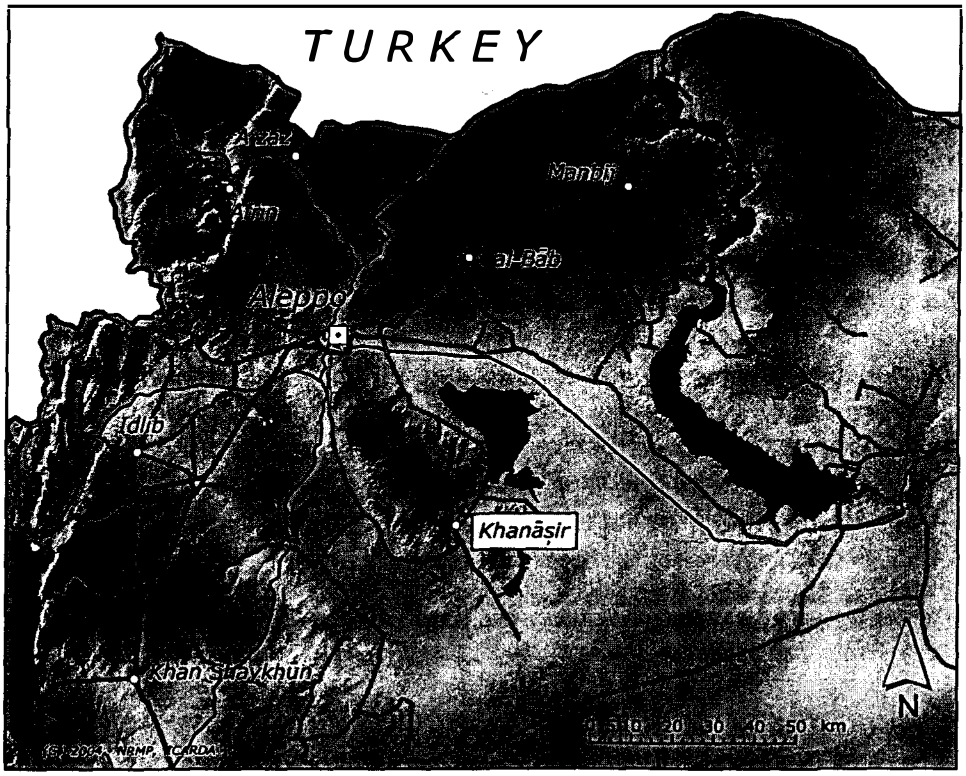

Figure 1 Overview of Northwest Syria with Khanasser Valley

The quantification of recharge as a criterion of sustainable groundwater abstractions in dry areas is difficult. Mathematical groundwater models are useful, but only reliable if accurate input data are available. Collection of such data is often beyond the scope of institutions in developing countries. Simple box models may be used as a substitute for more refined approaches. A box model is based on a simplified concept of the aquifer as a container, which receives and looses water in the form of vertical recharge, groundwater abstractions, groundwater inflows and outflows, water imports and exports. The changes in the water table are related to the balance of these processes and to aquifer storage. For instance, the higher the storage the less sensitive are water table levels to changes in aquifer volume or conversely as in case of the generally low storage found in Khanasser Valley (Schweers et al. 2002). Inflows, outflows and recharge can be grouped together as "net recharge." In case the balance of imports and exports (i.e. piped delivery of drinking water – transport of groundwater out of the watershed) and evaporation from the aquifer within the domain of the model are not significant, the change in storage is determined by:

$$dS = R_{net} - Q_{net} \qquad \text{(Equation 1)}$$

Where:
dS = (+/-) change in water storage
R_{net} = net recharge (inflow – outflow + recharge)
Q_{net} = net groundwater withdrawal (abstractions - return flows)

The change in storage equals the change in the average water level multiplied by the storage coefficient. Aquifer geometries can be determined from information on the stratification of wells or geo-electrical investigations; the storage coefficient can be computed from pumping test results. If the storage is not known for lack of reliable data, net recharge may be approximated from groundwater abstractions if the water table remains at the same level over the observation period, i.e. if there is no change in storage. This method can help to approximate an average net recharge value under the condition that the average rainfall during the period of observation is near the long-term average.

