View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Universiti Putra Malaysia Institutional Reposit

ISSN: 0128-7680

Pertanika J. Sci. & Technol. **19 (2)**: 213 – 227 (2011)

© Universiti Putra Malaysia Press

Short Communications

Impact of Water Resources Availability on Agricultural Sustainability in the Gavkhuni River Basin, Iran

Hamidreza Salemi[1], Mohd Amin Mohd Soom[2], Teang Shui Lee[1*] and Mohd Kamil Yusoff[3]

[1]*Department of Biological and Agricultural Engineering,*
Faculty of Engineering,
[2]*Smart Farming Technology Laboratory,*
Institute of Advance Technology (ITMA),
[3]*Department of Environmental Sciences,*
Faculty of Environmental Studies,
Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
[*]*E-mail: tslee@eng.upm.edu.my*

ABSTRACT

One of the most interesting water management case studies in Iran is the case of Zayandehrud River, the main river that supplies water to Isfahan Province which is located in Gavkhuni River Basin (GRB). This paper examines the present and future demands for water and determines the extent to which water will be available for agricultural use by the year 2020. Although demand and supply conditions in 2000 were more or less in balance, there was an increase in the supply of some 28% by 2010 due to the completion of the third trans-basin diversion and the development of other local water sources. However, the demand exceeded its supply in 2010 and the basin fell into severe deficit. In this condition, the only way to keep supply and demand in balance is to reduce allocations to agriculture. By 2020, agriculture would only have 5% more water than the present and water supply is only 90% that of the normal, and this would then shrink from 2025 onwards. In other words, agriculture would have to be sacrificed in order to ensure full supplies of water for the other sectors. The scenarios examined reveal that a sustainable agriculture can only be accomplished by water saving practices and management measures, which may further lead to reduced demand, control supplies, and improve the efficiency of water use.

Keywords: Water supply, water demand, Gavkhuni River Basin, Iran

INTRODUCTION

By 2025 AD, the population of Iran is expected to reach a level of around 97 million. In order to meet the food demand of the increasing population, food grain production has to be raised from 34 million tons in 1999–2000 to 48 million tons by 2025 (Ahmadi, 2008). Besides, the share of irrigation water to the agriculture sector is likely to go down due to the increasing urban and industrial needs. Despite continuing efforts to augment water supplies through reservoir construction and transbasin diversions, the Gavkhuni River Basin (GRB) in the centre of Iran is in water deficit, and it shows all of the symptoms of a basin where water is apparently insufficient. In fact, there are higher competitions for water between different sectors which are highly vulnerable to small water deficits, deteriorating water quality along the river due to salinity and industrial pollution, and shortage of water has now reached the Gavkhuni swamp that is located at the tail end of the river. Yet, the

[*]Corresponding Author

demand for water is growing with the increasing multiple uses within the basin, and this causes the currently fragile situation under an even greater threat. Morid *et al*. (2003) investigated the future impacts and adaptation strategies of climatic change on the water resources, food production, and environmental preservation of the GRB for two periods, namely 2010-2039 and 2070-2099. The results showed negative impacts on the total cropped area and available water resources in the river basin. Through a linear optimization model, Hsu & Cheng (2002) showed that the water shortage is smaller than that computed through a simulation model; hence, the well-calibrated simulation model was used to analyze future water supply-demand conditions for the basin area in Taiwan.

Lévite *et al*. (2003) revealed that demand management alone would not suffice during dry years where users were not able to meet all their requirements from the river. Nonetheless, the adoption of water supply-demand management procedures has offered opportunities for remedying this situation. Karamouz *et al*. (2004) applied a drought characteristic algorithm at Isfahan region and determined the probability of water shortages for a horizon of 30 years. The results showed the significant value of the proposed methodology for drought studies in arid and semi-arid regions with limited data availability. Meanwhile, Moghaddasi *et al*. (2009) found that the optimization method resulted in 42% more income for the agricultural sector, using the same amount of water allocated in the 1999 GRB drought. They stated that the optimization method could be applied to evaluate the different scenarios of deficit irrigation and water reallocation issues with minor modifications. Salemi & Murray-Rust (2002) attempted to balance out the supply and demand in the GRB, and selected agricultural sector which had to give up water, partly because it is the largest user of water in the basin, and because other sectors have higher priorities for human health and welfare. An important lesson deduced from many river basins is that agriculture is constrained by a double squeeze, usually after a phase of over-expansion due to basin over-development. On the supply side, water availability is sometimes reduced by long-term trend due to climate change. On the demand side, the large historical share of agricultural use collides with urbanization and environmentalism (Molle & Wester, 2009).

This paper addresses the issues of forecasting and optimization of water demands for different sectors at basin level, and proposes a number of scenarios that can be used as inputs into the different conditions adopted for the basin. These forecasts are based on a simple budgeting process rather than a strict water balance because the interest is in assessing the impact on agriculture and water allocation between different sectors and uses. In addition, the results of this paper can help guide policy makers and planners to a desirable solution on how to efficiently manage basin water resources.

MATERIALS AND METHODS

Study Area

With an area of 41,500 km^2, the GRB is located in the central part of Iran, and in the geographical coordinates between 50º 24' to 53º 24' longitudes and 31º 11' to 33º 42'N latitudes. The majority of the basin is a typical arid and semi-arid region, with an average rainfall of 165 mm that is concentrated throughout the months of December to May and it is almost impossible to have any economic form of agriculture without reliable irrigation. Modern surface irrigation was started in the 1970s with the completion of Chadegan reservoir and the construction of six irrigation networks. The command areas of these networks are about 297,000 hectares. The location of the study area and major irrigation networks in the GRB, as well as the overall layout of the different irrigation networks in the river basin is shown in *Fig. 1*.

