

# Climate change and economic approaches into water allocation: optimization via direct benefits of water—the case study of Rudbar Lorestan hydropower dam (Iran)

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**Abstract** Climate change will affect hydrologic patterns in the Middle East over future decades. Already limited water resources will become further limited, creating further challenges for water allocation protocols. While there is no integrated climate/water allocation framework to develop sophisticated dynamic allocation patterns, determining the economic value of water in various markets is one way to optimize water allocation. In this paper, a non-linear optimizer code through the Conjugate Gradient Method has been applied to optimize water allocation in the Rudbar Lorestan Hydropower system (Iran) across four sectors (agriculture, industry, power, and urban). Climate scenarios and direct benefits of water in each sector have been considered as the inputs of the model for a 37 years period (2014–2050). The results of optimized allocation show that while each particular sector is impacted substantially from different climate scenarios, the total direct benefits of water

in the basin vary between the narrow ranges of 14.75–16.75 billion USD for the same period. By considering the major characteristics of flexibility and adjustability, this methodology (Optimization via Economic Value of Water) can be considered an adaptive approach for addressing climate change and water allocation challenges.

**Keywords** Climate change · Water allocation · Optimization · Economic value of water · Adaptation

## Introduction

Globally, there are competing human uses for finite freshwater resources. While some water reservoirs may be designed and used for a single purpose, many are multi-purpose which includes being used for agriculture, hydropower, and urban water supply. There is a need to “optimally” allocate finite water resources among competing users, and this can be a complex task. The allocation of water among competing uses is and will continue to be a critical area of research and an area that affects the livelihoods and well-being of millions of people. As well as allocation between human uses, it is also increasingly recognized that freshwater should be allocated to the environment to ensure the functioning of downstream aquatic ecosystems, including downstream fisheries production that supports livelihoods and provides food. In comparison with single-purpose reservoirs, the optimization procedure for multi-purpose reservoirs serving various demands like agriculture, hydropower, and urban is complex. The challenge for optimal allocation of water resources is that the values between different stakeholders are not homogenous. In particular when considering the needs of hydropower, an additional level of complexity

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arises. Arunkumar and Jothiprakash (2012) believe that this complexity arises from the fact that hydropower production is not an isolated incident. Thus, more sophisticated algorithms are needed to comprehend non-linear and complex behaviors of system.

An additional challenge in water allocation is climate change. Climate change is projected to substantially alter the distribution, volume and timing of rainfall, and, hence, water resources across the globe. There is a need to factor climate change into water allocation and allocation mechanisms, particularly in locations where rainfall is projected to be substantially reduced, and where human populations are large and growing. Water allocations have typically focused on mechanisms for allocations to and between agricultural sectors that incorporate economic factors and long-term inflow data (and uncertainty) (McKinney 1999; Young and Loomis 2014). There is increasing realization that water allocations need to focus on more than just agricultural sectors, and expand to other sectors, and there are examples where this has been done, for example, in the Maipo river basin in Chile (Rosegrant et al. 2000). Water allocations have frequently focused on the Cost-Benefit Analysis (CBA), however, determining the true “value” of water is challenging. Considering all aspects of water cost needs a wide study over socio-economic, political, and environmental issues, and this is particularly the case when the allocation arrangements need to consider more than one sector. George et al. (2011) offered an integrated economic modeling framework to evaluate water allocation which contains the Cost-Benefit Analysis. Cost-Benefit Analysis would be an effective method for allocation if all model inputs were known completely and did not alter over time, but this is rarely if ever the case.

Undoubtedly, the agriculture sector is the predominant water consumer in Iran (Safa et al. 2012). However, the price of water allocated to this sector has been reduced via the governmental subsidies gained by oil marketing resources (Ansari et al. 2014; Jaghdani et al. 2012). The value of water in non-agricultural uses is typically at

double the maximum agricultural value, and of course, the value of water for human consumption in times of extreme shortage is effectively infinite. This leads analysts to believe that there is scope for enormous increase in economic benefit by market-based transfers of water from low-value agricultural use to high-value new uses in other sectors (Perry 2001). This fact could be mentioned as one of the driving factors of projects, such as the Dez to Qomrood water transfer project.

Hydrological model selection in hydroclimatic studies has been always a controversial subject, because of different sensitivities to the threshold values and also different uncertainties of parameters amongst the current models (Jin et al. 2010; Demirel et al. 2013). However, recent research indicates that uncertainty from hydrologic model selection is considerably smaller than that inherent in climate models (Global Circulation Models) (e.g., Jiang et al. 2007; Najafi et al. 2011; Exbrayat et al. 2014). Jiang et al. (2007) compared and quantified the capability of the six water balance models in simulating the climate change effects at basin scale. The results of the comparison identified that all six models have similar capabilities in terms of reproducing historical water balance components. The big difference between the models’ results arose from soil moisture modeling. By eliminating the direct index of soil moisture in the modeling procedure, the variability between the models and, hence, the importance of any one model over another are reduced with little or no impact on the output at least in the monthly scale.