In this contribution, "water-use" is defined as the amount of water abstracted from the aquifer, not the amount actually consumed by crops. The study on water use assessment and water use options in Khanasser Valley was undertaken with the following objectives:

1. To determine the state of groundwater use in one region of the marginal Agricultural Productivity Zone 4 of Syria
2. To use a simple method to estimate net recharge and sustainable abstraction benchmarks
3. To analyse the economic productivity of irrigation in support of decisions for alternative water use options

2 MATERIALS AND METHODS

Rainfall was recorded from automatic weather stations. Irrigated areas were mapped by GPS. Agricultural groundwater abstractions were assessed by irrigation monitoring during two consecutive seasons and the resulting average abstraction volumes of the monitored areas were extrapolated to all mapped areas with the same crops and irrigation methods (Schweers at al 2004b). Since rainfall during the monitored seasons of 2002/03 and 2003/04 was above average, a fictitious dry year with higher abstractions than the average of the monitored seasons was added to estimate long-term abstraction averages for winter crops. Decreasing availability of water during a dry season was taken into consideration, so that the irrigation was taken to be less than could be assumed just by compensating the missing rainfall. In the case of summer crops, the findings during the monitored seasons were considered representative.

Domestic water use assessment was based on average abstractions per capita and per head of livestock. Population figures were taken from Mazid and Al Hassan (2002). The operator of the distribution point of piped Euphrates water at Rasm Anafl in the northern part of the valley gave information on the dimension of water import from this source. Export volumes to the steppe basin were estimated from observations of an elder who had observed the movement of vehicles with water containers out of the Hobs-Harbaqiye valley, a side valley of the southern watershed with occurrence of fresh water. Agronomic and economic data were collected during interviews with farmers.

The effect of full irrigation (100% = crop water requirements – effective rainfall), deficit irrigation (-40% of full irrigation; sprinklers), and over-irrigation for leaching (+40% of full irrigation; basin irrigation) on water use efficiency and irrigation benefit was evaluated during a participatory field trial in the 2003/04 season (Schweers et al. 2004a). The farmer's regular irrigation practice was included for comparison. Deep percolation was computed from the root-zone soil moisture balance, based on successive neutron probe measurements, if the available water exceeded the evapotranspiration values.

$$D = R + Ir - (SM_{i+1} - SM_i) - ET$$

Where:

D	= deep percolation
SM	= soil moisture in the root-zone
R	= rain
Ir	= irrigation
ET	= evapotranspiration
i	= time step index

The ET was estimated using Penman-Montieth. Since the soil moisture in the root zone of basin-irrigated fields was always above 50% of the available soil moisture, it was assumed that the actual ET was not significantly different from the potential value.
The profitability of irrigating crops with different irrigation methods was also assessed. To this end, economic data were collected by interview in consultation with socio-economists to get base data for the calculation of crop budgets. The rainfed net income was subtracted from the net income resulting from irrigation. The differential net income (=irrigated minus rainfed) was then divided by the amount of abstracted groundwater to derive the average differential income per unit of water resource. Family labour, whether paid or unpaid was not accounted as a real cost. Rather, the differential net income was divided by the total family labour hours spent with the irrigated crop (including irrigation hours) to see if and how much additional income (to rainfed income) per family hour was generated as a result of irrigation.

3 Results

3.1 Groundwater Use Assessment

Seasonal rainfall during the period of observation (98/99-04/05) was near the long-term annual average (Figure 2). Despite seasonal fluctuations of +/- 0.5 m the water level remained more or less constant over the whole period (Figure 3). Based on the monitoring results in the 2002-04 seasons and an estimate of higher water-use for a dry year (Table 1), the following rounded average water-use was computed for winter crops: 140 mm (wheat-sprinkler), 360 mm (wheat-surface), 130 mm (barley-sprinkler), 200 mm (barley-surface) and 60 mm (cumin-sprinkler). Under this scenario, an estimated 790,000 m^3 (82%) are abstracted for supplementary irrigation of wheat (60%), barley (17.5%) and cumin (4.5%) and 176,000 (18%) for summer crops (Table 2). In contrast to the situation in 1998/99 (Hoogeveen and Zöbisch 1999) when sprinkler irrigation was exceptional, sprinklers were used on 64% of the irrigated area and delivered 49% of the total irrigation water (Figure 4). The rest was mainly basin irrigation. In a participatory field trial, deep percolation occurred only in one of the four trial sites. The irrigation water had an EC of 9 dS/m and the surplus was excessively high in some locations (425 mm) due to bad land preparation and high pump discharge (35 m^3/hr). In the other surface-irrigated field, the farmer kept soil moisture at a small deficit. Based on the trial results and differences in water-use, return flow from basin irrigation was roughly estimated at 8% for wheat and 4% for barley.