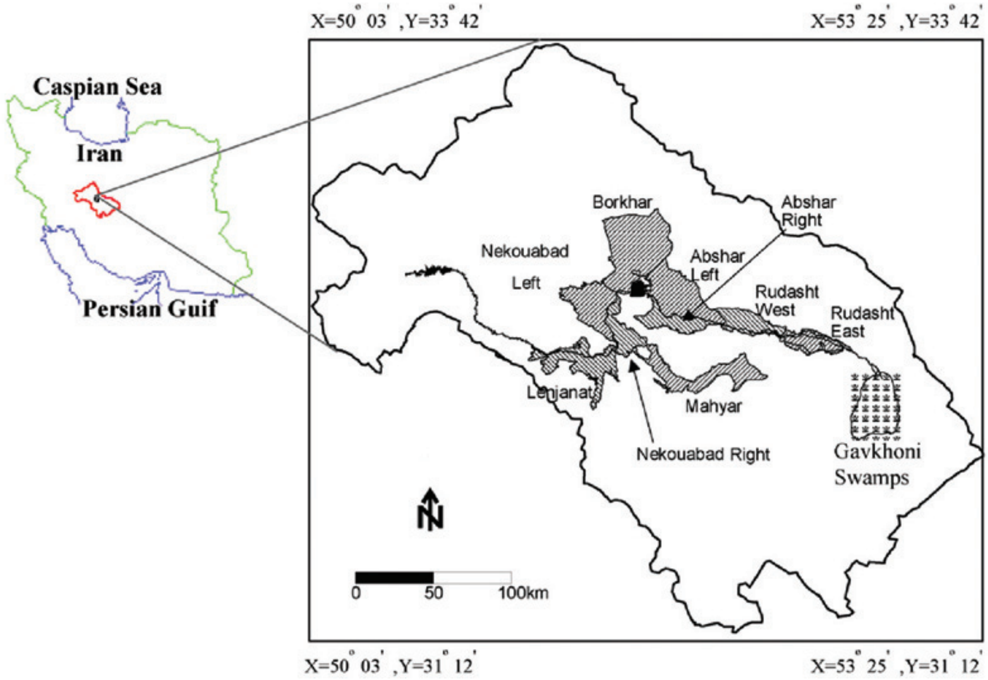

Fig. 1: Location of study area and major irrigation networks in the GRB, Isfahan, Iran

Institutional Arrangements

The main responsible entity for water resources exploitation and distribution is the Isfahan Water Authority that is supervised by the Ministry of Energy, Iran. This institute is responsible for large size water projects, although to some extent, small ones are also considered by them. The water distribution up to the tertiary irrigation channel level of the irrigation systems is also the responsibility of the Ministry of Energy. Meanwhile, the Isfahan Agriculture Authority, that is supervised by the Ministry of Jehad-Keshavarzy (Agriculture), Iran, coordinates the water distribution in the tertiary and lower level channel networks. The environmental issues in the basin are within the jurisdiction of the Isfahan Environment Authority of the Iranian Environment Organization, an independent organization which is directly under the supervision of the President of Iran (Morid *et al*., 2003). The master plan organization of the Isfahan province, the organization of plan and budget, as well as some consulting engineering companies, have been actively focusing on comprehensive studies for agriculture development of the GRB and the river ecosystem.

Scenarios

Scenarios are estimations of different combinations of supply and demand based on the assumptions that reflect the current and expected conditions in the future. Different scenarios on the basin scale have been used to explore alternatives in terms of different water resources. Many of the assumptions made in this paper were the results of various discussions held with the representatives of the Isfahan Regional Office at the Ministry of Energy, Iran, the Master Plan Organization of Isfahan Province, and the Agricultural Organization of the Ministry of Agriculture. Additional information has been obtained from Momtazpur (1996), Zahabsanei (2002), and Anonymous (1993; 2007). A full description of the hydrology of the basin is available in Murray-Rust *et al*. (2001).

From the range of possible scenarios, four have been selected for further analyses: (1) all sectors grow at 1% per annum; (2) all sectors grow at 2% per annum, (3) high urban growth, moderate growth in other sectors, and (4) high urban growth modest industrial growth, agricultural demand adjusted to balance out overall basin level supply and demand. Scenarios are the estimations of different combinations of supply and demand, based on the assumptions that reflect the condition in 2000 and the expected conditions in the future. It is important to highlight that these are not wild guesses, but they have been designed to offer policy makers and planners alike a set of alternatives from which to choose from. Nevertheless, complex scenarios may have different combinations of increases and decreases in the demand, alongside a different set of assumptions about supply. The conditions in 2000 were selected as the base year due to the more or less balance between the demand and supply in that year.