Considering that the climatic factors are the main source of uncertainties, at least in these types of long-term predictions, a lumped rainfall runoff model based on a genetic programming code could be used to develop future runoff series from historical data. The scientific literature extensively discusses the significant differences in results from the global circulation models (GCM) in climatic scenarios forecasting. To address the significant differences, the use of multi-model projection is well established (e.g. Andersson et al. 2006; Serrat-Capdevila et al. 2007; Van

**Table 1** Global Circulation Models applied in Rubar Lorestan basin to forecast flow pattern till 2050

Applied GCM	GCMs with similar results in basin scale	Forecasted domain and behavior
GFDLCM-2.0	CNRM-CM3, CSIRO-30, GFDLCM-2.0	Very optimistic: runoff raises in the basin scale
GISS-EH	ECHO-G, GISS-EH, INMCM-30, MICRO-HI, MRI-232A, UKHADCM3, MPI-ECH5	Optimistic: runoff declines in the basin scale (0–10 %)
UKHADGEM	BCCRBCM2, CCCMA-31, CCSM-30, UKHADGEM, MICRO-CMED, NCARPCM1	Moderate: runoff declines in the basin scale (10–20 %)
GFDLCM-2.1	GFDLCM-2.1	Pessimistic: runoff declines in the basin scale (20–30 %)
FGOALS-1G	FGOALS-1G, IPSL-CM4	Very pessimistic: runoff declines in the basin scale (more than 30 %)

The behavior of each model and similar GCMs are illustrated too

**Fig. 1** Geographical location of Rudbar Lorestan proposed hydropower dam



Oldenborgh et al. 2012; Chikamoto et al. 2013). In this paper, the results of five GCMs are selected and down-scaled to apply into modeling procedure. The outputs from the five GCMs chosen represent the full suite of predictions from upper to lower extreme predictions. The utilized GCMs and their forecasted scenarios are shown in Table 1. A water balance model has been used to simulate inflows and demand points for the proposed Rudbar Lorestan Dam. Gleick (1987) identified that the water balance model can provide considerably more information on the regional hydrologic effects of climatic changes that is currently available. Figure 1 illustrates the schematic model of a single reservoir with local inflows and demand points at the upper hand which is used for the case study (Rudbar Lorestan) of this paper. Rudbar Lorestan is a proposed gravity concrete hydroelectric dam with designed height of 158 m and the storage capacity of 200 MCM (Million Cubic Meter) located in the Zagros mountain range in Iran (Fig. 1). The proposed 450 MW hydropower plant will supply both local and national electric network during the peak hours. The reservoir is located in the major basin of the great Dez which flows into great Karun, the most important and biggest river of Iran. The great Dez basin has been the subject of several major water transfer projects since the 1980 s and the proposed Rudbar Lorestan dam is also located under the distribution facilities of a water transfer project supplying urban and industrial demands of Qom City.

## Methodology

Integrated optimization–allocation models that allow the assessment of the effects of alternative water management strategies have been advocated for and used previously. For

example, Schlüter et al. (2005) suggested these tools for long-term decision-making. Similar to the case study of this paper, Schlüter et al. used a water allocation module in accordance with the historical data in a semi-arid basin. A multi-disciplinary approach is required to inform water allocations and to ensure that such allocations are optimized. The use of such optimization approaches is relatively recent and the process is more complex when the number of stakeholders increases. Here, the direct benefit approach is used. This method has been recognized by the Food and Agriculture Organization of the United Nations (FAO) as a reliable technique, applied in comprehensive research, e.g., Turner (2004), by considering long-term climate scenarios to maximize total economic benefits of Rudbar Lorestan basin and to minimize uncertainty. Hydroeconomic modeling has been a topical and evolving research subject, since computer-aided analysis developed in the water resources management area. Heinz et al. (2007) considered the implications and applications of hydroeconomic models as river management tools for the European water framework. In that study, relevant economic parameters, such as cost recovery and water pricing, were discussed. In another notable work, the impacts of global change have been considered in the hydroeconomic modeling for the Spain Gállego river basin (Graveline et al. 2014). Hydroeconomic modeling and analysis have been also a topical issue in Iran, especially where maintaining or enhancing agricultural productivity and cost recovery are essential factors in decision-making; for example, in the case of cultivation of rice at Guilan province (Kalashami et al. 2014) and also for drinking water (Pour and Kalashami 2012).

The applied model used in this paper includes climate scenario, hydrology, policy (allocation protocol), economic, and basin blocks. In the climate scenario block, to

evaluate future hydroclimatic condition, the  $0.5 \times 0.5$  degree resolution map of basin was adjusted by GCMs introduced in Table 1. Reverse distance methodology and historical data were applied to downscale the results. Consequently, a lumped GP-based rainfall-runoff has been used to forecast runoff scenarios in the hydrology block. The five GCMs selected ranged in results from very optimistic to very pessimistic scenarios. In the economic block, a matrix of water price is defined, in which the applied price for each specific demand (during the forecasted period) is drawn from consideration of current data and inflation rate. The forecasted runoff was then applied in the optimizing code under constrains of water balance and a series of operational limits. The optimization block intends to find the best allocation pattern maximizing the total economic benefit index in this block, the matrix of prices is multiplied by various water allocation matrixes to produce an index showing the total economic benefits during the forecasted period. Therefore, the target is to find a water allocation matrix that maximizes the total economic benefit index. Owing the fact that the basin is located in mountain region with steep slopes and rocky ground, the effect of ground water has not been considered in this model, as it was deemed to not be a parameter in this case that would not substantially influence the model outcomes. The flowchart of the methodology is illustrated in Fig. 2.