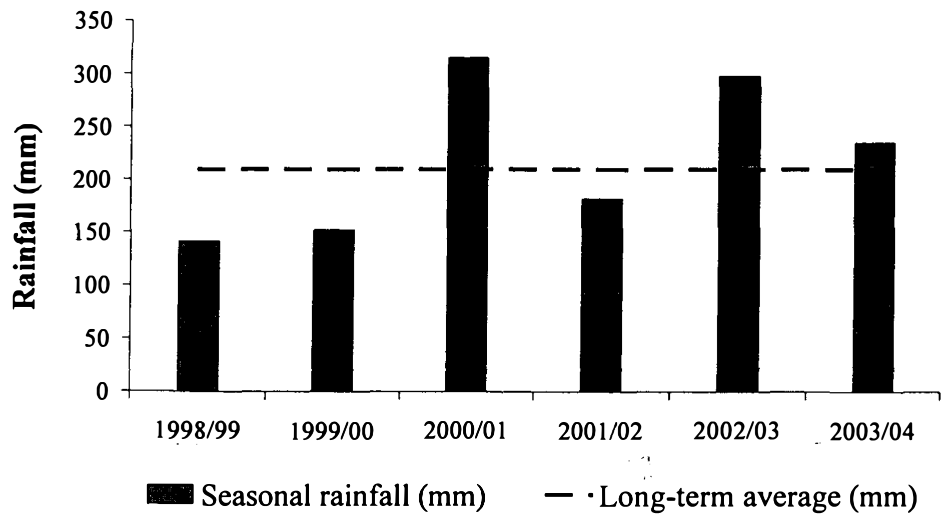

Figure 2 Seasonal rainfall 1998/99 – 2003/04 and long-term annual rainfall average

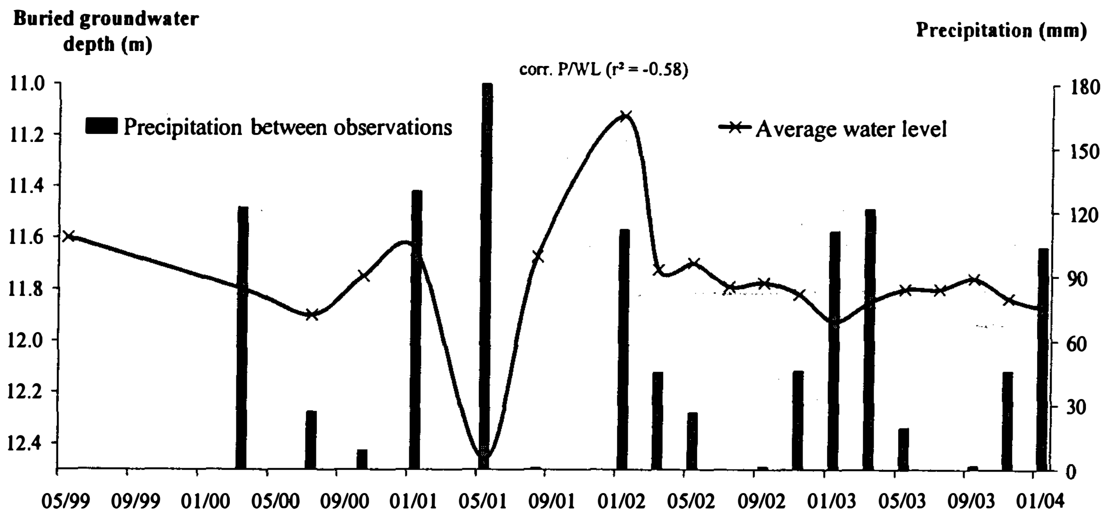

Figure 3 Precipitation and water level fluctuations (average of 2 undisturbed wells)

Net water import into Khanasser valley amounted to 30,000 cubic meters or 10% of total domestic abstractions (Table 3). The domestic water-use per capita was approximately 54 L/day, 10 L more than the middle-east average (FAO 2004). According to the estimate, total drinking water consumption reached 100,000 litres. Local and migrant sheep consumed nearly as much water as the inhabitants of the valley. The remainder, about 50% of the total was used for cleaning, washing, and the irrigation of vegetables in home gardens. Under the condition that during a period of average rainfall, groundwater abstractions were largely in balance with net recharge, its estimate, assuming an error of 20% ranged from 1.9% to 2.9% of the long-term rainfall average (Table 4). For an irrigated area of 600 ha, this resulted in an average equivalent abstraction of 1600 m^3/ha.