Water Supply in 2000

Water supply to the networks was obtained by analyzing the data provided by the Ministry of Energy, Iran, on a monthly basis for 1999-2000. There are several sources of water supply in the basin that need to be included in the assessment of the scenario. The natural in-flow into the Chadegan reservoir on an annual basis from the long-term historical yield over the past 30 years was approximately 900 million cubic meters (MCM). There are three tunnels to transfer the water from the Kurang River into the catchments of Chadegan Reservoir. The first two tunnels (Kurang tunnels No. 1 and No. 2) were constructed in 1953 and 1986, respectively, supplying 337 and 250 MCM each year. The third tunnel, which is still currently under construction, will deliver an additional of 280 MCM per year. There are a few springs and other natural sources of water that are still available for development, with a total annual yield of about 150 MCM. The phases of water resources development of the basin during time period of 1945-2020 is illustrated in *Fig. 2*.

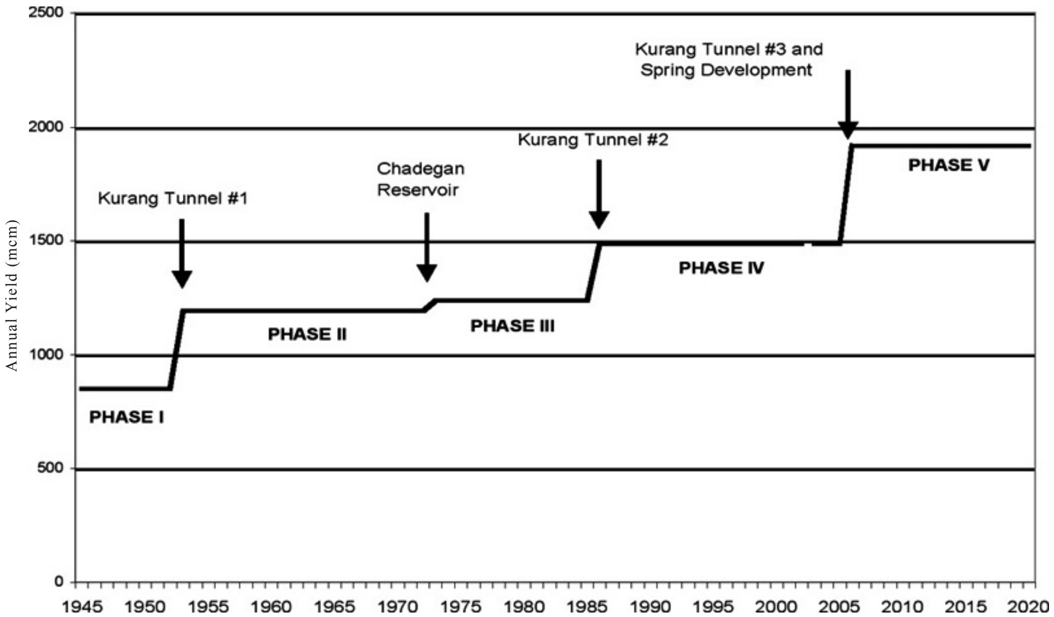

Fig. 2: Phases of water resources development in the GRB (1945-2020)

Water Demand in 2000

Estimating the demand for water is much more difficult because many water abstractions are only estimates, and a set of assumptions about the return flows into the river from different uses are required. These are estimated at about 50% and 20% of the total diversions for the urban and agricultural demands, respectively (Droogers *et al*., 2001). The figures are the best estimates available for the current demand patterns based on the figures for 2000. Greater Isfahan and its surrounding areas are estimated to have a population of about 2.3 million people. The fastest Isfahan population growth was between 1956 and 1986, averaging close to 7% a year; however, in the past twenty years, this has slowed to between 2-2.5% a year, while population outside the city has risen to 2.5-3% a year (Khoshakhlagh, 2005). The per capita of water availability is high, i.e. as much as 275 l/day (Anonymous, 2005) or around 210 MCM per year. There are specific large water users in the basin, and these include cement works, steel works, iron smelter, oil refinery, and electricity generation which demand 100 MCM. Meanwhile, the agricultural water demand was estimated by applying FAO-CROPWAT (Smith, 1991) programmes. The crop evapotranspiration of 10 crops selected as staple crops out of a total of 45 grown in the basin was estimated using the programme and by multiplying the results with the cropping pattern in each network. The data records for the local meteorological stations and statistical yearbook by province were used for these purposes. In the year 2000, there was no specific allocation of water for the protection of the Gavkhuni Swamp, but the Environment Organization of Isfahan called for a minimum flow of 70 MCM per year into Gavkhuni Swamp. In addition, 34 MCM could be delivered to neighbouring cities, and this would rise to 125 MCM before 2010. Inevitably, there are unaccounted “losses” in any large basin by evaporation from the reservoir, the river surface, and other non-beneficial depletions. It is estimated to be 75 MCM or about 5% of the total river flow. Based on all of these estimates, the total current demand is estimated to be 1513 MCM.

RESULTS AND DISCUSSION

Results

Baseline scenario: The condition in 2000

Based on these figures, the baseline scenario for 2000 levels of water supply and demand is presented. It is perfectly clear that even with average flows, the basin suffers deficit, in the order of 26 MCM, or roughly 2% of the total available water in a normal year. The baseline scenario can be used to justify the need to increase the transbasin diversions because the present water resources are clearly inadequate to sustain the current levels of economic development, let alone permit continued growth. Table 1 summarizes the main supplies and demands for water in the GRB in 2000.