In the basin/land block, the reliability of water supply for the urban sector assumed to be 95 % and the minimum allocation set to 7 MCM/Month (70 % of average monthly demand). The 450 MW power plant limited to 35 % annual busy time and the Francis turbines' efficiency assumed to be 95 %. The initial storage was set to 114 MCM. By considering 20 MCM/Year demand in the industrial sector, the minimum allocation set to 1 MCM/Month. As a rational assumption, the agriculture sector is able to carry higher risk than either the urban and industry sectors; therefore, the minimum monthly allocation is set to two MCM/Month, while the annual demand in this sector is around 100 MCM (Hydrologic assumptions and materials are available at "Appendix 1"). By the defined constraints, the conjugate gradient-based optimizer model was run to find the  $A^*$  allocation matrix producing the maximum value of TEco index. According to the design data, the urban demand of Qom city would be supplied by a water transfer link. To develop a tangible factor, water allocation from the deviation point into Qom city has been assumed as the decision parameter.

The core of the optimization block has been developed on the base of the Conjugate Gradient Method in LINGO optimization code. The implication of LINGO codes was based on relatively early computer-aided water management studies as like as optimized allocation for pollution

control (Brown et al. 1999) and continued to new research applications like comprehensive simulation of water management (Singh and Panda 2013). Conjugate gradient method is a modification of the Steepest Descent Method which avoids the zigzagging effect of the latter which can reduce the iterations that let the user to monitor the calculation procedure more efficiently. However, the trade-off is that each iteration takes computationally longer. The non-linear behavior of model emerged from the two main factors; Hydroelectric power production equation and the Volume-Depth relation of the reservoir (Fig. 3). The goal of optimization is to find optimum water allocation time series for each consumer sector (here in this paper: agriculture, industry, and urban at the upstream of reservoir, and hydropower produced by varying volumes of downstream release). For this purpose, developing allocation matrix is a very useful method to both understanding of procedure and applying in optimizing codes. There are notable cases of matrix methodology in recent researches; solving water allocation problem in the Spree River basin by Messner et al. (2006), and optimization of Nebhana Reservoir Water Allocation by Alaya et al. (2003) are very good samples of this methodology for developing multi-criteria decision support systems. According to the most predominant definition, the matrix format of each probable time series combination can be shown as matrix "A" defined below:

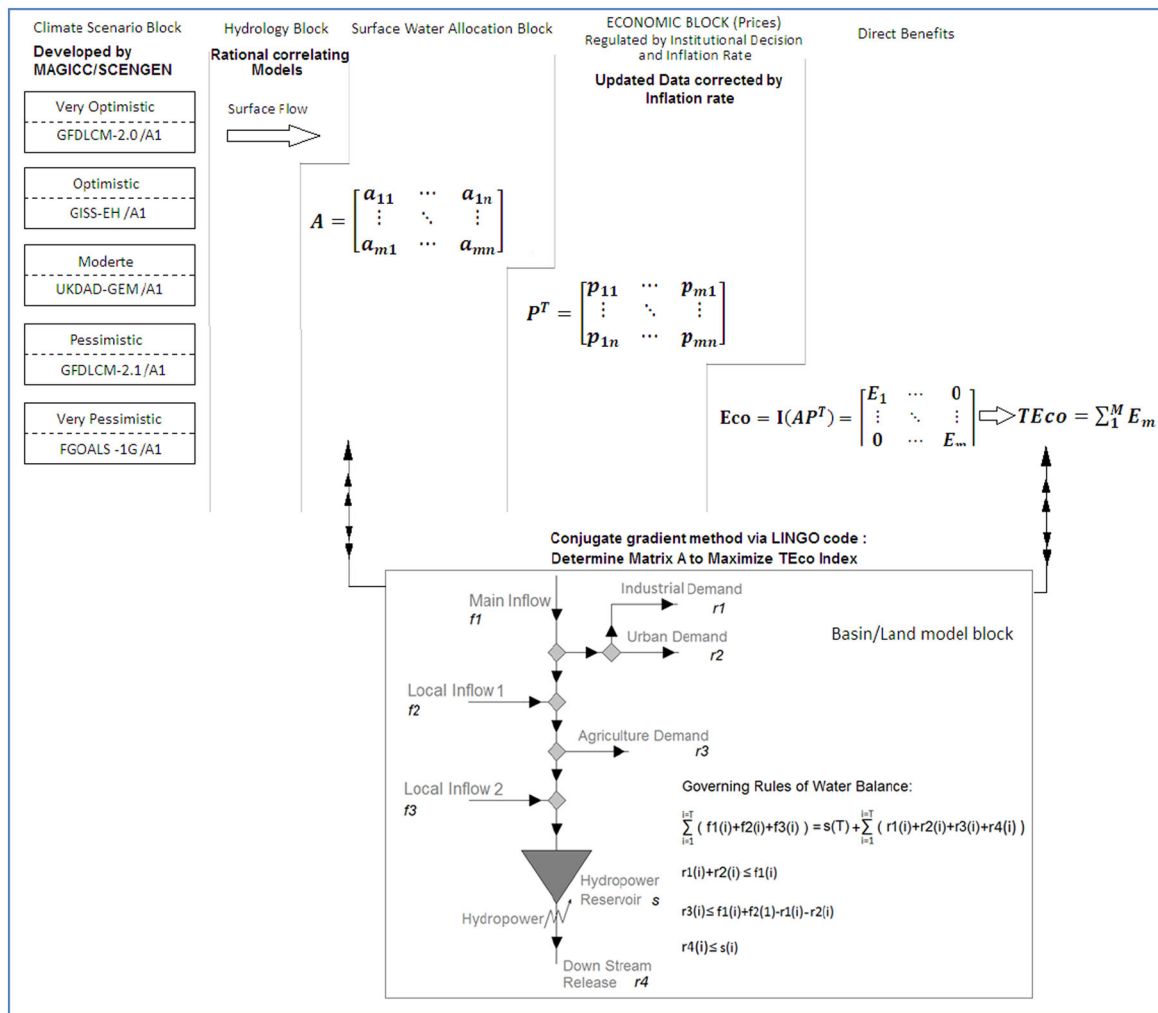
$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad (1)$$