Table 1 Monitored area and water-use of winter crops

Crop				Barley		Cumin	Wheat	
Irrigation Method				Sprinkler	Surface	Sprinkler	Sprinkler	Surface
Monitored fields				9	5	5	12	7
Monitored area (ha)				26.8	6.8	7.8	37.5	14.6
2002-03	Rain (mm)	299	Water-use (mm)	95	145	27	105	327
2003-04		235		134	215	84	146	320
Dry year*		93		150	234	73	163	421
Average		209		126	198	61	138	356

*estimate

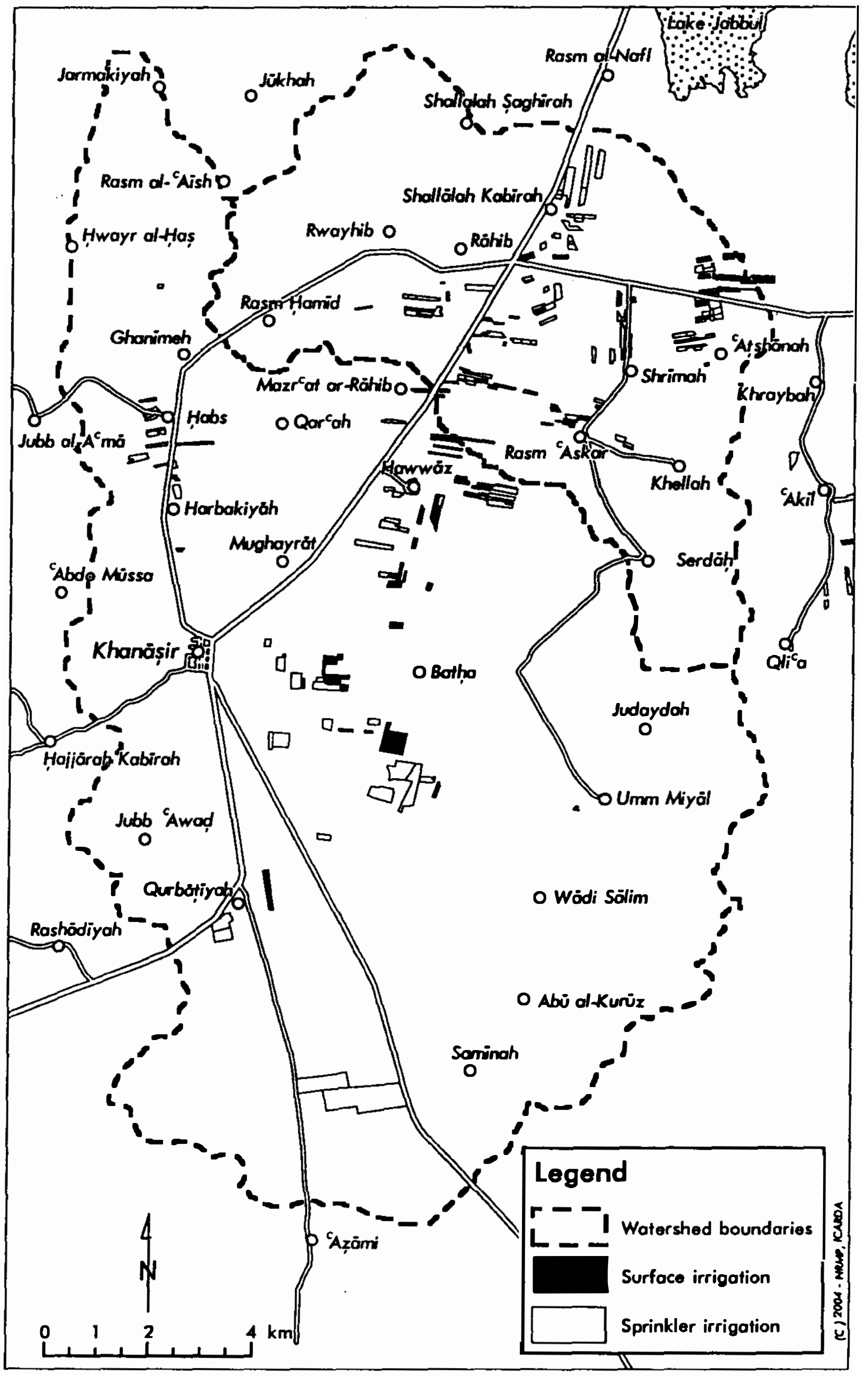

Figure 4 Khanasser Valley, 2002-03 cropping season: Fields irrigated by sprinkler irrigation and surface irrigation (from Schweers et al. 2004b)