Calculation of crop water requirement

The long-term meteorological data from 1984 to 2000, recorded by the local agricultural weather station, were applied to the CROPWAT model to calculate crop evapotranspiration. Estimating the demand for irrigation water is much more difficult because the cropping data are reported by the district level only, and these do not coincide with the irrigation system boundaries. However, the combinations of district and village data gave reliable results and were used for the calculation of the crop water requirements. Thus, the crop water requirements obtained were then applied to the estimated crop areas and the cropping patterns to determine the water demands of the irrigation networks in 2000. It is noteworthy to mention that not all of the cultivated areas are directly fed by the Zayandehrud River. The major irrigation networks are located along the river. The total area

TABLE 1
Water balance for Zayandehrud Basin, Isfahan

Supply estimations	MCM	%	Source/Assumption
Natural flow of river at Chadegan	900	61	Based on historic average
Kurang tunnel 1	337	23	Ministry of Energy
Kurang tunnel 2	250	17	Ministry of Energy
Kurang tunnel 3	0	0	Ministry of Energy
Langan and Khadangestan springs	0	0	Ministry of Energy
Total supply	1487		
Demand estimations			
Urban areas			
Greater Esfahan	210		275 lit/day/person for 2,300,000 people
Supply for other cities near river	0		
Total urban supply	210	14	
Return flows from urban areas	-105	-7	50% return flow
Industry	100	7	Master plan organization
Agriculture	1500	101	100,000 ha at 1500 mm/year diversion
Return flows from agriculture	-300	-20	20% return flow none
Environmental demand	0	0	None
Transbasin diversion	34	2	Ministry of Energy
Evaporation	74	5	5% of total river flow
Total demand	1513		
Deficit	-26	-2	

of these networks is estimated to be about 100,000 ha, whereby Nekuabad, Abshar, Borkhar and Rudasht are the major irrigation systems in the basin (*Fig. 1*). It is estimated that water consumption per hectare for wheat, barley, rice, sunflower, cotton, silage maize, potato, onion, tomato, and lentil varies from 6,000 to 20,500 cubic meters. On average, water extractions depend on the cropped area is 1500 mm during the growing season, or a total annual demand of 1500 MCM. This makes agriculture by far the largest single user of water in the basin, i.e. consuming 73% of the river yield (*Fig. 3*).

Qualitative assessment of the scenarios using WSBM

To evaluate the qualitative effects of the different scenarios, WSBM (Water and Salinity Basin Model) was used in MS-Excel 2000 spreadsheet. The effects of lower return flows from irrigation, due to the drop in basin level supply and higher water use efficiency, have subsequently had almost no impact on the upstream part of the basin, but the effects could be seen from Nekuabad network and the downstream areas (*Fig. 1*). Meanwhile, the effect of the increase in water extraction for Greater Isfahan was evaluated based on the assumption of the growth in the population (i.e. from 2 million to 3 million) and an increase in per capita use (i.e. from 200 l/d to 400 l/d) as a result of higher standard of living. There was an increase in water demand for irrigation (Droogers *et al*., 2001).

Future scenarios (2010 and 2020) based on the average conditions

There is obviously a wide range of potential scenarios available but it is useful to pick the ones that enable the researchers to make realistic choices for planners and policy makers. This paper projected GRB's water future in 2010 and 2020 and assessed their sensitivities with respect to water demand options. Hence, two additions to the demand estimations of the baseline scenario were proposed.