In this matrix,  $a_{mn}$  means the volume of allocated water into sector "m" at the  $n^{\text{th}}$  time step. Similarly, we can develop P and  $P^T$  for price or direct benefit matrix; here,  $p_{mn}$  is the direct economic benefit produced in sector "m" by getting a unique volume of water at  $n^{\text{th}}$  time step

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{m1} & \cdots & p_{mn} \end{bmatrix} \xrightarrow{\text{Transposition}} \quad (2)$$

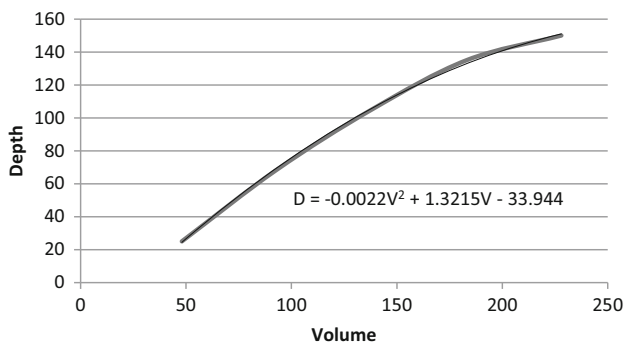
$$P^T = \begin{bmatrix} p_{11} & \cdots & p_{m1} \\ \vdots & \ddots & \vdots \\ p_{1n} & \cdots & p_{mn} \end{bmatrix}.$$

We can define Eco, as a diagonal matrix, which calculated by summing up all economic benefits for each sector during the whole period. We also defined TEco index which resembles total economic benefit of each water allocation strategy for the whole period. Eco and TEco are described here:



**Fig. 2** Hydroeconomic model developed for the Rudbar Lorestan basin, including climate, hydrology, policy (allocation), economic, and land blocks. The basin/land block illustrates the schematic model of a single reservoir, including local inflows and demand points, the

governing rules (water balance equations) are shown here. This model is used for the case study of the paper (Rudbar Lorestan hydropower dam)

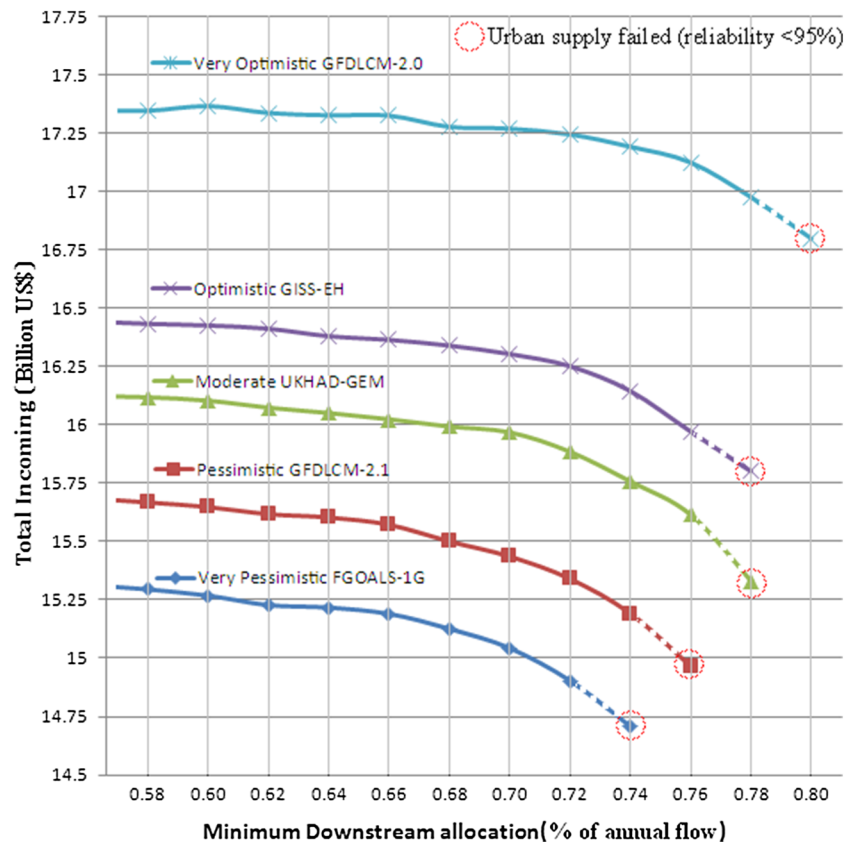


**Fig. 3** Depth–volume curve and the correlated function of Rudbar Lorestan reservoir. The “D” prompts absolute depth of reservoir in meter, and the “V” is the total volume of reservoir, including dead volume in million cubic meters

$$Eco = I(AP^T) = \begin{bmatrix} 1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1 \end{bmatrix} \times \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \dots & a_{mn} \end{bmatrix} \times \begin{bmatrix} p_{11} & \dots & p_{m1} \\ \vdots & \ddots & \vdots \\ p_{1n} & \dots & p_{mn} \end{bmatrix} = \begin{bmatrix} E_1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & E_m \end{bmatrix} \quad (3)$$

$$TEco = \sum_1^M E_m \quad (4)$$

**Fig. 4** Total incoming (Direct benefits/TEco in the matrix definition) of Rudbar Lorestan basin in billion US\$ for the 2014–2050 duration. The horizontal axis shows the minimum downstream allocation from the deviation point of water transfer link into Qom (Ghom) city. *GFDLCM* GCM indicates the most optimistic forecast, while the *FGOALS* GCM resembles the worst condition