Table 2 Agricultural groundwater abstractions

Crops		Irrigation method	Average water-use (m^3/ha)	Total area			
				Area (ha)	Area (%)	WU (m^3)	WU (%)
Winter crops	Wheat	sp	1400	221.6	37.0	310240	32.2
		su	3600	80.1	13.4	288360	29.9
	Re.flow wh (8%)[1]	su	-288			-23069	-2.4
	Barley	sp		89.3	14.9	116090	12.0
		su		28.3	4.7	56600	5.9
	Re.flow ba (4%)[1]	su	-80			-2264	-0.2
	Cumin	sp	600	68.5	11.4	41100	4.3
	Others[2]	sp	800	1.7	0.3	1360	0.1
	Average/Total		1611	489.5	81.7	788417	81.7
Summer crops	Vegetables	su	3300	8.5	1.4	28139	2.9
		dr	4500	3.8	0.6	17100	1.8
	Cotton	su	13500	8.3	1.4	112050	11.6
	Olives	su	300	36.2	6.0	10860	1.1
		dr	250	3.7	0.6	925	0.1
		ta	140	46.2	7.7	6468	0.7
	Others[3]	su	160	3.0	0.5	480	0.0
	Average/Total		1600	110.7	18.3	176022	18.3
All Average/Total			1609	599.2	100.0	964439	100.0

[1]estimate [2]nigella, lentils [3]pistacios sp ='sprinkler su = surface dr = drip

Table 3 Domestic groundwater abstractions

Domestic water-use		Estimated per-capita consumption (m^3/day)	No. of days	No. of residents		Water-use (m^3/yr)		
				North	South	North	South	Total
Drinking water, sanitation	residents	0.020	365	5475	5775	39968	42158	82125
	migrants	0.020	240	1825	1925	8760	9240	18000
	total	-	-	7300	7700	48728	51398	100125
	water import	-	-	-	-	30000	20000	50000
	effective	-	-	-	-	18728	31398	50125
Livestock	residents	0.005	365	12000	28000	21900	51100	73000
	migrants	0.005	90	6000	14000	2700	6300	9000
	total			18000	42000	24600	57400	82000
Other	cleaning, washing, gardens	-	-	-	-	60909	89946	150855
	water export	-	-	-	-	-	21000	21000
Total domestic	-	-	-	-	-	104237	199743	303980

Table 4 Total water-use and recharge estimates

	North		South		Total	
	m^3	%	m^3	%	m^3	%
Agricultural water-use	332268	34.5	632172	65.5	964439	76.0
Domestic water-use	104237	34.3	199743	65.7	303980	24.0
Total water-use	436504	34.6	831915	65.4	1268419	100.0
Watershed area (ha)	7640	30.3	17610	69.7	25250	100.0
Water-use (mm)	5.7		4.7		5.0	

3.2 GROUNDWATER USE OPTIONS

Irrigated yields in the monitored seasons were more representative of average conditions than rainfed yields, which were higher due to excellent rains in the 2002-03 season. The salinity of the irrigation water applied to winter crops was highest for barley, lower for wheat and lowest for cumin. Saline water was used preferably with surface irrigation methods. On average, one third more water was applied to winter crops than needed to satisfy the crop water requirements (Schweers et al. 2004b). In the context of the study, irrigation water use efficiency (WUE_{ir}) was defined as the differential yield (to rainfed yield) in kg per m^3 of abstracted irrigation water. For sprinkler-irrigated wheat (0.79 kg/m^3), it was higher than the rainwater use efficiency (0.62 kg/m^3). In the wet 2002-03 season, supplemental sprinkler irrigation achieved the best irrigation water use efficiency (1.21 kg/m^3). In the following season with just above average rainfall and a long dry period in spring, surface irrigation (0.71 kg/m^3) was more productive than sprinkler irrigation (0.37 kg/m^3).

As compared to the physical efficiency, the economic efficiency of water resources (net irrigation benefit = [differential] net income/irrigation) can better support decisions of choice between crops and irrigation methods. Table 5 shows an economic comparison of irrigated crops grown in Khanasser valley: Grazing lambs in early spring increased the profitability of sprinkler-irrigated barley. According to Pape-Christiansen (2001), 144 kg life weight gain during 6 weeks of grazing resulted in 275 USD gross income. In return to family labour, wheat turned out to be the most profitable crop. Irrigation of cumin at low application rates yielded 0.3 USD per ha·mm. The economic water use efficiency of summer crops was higher than that of winter crops, which derive only a differential income (to the rainfed income) from irrigation. The profitability per land unit was highest in the case of irrigated vegetables. Olives achieved the best irrigation benefit.