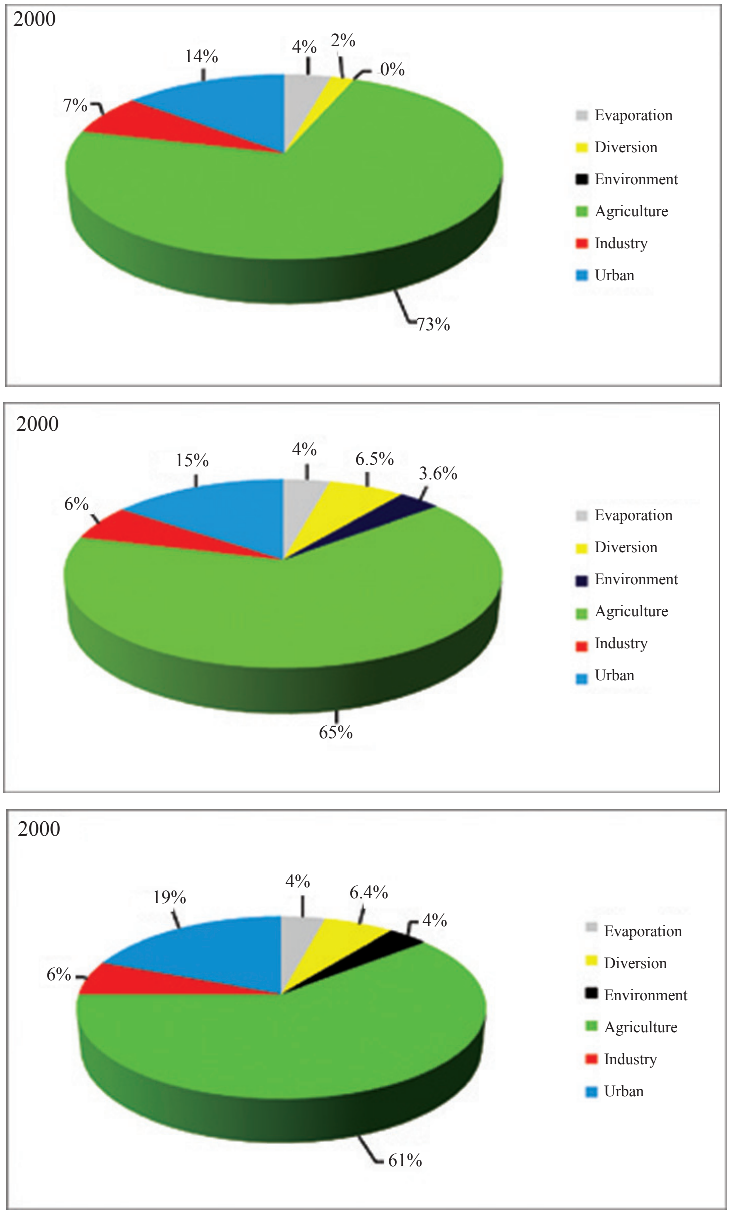

Fig. 3: Net water allocations by sector when water supplies are 20% below average (return flows have been deducted from urban and agricultural allocations)
Source: Isfahan Regional Office of the Ministry of Energy, Iran

First, water allocation to the neighbouring city was assumed to rise as planned, i.e. from 34 MCM per year to 125 MCM per year. This system does not generate any return flow to the Zayandehrud River. Second, an implemented environmental demand was assumed to maintain the in-stream flows along the river to increase the flow into the tail-end Gavkhouni Swamp. This has been fixed at 70 MCM per year. In addition, the two additional water demands remain constant throughout all of the scenarios and result in an additional demand over the baseline scenario of 161 MCM per year. To compensate for this on the supply side, however, the third tunnel at Kurang was assumed to be completed and function as designed, i.e. providing an additional of 280 MCM per year. The locally developed springs would provide 150 MCM more, and hence, giving a total increase in the supply of 430 MCM, increasing the total water available to the basin under the average conditions (i.e. from 1487 MCM to 1917 MCM). The effect of these on-off changes in the supply and demand results in a net annual increase of 259 MCM (i.e. 430 increases in supply less 171 MCM increase in demand to transbasin and environmental commitments). In this study, this was assumed to be the maximum additional water availability to be expected under the average conditions.

Scenario 1: All sectors grow at 1% per annum

In this scenario, all the sectors were assumed to only grow at 1% per annum over the next 20 years. Based on this scenario in 2010, the additional water from Kurang and local sources would be sufficient enough to meet the increased demand, and there would even be a 3% surplus of supply over demand. By 2020, however, the deficit would be similar to that experienced in 2000. This is considered to be a realistic scenario in terms of supply but it has economic implications because a mandatory very low growth of Isfahan is required. In other words, to expect the current rapid growth of the city and its surroundings to fall to only 1% a year would require a great deal of intervention which may not be feasible at all.

Scenario 2: All sectors grow at 2% per annum

In this scenario, all sectors (i.e. urban, industrial, and agriculture) were assumed to grow at 2% a year for the next 20 years. Under this scenario, it is clear that despite the increases in the supply, the basin will continue to be in deficit in both 2010 and 2020. In 2010, the deficit is slightly larger than what is currently experienced, i.e. at 67 MCM or 3% of the total supply. By 2020, however, the deficit reaches 406 MCM or 17% of the available supply. This scenario appears unsustainable and it is therefore rejected as a rather unrealistic option.

Scenario 3: High urban growth, moderate growth in other sectors

The increased water demand for the urban water supply has only a minor effect on the water balance of the basin. The two main reasons are that these extractions are relatively low as compared to the agricultural demands and that the return flow from urban extractions is high. In this scenario, it was assumed that there would be a much greater increase in the urban demand than those in the other sectors. The urban demand was estimated to rise by 25% each decade, while those of the industrial and agriculture grow by only 10% each decade. Meanwhile, the recent growth rates for Isfahan have been high, and water consumption patterns may change over time. Therefore, an increase in the urban demand was anticipated to grow from 210 MCM at present to 273MCM in 2010 and 355 MCM in 2020. In addition, a total of 15 MCM would be required for the upstream city in 2010, rising to 20 MCM in 2020. Under these assumptions, the basin would be able to meet all the water demands in 2010, but this would drop into a substantial deficit by 2020.

Table 2 summarizes the impacts of these three scenarios on the overall basin surpluses and deficits. Although the overall situation is favourable for scenarios 2 and 3 in 2010, all will be in a substantial deficit by 2020 and it is felt that none of these scenarios is really realistic. Hence, an alternative approach as illustrated in scenario 4 was proposed.

TABLE 2
Basin level surplus/deficit of water under different growth scenarios

Scenario	Supply	Demand	Surplus/ Deficit	Supply	Demand	Surplus/ Deficit	Supply	Demand	Surplus/ Deficit
1	1487	1513	-26	1917	1844	73	1917	2323	-406
2	1487	1513	-26	1917	1984	-67	1917	1999	-82
3	1487	1513	-26	1917	1865	52	1917	2051	-134

TABLE 3
Water balance for Zayandehrud Basin, Isfahan, Scenario 4: Higher urban demand, agricultural sector adjusted to balance supply and demand