In the matrix optimization terminology, we try to find the unique matrix named  $A^*$  which produce the maximum value of TEco index. Each particular array of  $A^*$  is not the best allocation in its time step necessarily, but the individual set of them forms  $A^*$  that produces the maximum value of TEco index. As constrains, every candidate answer for  $A^*$  should satisfy the governing rules for water balance in the basin which itself is controlled by climatic scenarios. This definitions and matrix solutions can be used for developing more complicated indexes, such as net economic incoming or job creation in the basin. The method is also practical in smaller hydrosystems; Takama et al. (1980) defined total cost index to minimize the expenditures of water allocation in a petroleum refinery system.

### Economic parameters

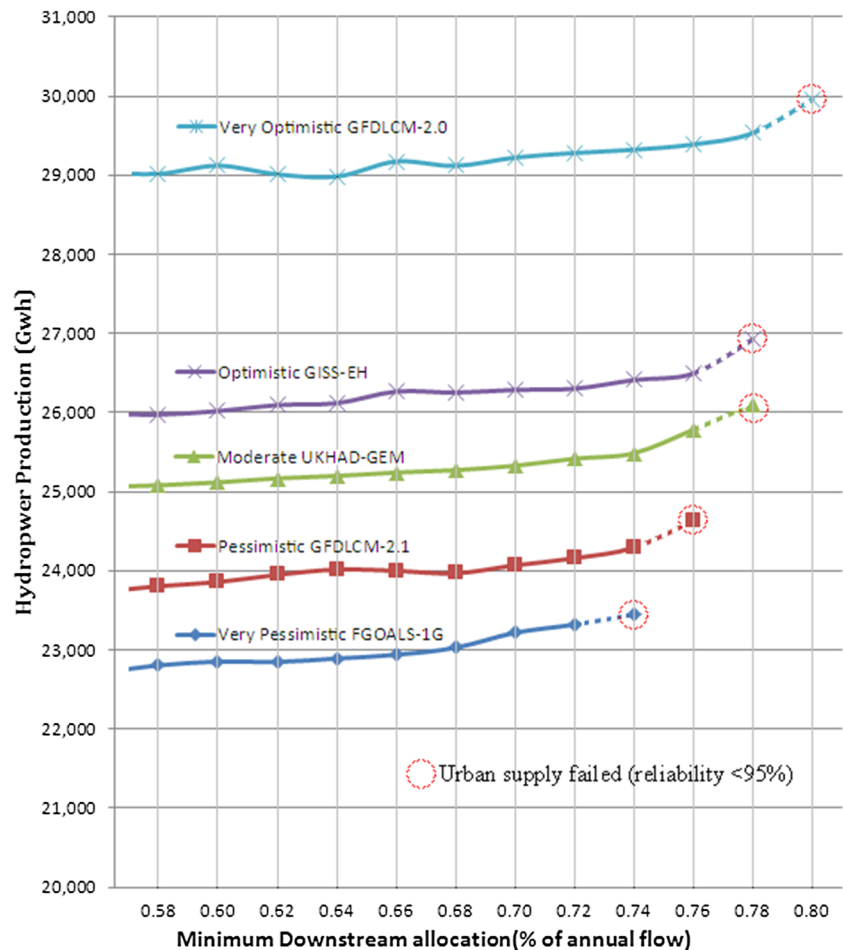
A series of assumptions have been considered modeling the benefits of water allocated to agriculture sector in this project (“Appendix 2”). An overwhelming majority of agricultural fields in Lorestan and Qom provinces are wheat farms. Crop Water Productivity (CWP) can be defined as the kilograms (kg) of yield per unit of consumed water. As a rule of thumb, a reasonable level of wheat productivity is about 1 kg

(wheat)/m<sup>3</sup> (water) in 2005. However, there are reports, indicating that the real wheat productivity is around 0.55 kg (wheat)/m<sup>3</sup> (water) in the traditional farming systems (Keshavarz et al. 2005). Furthermore, similar figures have been reported, showing wheat CWP from 0.5 to 1.63 kg/m<sup>3</sup> in Iran (Muthuwatta et al. 2013). In this paper, we assumed CWP of 1 kg (Wheat)/m<sup>3</sup> (Water) to model economic benefits of water allocated to agriculture sector in Iran. In addition, information in the United States Department of Agriculture (USDA) data base estimates the international price of wheat at 317 US\$/ton. Therefore, we can consider the gross economic benefit of 0.317 US\$/m<sup>3</sup> (Water) for water allocated to the agriculture sector. However, this figure does not contain social benefits, such as job opportunities.

In terms of urban water supply, it is difficult to obtain a reliable price estimate without subsidies. However, we used research done in the adjacent providence (Kohkeloye and Boyerahmad) with very similarities in infrastructures and consuming culture that estimated the economic value of drinking water as 6877 Rials (0.275 US\$) per cubic meter (Tahami Pour and Kavooosi Kalashami 2012).