Table 5 Water use economy of irrigated crops in Khanasser valley (in USD/ha; in 2003: 50 SYP ≈ 1USD*)

Crop		**Winter crops**					**Summer crops**			
		Barley		**Cumin**	**Wheat**		**Vegetables**		**Olives**	
Irrigation method		**sp**	**su**	**sp**	**sp**	**su**	**dr**	**su**	**dr**	**su**
Income	Yield (kg/ha)	1819	2298	525	2436	3459	45283	40250	2464	1971
	Income (USD/ha)	254.7	321.7	504.0	511.6	726.4	5195.7	3929.2	1478.6	1182.9
	Yield of byproduct. e.g. straw (kg/ha)	3092	3907	-	4141	5880	-	-	-	-
	Income from byproduct (USD/ha)	154.6	195.3	-	207.1	294.0	-	-	-	-
	Other income. e.g. grazing (USD/ha)	273.6	-	-	-	-	-	-	-	-
	Total income	**682.9**	**517.1**	**504.0**	**718.6**	**1020.4**	**5195.7**	**3929.2**	**1478.6**	**1182.9**
Expenditure (excl. family labour)	Cultivation	16.0	40.0	29.8	16.0	40.0	40.0	40.0	19.2	19.2
	Establishment	45.9	57.6	54.3	790.7	100.7	167.3	173.3	7.6	7.6
	Fertilization	44.5	68.8	25.4	67.4	76.6	920.0	920.0	90.4	90.4
	Crop protection	-	-	30.7	19.0	19.0	555.0	555.0	44.1	44.1
	Irrigation	33.1	50.0	15.0	34.4	90.0	162.0	73.0	22.5	15.0
	Harvest	55.2	82.1	70.8	80.8	120.7	400.0	400.0	480.0	480.0
	Other operation costs	136.8	-	-	-	-	821.5	575.0	105.1	105.1
	Capital costs	141.2	83.6	141.2	141.2	83.6	444.2	60.0	83.6	83.6
	Total expenditure	**472.8**	**382.1**	**367.2**	**437.9**	**530.6**	**3510.0**	**2796.3**	**852.6**	**845.1**
Irrigated net income		**210,1**	**135.0**	**136.8**	**280.7**	**489.8**	**1685.7**	**1132.8**	**626.0**	**337.8**
Rainfed	Grain yield	1011	1011	494	951	951	-	-	-	-
	Gross income	227.4	227.4	474.2	280.5	280.5	-	-	-	-
	Expenditure	97.6	97.6	354.5	133.4	133.4	-	-	-	-
	Net income	129.9	129.9	119.8	147.1	147.1	-	-	-	-
Differential income (irrigated - rainfed)		**80.2**	**5.1**	**17.1**	**133.6**	**342.7**		-	-	-
Water	Irrigation amount (mm)	130	200	60	140	360	450	330	90	60
	Net irrigation benefit/cost (USD/ ha·mm)	**0.62**	**0.03**	**0.28**	**0.95**	**0.95**	**3.75**	**3.43**	**6.96**	**5.63**
Labour	Irrigation labour (hrs/ha)	88	133	50	92	240	141	219	30	40
	Other family labour (hrs/ha)	126	44	228	48	66	2295	2295	1284	1284
	Total family labour (hrs/ha)	214	177	278	140	306	2436	2514	1314	1324
	Irrigation labour income (USD/hr)	**0.37**	**0.03**	**0.06**	**0.95**	**1.12**	**0.69**	**0.45**	**0.48**	**0.26**

sp ='sprinkler su =s urface dr = drip *direct comparisons between currencies are distorted by differences in purchasing parity, that way 50 SYP > 1 USD

4 DISCUSSION

4.1 GROUNDWATER USE ASSESSMENT

Farmers of Rahib-Roehib village mentioned that they harvest about 30% more on drip-irrigated vegetable plots than on surface-irrigated plots. Their impression that the amount of water used per unit area had been higher with drip irrigation (4500 m^3/ha) than surface irrigation (3300 m^3/ha) was confirmed by water-use monitoring. Most vegetables, e.g. cucumber have a shorter growth period than for example cotton, which requires 6-7 months. They are grown successively on adjacent plots, a practice that reduces the irrigation volume per unit area. For comparison: In the Angas Bremer district of South-Australia, vegetables received an average of 4900 m^3/ha from 1996/07 to 2002/03 (Thomson 2004). Irrigation of olives in Khanasser was low due to the comparatively young age of plantations (5-6 yrs). Tubeileh et al. (2004) calculated an irrigation requirement of mature olive trees for Khanasser valley of about 1300 m^3/ha. This means, that in the future, olives will require a larger proportion of the available water resources.