Year	2000		2010		2020	
Supply estimations	MCM	%	MCM	%	MCM	%
Natural flow of river at Chadegan	900	61	900	47	900	47
Kurang tunnel 1	337	23	337	18	337	18
Kurang tunnel 2	250	17	250	13	250	13
Kurang tunnel 3	0	0	280	15	280	15
Langan and Khadangestan springs	0	0	150	8	150	8
Total supply	1487		1917		1917	
Demand estimations						
Urban areas						
Greater Esfahan	210		273		355	
Supply for other cities near river	0		15		20	
Total urban supply	210	14	288	15	375	20
Return flows from urban areas	-105	-7	-144	-8	-187	-10
Industry	100	7	110	6	121	6
Agriculture	1500	101	1715	89	1647	86
Return flows from agriculture	-300	-20	-343	-18	-329	-17
Environmental demand	0	0	70	4	70	4
Transbasin diversion	34	2	125	7	125	7
Evaporation	74	5	96	5	96	5
Total demand	1513		1917		1917	
Deficit	-26	-2	0	0	0	0

Scenario 4: High urban growth with modest industrial growth, agricultural demand adjusted to balance out the overall basin level supply and demand

In this scenario, an increase was assumed in the urban demand, as illustrated in scenario 3, a 1% growth rate in industrial water demand, and a balanced supply and demand for water at the basin level. This is accomplished by adjusting the water available for agriculture so as to obtain a proper balance between the supply and demand. Traditionally, the agricultural sector has been blamed for the deficit in the water resources since it is the major water resource consumer with low irrigation efficiency. The drastic reduction of the amount of water diverted to irrigation areas in 2001 and 2002 illustrates how agriculture gets squeezed in times of shortage, while other uses get the priority.

In 2010, the increases in water supply allow for an increase in the net water allocation for agriculture up to 1372 MCM, a growth of about 1.4% per annum over the current levels; nevertheless, by 2020, the residual available to agriculture would be back to about 1318 MCM, or an overall growth of only 0.5% per year over the current levels. Details are provided in Table 3. Unpalatable as this may seem for agriculture, this scenario appears to be the most realistic and it forms the basis for assessing the impact of deviations from average. The allocations by sector for 2000 to 2020 are shown in Table 4. In reality, however, there is rarely an "average" year with supplies ranging significantly on a year-to-year basis. To illustrate the impact of this, Scenario 4 was adapted to allow for two different levels of water deficit and one surplus. The urban, industrial, environmental, and transbasin diversion requirements all remain the same, the impact being absorbed entirely by the agricultural sector. One critical assumption made here is that the transbasin diversions into the basin would reflect the overall changes in water supply through natural flows. This has indeed occurred over the years, such that in years of low rainfall and snowfall, the tunnels at Kurang cannot run at full discharge.

TABLE 4
Effect on agriculture sector allocations when supply and demand are balanced out

	2000			2010			2020		
Scenario	Basin supply	Supply to agri-culture	Change from 2000	Basin supply	Supply to agri-culture	Change from 2000	Basin supply	Supply to agri-culture	Change from 2000
4	1487	1200	0	1917	1372	172	1917	1318	118
4.1	1338	1032	-168	1726	1190	-20	1726	1136	-64
4.2	1190	891	-309	1534	1008	-192	1534	954	-246

i. Scenario 4.1: 10% drop in discharge into Chadegan Reservoir

The impact of a 10% flow reduction into Chadegan is substantial. Under the present conditions, this would mean a drop in the supply, i.e. from 1487 to 1338 MCM, and a drop from 1917 MCM to 1725 MCM, once all the water sources have been developed. Details are given in Table 5. If agriculture takes the full impact of this reduction, the present day net allocation to agriculture would then be only 1032 MCM, rising to 1190 MCM in 2010 and falling again to 1136 MCM by 2020. Thus, a 10% reduction in the supply means that there will never be as much water for agriculture as it is under the present day conditions.

ii. Scenario 4.2: 20% drop in discharge into Chadegan Reservoir

The impact of a 20% flow reduction into Chadegan is substantial, where agriculture gets about 25% less water than that under the assumptions of Scenario 4. Under the present conditions, this would mean a drop in the basin level supply (i.e. from 1487 to 1190 MCM) and a drop from 1917 MCM to 1534 MCM, once all the water sources have been developed (Table 6). If agriculture takes the full impact of this reduction, the present day net allocation would only be 891 MCM, i.e.

TABLE 5
Water balance for Zayandeh rud, Isfahan, Scenario 4.1: 10% reduction in overall water supply

Year	2000		2010		2020	
Supply estimations	MCM	%	MCM	%	MCM	%
Natural flow of river at Chadegan	810	61	810	47	810	47
Kurang tunnel 1	303	23	303	18	303	18
Kurang tunnel 2	225	17	225	13	225	13
Kurang tunnel 3	0	0	252	15	252	15
Langan and Khadangestan springs	0	0	135	8	135	8
Total supply	1338		1725		1725	
Demand estimations						
Urban areas						
Greater Esfahan	210		273		355	
Supply for other cities near river	0		15		20	
Total urban supply	210	16	288	17	375	22
Return flows from urban areas	-105	-8	-144	-8	-187	-11
Industry	100	7	110	6	121	7
Agriculture	1290	96	1488	86	1420	82
Return flows from agriculture	-258	-19	-298	-17	-284	-16
Environmental demand	0	0	70	4	70	4
Transbasin diversion	34	3	125	7	125	7
Evaporation	67	5	86	5	86	5
Total demand	1338		1726		1726	
Deficit	0	0	0	0	0	0

an increase to 1008 MCM in 2010 which would fall again to 954 MCM by 2020. In other words, a 20% reduction in the net allocations to agriculture would have major impacts on the productivity and profitability of irrigated agriculture. To put this into perspective, the average of inflows during the 1996-1998 period was about 1400 MCM and this was only 900 MCM during the drought in 1999. These are way below the pessimistic assumption of a 20% decline in the overall water availability. The growing rate of the industrial water demand has been assumed to be 1% up to 2010 that this becomes about 110 MCM at this time and 121 MCM in 2020, before it is considered as remaining constant. This assumption was based on the conservative policies in the water demands for the industry. The net diversions by sector under this scenario are shown in *Fig. 3*.