Determining the true price of electrical energy in Iran is also not simple. Where the previous pattern has focused on variable price depending on the weather condition, the government has decided to make a uniform charge table for

**Fig. 5** Total hydropower production in GWh Scale for 2014–2050 duration against minimum downstream allocation. The maximum coefficient of annual production/theoretical capacity is limited to 35 %



all provinces. The average cost of electricity from a hydro plant larger than 10 MW is 3–5 US cents/kWh (WWI 2011–2012). In this research, the price of hydropower is assumed to be 0.04 USD/kWh; However, Iran Ministry of Energy sells it for 0.017US\$/kWh (Guillaume and Zytek 2008). The total renewable water resource of Iran is 130 billion cubic meters, out of which 2 % is used for the industrial uses (Tahami Pour and Kavooosi Kalashami 2012). However, this sector receives a low proportion of total water resources in Iran, although water supply to this sector is very important. According to the Portal of Iran Ministry of Energy, the present price for water in industrial sector is 4120 Rials (0.1648 US\$/m<sup>3</sup>) which is a higher price in comparison with the agriculture sector.

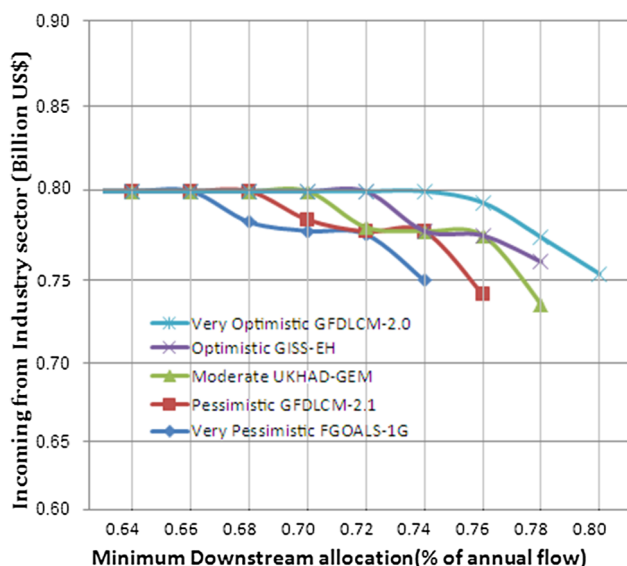
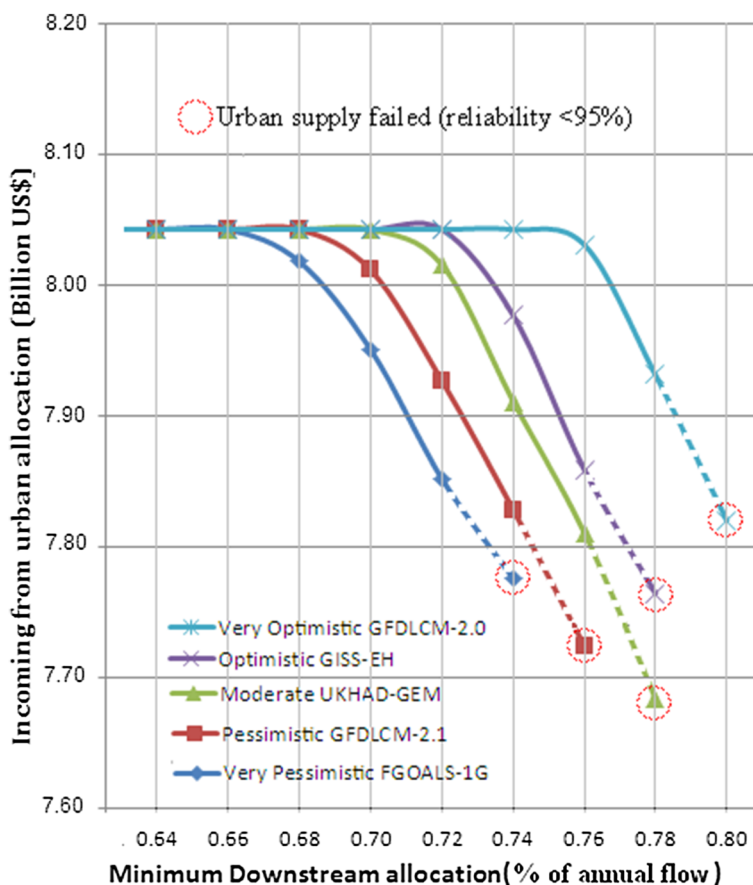
Finally, one of the most important factors which must be considered is the high inflation rate in Iran. The inflation rate in water and energy sectors is potentially higher than the general trend. This happens because of government price modification program trying to reduce subsidies with a rather steep rate. The inflation rate has been considered for each sector separately and the long-term price series inserted into the optimization model increase over the time dynamically (See “Appendix 2”).

## Results

Figure 4 illustrates the total benefits of system under five GCM-scenario combinations and shows total direct benefits (incoming) of system against minimum downstream allocation (from deviation point). By rising downstream allocation, the total benefits of system will reduce. The worst condition happens for the very pessimistic FGOALS GCM with 74 % downstream allocation when the TEco drops into less than 14.75 billion US\$ for the 37 years period. The best probable condition is for very optimistic GFDLCM GCM at the 50 % downstream allocation by around 17.3 billion US\$ for the same duration. In addition to drop of the TEco, more downstream allocation is constrained by a policy imperative that is 95 % reliability of urban water supply.