It must be conceded that there were uncertainties in the water balance, from the accuracy of the abstraction assessment to the concept that recharge during the period of observation was in balance with groundwater abstractions. Yet, a benchmark value of 1600 m^3/ha abstraction for an irrigated area of around 600 ha in a total watershed area of 252.5 km^2 (with around 300,000 m^3 domestic abstractions) could be taken as a point of departure for delineating sustainable groundwater abstractions. Further observations should be made to validate the dimension of the sustainable average abstraction value. According to Wagner (1998) *"groundwater balance estimates may also be made for selected areas, if a relationship between water level fluctuations, groundwater extraction volumes and rainfall can be found. The necessary information may be obtained from water level monitoring in unused boreholes at monthly to 3-monthly intervals, assessment of groundwater extraction through interviews of farmers and calculation from irrigated areas and rainfall data."* Such approach obviously presupposes that a realistic value for the storage component can be obtained. As long as both net recharge and storage remain unknown, the solution of the balance formula remains ambiguous. This ambiguity can be resolved only if either rainfall is so little, that net recharge in some season is next to zero or if water levels remain unchanged over a certain period.

4.2 Groundwater Use Options

Despite the fact that the physical water use efficiency of sprinkler-irrigated wheat was on the average 25% higher than surface-irrigated wheat, the net irrigation benefit per unit of water (USD/ha·mm) and labour (USD/labour hr) was about equal for both methods (~1 USD). Moreover, the net irrigation benefit per unit of land was about twice as high in the case of surface irrigation due to higher yields. Surface irrigation is not generally inappropriate in dry areas, but deserves a more differentiated view. Agricultural producers with lower quality water usually have no alternative for staple food production in such areas. Farmers like well owner No. 27 from Atshaneh village proved that surface irrigation, with good land levelling and diligent irrigation management can easily top the water use efficiency of sprinkler irrigation under near average seasonal rainfall conditions ($WUE_i > 2$ kg/m³; EC_i 3.2 dS/m; seasonal rain: 235mm).

At first sight, barley was apparently not worth irrigating unless it served to bridge a serious gap in moisture supply at a crucial development stage. However, this view does not take into account the fact that farmers are using the yield, which is higher in the case of irrigated production, as ration for sheep fattening, a largely profitable enterprise. Similarly, the irrigation of barley for the purpose of rearing sheep in early spring, when other grazing sources are rare, was a profitable activity. Especially lambs can grow well on the fresh barley shoots. Sprinkler irrigation was the method of choice, because it stimulates vegetative growth, at least if the water is not saline and the air temperature still moderate. The farmers were watering barley quite intensively until tillering. Then the sheep were kept out, not to harm generative growth further than already the case from the reduction of assimilating biomass. Generally, barley was not receiving much water after grazing had stopped.

On average, irrigating cumin was profitable, but like the profitability of the enterprise as a whole, this depended much on the market price of cumin, which underwent frequent fluctuations. In the context of this study, a price of near 1 USD/kg was assumed representative as prices were fluctuating within a range of about 0.6 USD/kg to 1.4 USD/kg. Irrigating cumin after flowering and with an EC of more than 6 dS/m was usually not beneficial. In some cases too much water boosted the growth of weeds that ended up suffocating the small plants. The crop was labour intensive. Weeding and harvesting were quite costly if cheap family labour was not available. Herbicides, like Afalon® could be applied without harm to the host crop only at very early development stages.

Vegetables appeared to be quite attractive financially, besides being a source of healthy food that carries an opportunity benefit for not having to be purchased at higher rates than the production cost and transported from far. However, this enterprise requires experience, skills and a considerable amount of labour, about 1200 hrs/ha. Investment costs for drip equipment were approximately 2000 USD/ha with short depreciation periods for tubes and fittings. Sufficient income is therefore needed to pay back the investment. Some risks remain in form of market price fluctuations and diseases or pests. Good quality water (< 4 dS/m) is conditional, since many vegetables, like for example cucumber yield less than 50% of their potential at an electrical conductivity of the irrigation water above 4 dS/m (Ayers and Westcot 1994). According to Tubeileh et al. (2004), care must be taken with intercropping of olives and vegetables, as they could be a source of *Verticillium* wilt for the trees.