Discussion

The analysis of several scenarios has shown that once the supplies drop below the historic averages, agriculture takes a significant cut in water supplies. In more specific terms, if the total supplies are only 10% below the average, then even in 2010 the most favourable year in these scenarios, the total water supplies for agriculture would be less than that of 2000. A 20% drop in supply means the agricultural water allocations would drop by up to 25% compared to the allocations in 2000. The implications of these trends for agricultural sustainability are disturbing because it means that there will be a lot less water for food production than that in 2000. A remarkable deduction of this analysis is that a drastic reduction of water supply in irrigation networks has been largely

TABLE 6
Water balance for Zayandeh rud, Isfahan, Scenario 4.2: 20% reduction in overall water supply

Year	2000		2010		2020	
Supply estimations	MCM	%	MCM	%	MCM	%
Natural flow of river at Chadegan	720	61	720	47	720	47
Kurang tunnel 1	270	23	270	18	270	18
Kurang tunnel 2	200	17	200	13	200	13
Kurang tunnel 3	0	0	224	15	224	15
Langan and Khadangestan springs	0	0	120	8	120	8
Total supply	1190		1534		1534	
Demand estimations						
Urban areas						
Greater Esfahan	210		273		355	
Supply for other cities near river	0		15		20	
Total urban supply	210	18	288	19	375	24
Return flows from urban areas	-105	-9	-144	-9	-187	-12
Industry	100	8	110	7	121	8
Agriculture	1114	94	1260	82	1192	78
Return flows from agriculture	-223	-19	-252	-16	-238	-16
Environmental demand	0	0	70	5	70	5
Transbasin diversion	34	3	125	8	125	8
Evaporation	59	5	77	5	77	5
Total demand	1190		1534		1534	
Deficit	0	0	0	0	0	0

compensated by a reduction in the cropping area and an increase in urbanization and continuation of such actions in dry years (precipitation below historical averages), while changes are also expected due to climatic changes. As stated earlier on, Morid *et al*. (2003) showed a negative impact on the total cropped area due to a reduction in water supply. In this regard, Molle *et al*. (2008) estimated an amount of impact around 30% but the crop yield was declined by 36% in 2001, a reduction that appeared to be much lesser than expected.

A further continuation of agricultural activities can only be accomplished by increasing higher water productivity in terms of kg produced per cubic meter of water use. Amarasinghe *et al*. (2006) showed that an increase (1.3% annually) in water productivity could reduce the additional consumptive water demand for crops, whereas the water requirement of the other sectors could be met by the existing water allocations. Increased field scale management, more productive crops by means of some changes in cropping patterns and decreased non-beneficial evaporation by efficient irrigation techniques are among the ways that are utilized to achieve higher agricultural water productivity (Droogers *et al*., 2001). In 2000, the domestic demands reached 14% of the total available water (*Fig. 3*), but at the end of this century (2099), it would reach to about 35% (Morid *et al*., 2003). This increase is mainly a result of population growth. Based on political decision-making and sector prioritizing (domestic, industrial, environment and agriculture, respectively), the portion of agriculture water will therefore be expected to be lower.

Despite the predictions of scenarios 1 and 3 which do not indicate water deficit in 2010, the non-running of tunnel No. 3, local springs, and precipitation reduction this year, the basin will still face even more severe and longer water deficits. This is caused by the drying up of the river in Isfahan city and downstream areas. Farmers in the centre and downstream of the irrigation networks do not receive any water. The goal of the local water providers has been supplying drinking water to the urban areas, industries, and limited agricultural areas that are located in the upstream of the river basin to produce strategic crop (wheat) that has caused over-extraction of the aquifer for irrigation relied only on groundwater extraction. It allows most farmers to withstand and go through what appears to have been the most critical climatic event of at least half a century.

It should be noted that dam release had been around 500 MCM in 2009-2010, and this is equivalent to 37% less than the average of the last ten years. This drastic reduction of dam releases this year has illustrated how agriculture gets squeezed in times of shortage, while other uses get priority. Nevertheless, in this year, the flow to the Gavkhuni Swamp has been zero and no positive effort has been taken by the policy makers to achieve a minimum flow to the swamp to preserve the river and swamp ecosystems (note that Gavkhuni is one of the internationally recognized wetlands according to the Convention of Ramsar, 1975). In this way, Molle & Wester (2009) demonstrated that the Merguellil, Jordan, and GRB basins are typical cases where aquifers are declining and authorities have found no way of reversing this process. It has also been reported that in the GRB and Jordan basins, the environmental objective of maintaining the terminal sink (Gavkhuni swamp and Dead Sea) has been simply cancelled. When all the results were combined, a tragic view of the basin in future has been painted. While dam inflow during the past three years (1999, 2008, and 2009) has been around half of average values, dams release have not been fully adjusted accordingly.