The considerable difference between hydroelectric price and urban water price might be a reason to interpret why more downstream allocation acts against TEco index. By reviewing the graph, this fact must be considered that all points of graph have been developed by an optimizer model that shows the best probable allocation pattern for an exclusive downstream allocation. However, the purpose of the model is to maximize TEco index, and the figures of hydropower production must

**Fig. 6** Total incoming (direct benefits) for urban sector during 2014–2050 period against minimum downstream allocation



**Fig. 7** Total incoming (direct benefits) for industrial sector during 2014–2050 period against minimum downstream allocation

be considered in the decision-making procedure. Figure 5 illustrates the projected hydropower production for the 37 years period (2014–2050) in the GWh scale. According to this graph, the maximum power production will limit in 30000 GWh for the best condition and can never exceed this

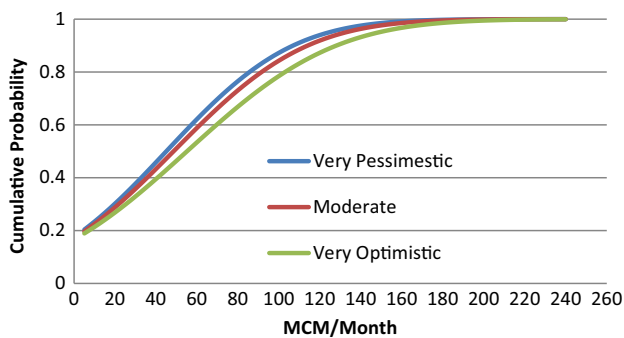
amount, because of the risk of failure to urban water supply. However, in an optimized allocation pattern, it would never be less than 22700 GWh, where the 48 % of total flow allocated into upstream, and the climate prediction shows the worst condition. Finally, Figs. 6, 7 illustrate the total benefits in urban and industrial sectors under five GCM-scenario combinations, respectively. Due to the high standards of water supply applied in the model (95 % of reliability), the figures for these sectors are very sensitive to the downstream allocation and decent very rapidly after critical downstream allocation. Agriculture sector shows a relatively robust behavior over the various scenarios, Table 2 illustrates the total economic benefit of agriculture sector for the target duration. It should be mentioned here that why minimum economic benefits in the pessimistic and very pessimistic scenarios are higher than a moderate scenario; the fact is that in the moderate scenario, the total downstream water allocation could reach to 78 % without disrupting upstream constrains; in contrast, this proportion is limited to 76 and 74 % of total inflow for pessimistic and very pessimistic scenarios, respectively. However, as the Rudbar Lorestan basin is situated in a mountain range, the agriculture sector is relatively small and with very limit water demand. Therefore, it plays the minor role in water balance and is able to keep its productivity of the limited downstream allocation.



**Table 2** Total economic benefit of agriculture sector for 2014–2050

Total economic benefit (billion US\$) 2014–2050					
GCM Condition	Very pessimistic FGOALS-1G	Pessimistic GFDLCM-2.1	Moderate UKHAD-GEM	Optimistic GISS-EH	Very Optimistic GFDLCM-2.0
Minimum	1.44	1.38	1.33	1.44	1.51
Average	1.79	1.80	1.81	1.84	1.87
Maximum	1.97	1.98	1.98	1.98	1.98

The figures are shown in billion US\$



**Fig. 8** Cumulative probability of downstream flow that can be considered for supplying the environmental demand in a fix 50 % downstream allocation protocol

Although minimum environmental demand has not been considered as a direct restriction in the model, considering the flow regime of the river in the forecasted period, a minimum river flow of 15 MCM/Month by the reliably rate of 75 % (for environmental proposes) has been secured in a fixed 50 % downstream allocation protocol. This rate of flow will most probably occur during August. Figure 8 illustrates the cumulative probability curves for downstream flow for the moderate and extreme scenarios. The largest gap between very optimistic and very pessimistic scenarios happened in a flow around 80 MCM/Month, where the reliability rate differs between 66 and 76 %. In addition to the secured downstream flow, other branches of Dez basin would supply the downstream flow before the next major reservoir (Dez Hydropower dam); however, this supply is not reliable in the long term. This is due to the fact that further water management programs on the upstream side of other branches are under study. There is also an under construction project to transfer water from the adjacent branch of this basin to Qom city for urban proposes. Nevertheless, there is no official plan for further water transfer plans in the upstream of the Rudbar Lorestan branch, at least during the next decade.

## Discussion

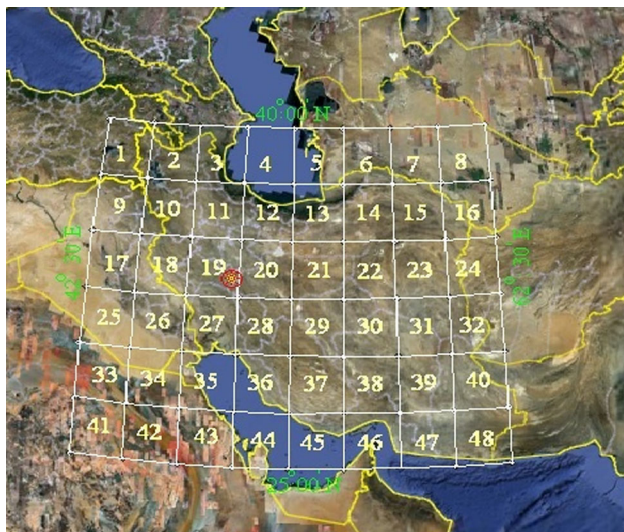
While climate change may have considerable impacts over water resources systems and subsequently over the stakeholders, it is possible to reduce economic impacts via an