In view of the relatively low irrigation requirement of olives trees, the economic efficiency of applying water to olives was found to be high. Whereas the assumption that olives do not yield without irrigation or water harvesting in Khanasser valley may not be true in exceptionally good rainfall years, the yield of rainfed olives in the valley remains below a commercially lucrative level under average rainfall conditions. The cumulative number of trees planted (Tubeileh et al. 2004) gave evidence to the popularity of olive trees as a potential source of income. With water of sufficient quality (~ 6 dS/m; Gucci and Tattini 1997), more land than water, family members who can help with the harvest, and with knowledge of tree husbandry, olive groves are attractive to farmers in Khanasser Valley. Provided Syria manages to further promote export sales of good quality oil, the price level should remain profitable.

With few options available, the Khanasser farmers usually opt for a mix of products, practicing risk minimization. Unknown exterior factors, like marketing, prices and policies make rational optimization of water resource use a difficult task. On most farms land is not the limiting production factor. But besides water, being the scarcest, labour availability can also be decisive. Farmers with sheep have a preference for barley, those with access to family labour opt for summer crops or cumin if they speculate on a short-supplied market, and those with few children to help in agriculture might prefer extending the irrigated area grown with wheat. Of course, the construction of wells and the purchase of pumps and motors or pressurized irrigation systems require capital, which poorer farmers simply do not have. So the financial resources, including income from activities outside the farm, also determine what is feasible.

The crop rotation in this marginal environment is fairly monotonous. So far, only crops, which can provide some yield without irrigation, have occupied a lasting position in the production system. It would be most desirable to increase the diversity of the current rotation, for example with drought resistant legumes and oil crops. Sturdy windbreaks, which produce fodder or wood, could reduce advective evaporation and save some soil moisture for better plant growth. Manuring the Khanasser soils is expensive, but probably worth the investment. Apart from creating better soil fertility and structure, manure also improves soil moisture characteristics (Martens and Frankenberger 1992).

5 SUMMARY AND CONCLUSIONS

Since the groundwater level was predominantly stable during the period of observation, it was concluded that at the present rate, groundwater use in Khanasser valley was largely sustainable and in balance with an estimated average annual net groundwater recharge of 2 - 3 % of the precipitation. This finding, which yet neglects potential adverse effects resulting from the use of saline groundwater, was largely credited to a change in the composition of the irrigated area starting at the end of the 90s, with more olives and the near disappearance of cotton after its prohibition in Agricultural Productivity Zone 4.

Cumin had become quite common in the rotation, some of it irrigated with small amounts. This made sense in case of a significant deficit before flowering, provided the water was of an appropriate quality. Barley was unattractive as a source of cash income by itself. However, the sheep economy benefited from an increased production of ration feed and grazing of sprinkler-irrigated barley after the birth of lambs in early spring. Wheat accounted for 50% of the irrigated area (with 75% of wheat under sprinkler irrigation) and consumed 60% of the total irrigation water. In view of a high irrigation water use efficiency (6-8 kg/ha·mm) and labour productivity, wheat was still a good source of income for the farmers of Khanasser valley: 0.95 USD per ha·mm and about 1 USD per family labour hour equally with application of 140 mm (sprinkler) and 360 mm (basin) and corresponding yields of around 2400 kg/ha (sprinkler) and 3500 kg/ha (basin).

Family labour was an asset for the farmers who ventured into vegetables and/or olives due to the high labour requirement. On the observed farms, drip-irrigated vegetables were better supplied with water and therefore more productive. With good performance and sufficient demand of vegetable products, the income per ha could be as high as 1700 USD/ha, but this required 2400 labour hours. Olives were also labour intensive, especially at harvest, which is rather costly without cheap family labour. The net benefit per unit of good quality water applied to well-adapted olive varieties with proper management was highest: around 6 USD/ha·mm at 75 mm irrigation for mature orchards. In a water-scarce area like Khanasser such high economic productivity is an advantage. Due to the related costs, an incremental benefit from irrigation cannot be taken for granted and water needs to be applied wisely to be profitable. The fragility of the natural environment was reflected by a fragility of the production system and its economic viability even with the use of irrigation. As socio-economic factors and environmental factors are intricately linked, the economic feasibility of agricultural enterprises is a key element conditioning the sustainable use of natural resources in marginal dry areas.

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