CONCLUSIONS

The methodology applied in this study has been proven as an essential tool in analyzing the supply and demand in the irrigation networks as a vital step to reach a more productive use of water. The general condition of the GRB shows that in facing water reallocation issues, the basin has many challenges. It is always politically very sensitive to take water away from the existing users to serve the expanding urban sector and set water apart for environmental use. The inappropriate supply and demand in 2010, the most favourable year in the scenarios of the current study, have indicated a non-sustainable agriculture in the study area. Meanwhile, evaluating the probable scenarios and presenting new scenarios can help policy makers in appropriating financial resources to solve water shortage problem in the area. An example for economical investigation is the proposal for increasing the height of the Chadegan dam in the attempts to increase water reserve volume and decrease the risk of shortage in the subsequent years.

ACKNOWLEDGEMENTS

The authors are deeply indebted to Dr. Hammound Murray-Rust of International Water Management Institute (IWMI) and Dr. Nader Heydari of Iranian Agricultural Engineering Research Institute (IAERI) for their technical help. Our sincere gratitude also goes to the Isfahan staff of the Ministry of Energy, Iran, the Department of Environment and the Master Plan Organization.

REFERENCES

Ahmadi, M.T. (2008). Estimation growth rates and decomposition analysis of agricultural production in Iran. *Trends in Agriculture Economic*, *1*, 14-26.

Amarasinghe, U., Shah, A., & Singh, T. (2006). Changing consumption patterns: Implications for food and water demand in India. *Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'*.

Anonymous. (1975). The Ramsar convention on wetlands, Ramsar, Iran. Retrieved August 9, 2010 from www.ramsar.org/pdf

Anonymous. (1993). Comprehensive studies for agriculture development of the Gavkhuni river basin. *Water Resources*, 25, Revision January 2005. *Environment, Yekom Consulting Engineers*, Ministry of Agriculture. Isfahan, Iran, 25-33. (in Farsi).

Anonymous. (2005). Modernization and everyday life. *Organization of Plan and Budget*. Isfahan, Iran.

Anonymous. (2007). Supplementary studies of water resources within the Gavkhuni river basin. Technical report, Water Resources. Department of budget and planning, *Yekom Consulting Engineers*, Ministry of Agriculture. Isfahan, Iran. (in Farsi).

Droogers, P., Salemi, H.R., & Mamanpoush. A.R. (2001). Exploring basin scale salinity problems using a simplified water accounting model: The example of Zayandeh Rud Basin, Iran. *Irrigation and Drainage*, *50*, 335-348.

Hsu, N.S., & Cheng, K.W. (2002). Network flow optimization model for basin-scale water supply planning. *Journal of Water Resources Planning and Management*, *128*, 102-112.

Karamouz, M., Torabi, S., & Araghinejad, S. (2004). Analysis of hydrologic and agricultural droughts in central part of Iran. *Journal of Hydrologic Engineering*, *9*, 402-414.

Khoshakhlagh, R. (2005). Economic Impact Assessment of Water in the Zayandeh Rud Basin, Iran. University of Isfahan, Iran. Comprehensive Assessment of Water Management in Agriculture, *Working Paper*, p.40.

Lévite, H., Sally, H., & Cour, J. (2003). Testing water demand management scenarios in awater-stressed basin in South Africa: Application of the WEAP model. *Physics and Chemistry of the Earth*, parts A/B/C, 28, 779-786.

Molle, F., Hoogesteger, J., & Mamanpoush, A. (2008). Macro- and micro-level impacts of droughts: The case of the Zayandeh Rud river basin, Iran. *Irrigation and Drainage*, *57*, 219-227.

Molle, F., & Wester, P. (2009). River basin trajectories, societies, environments and development. In D. Molden (Ed.) *River basin trajectories: An inquiry into changing waterscapes: Comprehensive assessment of management in agriculture series*. *IWMI*, 8, Colombo, Sri Lanka. p.33.

Momtazpur, M. (1996). An explanation of characteristics of the Zayandeh Rud basin and revision of water resources for optimal use of water. *Proceedings of the Isfahan Conference on Water Resources Management*, Isfahan, Iran, (in Farsi).

Morid, S., Massah, A.R., Agha Alikhani, M., Mohammadi, K., & Lasage, R. (2003). Water, Climate, Food, and Environment in the Zayandehrud Basin. *An ADAPT project report*. Tarbiat Modarres University, Tehran, Iran and Institute of Environmental Studies.

Moghaddasi, M., Morid, S., Araghinejad, S., & Aghaalikhani, M. (2009). Assessment of irrigation water allocation based on optimization and equitable water reduction approaches to reduce agricultural drought losses: The 1999 drought in the Zayandehrud irrigation system (Iran). *Irrigation and drainage*. Published online in Wiley Inter Science (www.interscience.wiley.com) DOI: 10.1002/ird.499

Murray-Rust, H., Sally, H., Salemi, H.R., & Mamanpoush, A. (2001). An overview of the hydrology of the Gavkhuni river basin. *IWMI Report*, *3*, 1-23.

Salemi, H.R., & Murray-Rust, H. (2002). Water supply and demand forecasting in the Gavkhuni river basin, Iran. *IWMI Report*, *13*, 1-22.

Smith, M. (1991). CROPWAT: A computer program for irrigation planning and management. *FAO Land and Water Development Division*. FAO, Rome.

Zahabsanei, A. (2002). Investigation of data summary of water situation in the Zayandehrud. *Isfahan Regional Water Authority* (in Farsi).