optimized water allocation. In Rudbar Lorestan basin, the maximum rate of flow decent is evaluated to be around 30 % for A1 scenario under FGOALS-1G GCM. The results of the optimized allocation show that the agriculture sector is able to save its economic efficiency without any considerable decent in the economic index. In the general scope, a comparison between GISS-EH and FGOALS-1G revealed that the total economic benefits of basin for a 50 % fix downstream allocation are 16.4 and 15.35 billion US \$, respectively. These figures show a 5 % drop of economic efficiency, while the difference between predicted flows of these two scenarios is more than 20 %. Loss of urban water is the most critical constraint which limits hydropower production under 30000 GWh for the 37 years period which means that the power plant will be operational with 20 % annual efficiency, while the designed annual efficiency is 35 %. Subsequently, a review of the trends indicates that in this model, the main trade-off is between Urban and Hydropower, and agriculture and industrial sectors play only minor roles. Similar condition is also visible amongst other reservoirs in Iran with big group of urban water consumers in arid and semi-arid regions (Alizadeh and Keshavarz 2005; Abrishamchi and Tajrishi 2005). The significant gap in the prices of hydroelectric and urban water is the main reason that explains why a greater the downstream allocation reduces the TEco index. Owing to this fact, urban demand is going to be the major factor in water allocation not only because of the volume but also for the reliability standards which trends to keep the future storage via restriction of hydropower production. Next step, after this paper, would be using of true value of water instead of the direct benefit; therefore, it is our pleasure to announce that a research work has been initiated to apply true value of water as the economic indicator via socio-economic review.

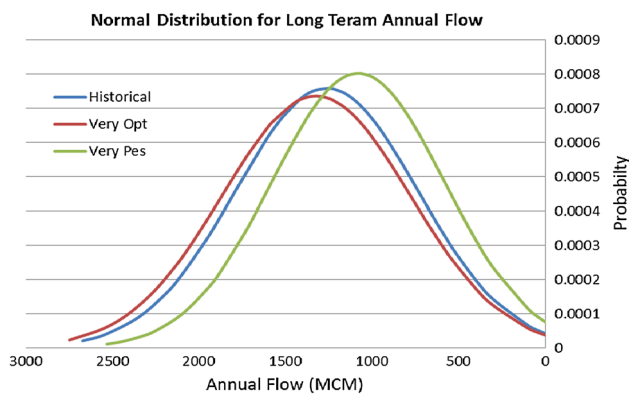
**Acknowledgments** Special thanks go to Mr. Alireza Daemi Deputy of Planning and Economic Affairs, Iran Ministry of Energy, for her cooperation to provide local data and raw hydrologic materials.

## Appendix 1

The hydrologic base of model is constructed on the base of a forecasted flow series from historical data and applied effects of GCMs outputs in the regional scale. MAGICC/



**Fig. 9** 2.5 × 2.5 degrees resolution of MAGICC/SCENGEN over Iran, the location of the basin is displayed in the eastern border of Cell No. 19



**Fig. 10** Normal distribution of flow in MCM scale for three scenarios of historical (without climate change effect), very optimistic, and very pessimistic

**Fig. 11** Geographical position of hydrometric and synoptic station in Rudbar Lorestan basin



**Table 3** Hydrologic assumption applied in the reservoir model

Maximum reservoir capacity of Rudbar Lorestan Dam	200 MCM
Minimum operational Capacity of Rudbar Lorestan Dam	48 MCM
Initial storage of the Reservoir	114 MCM
Depth–volume curve	$D = -0.0022(V^2) + 1.3215 V - 33.944$
Turbine efficiency	95 %
Maximum annual busy rate	35 %
Power plant capacity	450 MW
Max downstream transfer rate	59.6 MCM/month

SCENGEN (version 5.3) has been used to forecast precipitation changes in a regional scale. The outputs are gridded to 2.5 × 2.5 degrees latitude/longitude network which is shown in Fig. 9. To downscale results, a 0.5 × 0.5 degrees subnetwork developed in the cells No. 19 and No. 20 calculated results by the reverse-distance method. Using a rational rainfall-runoff model, the forecasted flow pattern is calculated till 2015. The normal distribution for annual flow in MCM (Million Cubic Meters) scale for the three conditions is illustrated in Fig. 10. The modeled region includes two hydrometric stations (Qalyan and the Construction site stations) and two synoptic stations (Qalyan Sakaneh and Kakolestan Synoptic stations); in addition, the data of two adjacent synoptic stations (Buin va Miandashht and Aligudarz) have been applied to fill some gaps of the historical data. The stations and their geographic position are shown in Fig. 11.

In addition, a LINGO base optimization code is used with a combination of hydrological (Table 3) and economic assumption (Table 4, “Appendix 2”) to find the most optimum allocation scenario.

## Appendix 2

See Table 4

**Table 4** Economic assumptions applied in the LINGO optimization code

Assumption	Reference	Model Input
Price of water in urban sector is 0.275 US\$ per cubic meter	Tahami Pour and Kavooosi Kalashami (2012)	Government Gross Benefit of 1 cubic meter of water in urban sector = 0.275 US\$
Crop water productivity (CWP) for wheat is 0.5 to 1.63 kg/cubic meter	Muthuwatta et al. (2013)	Government Gross Benefit of 1 cubic meter of water in agriculture sector = 0.317 US\$
The applied value is 1 kg/cubic meter		
International price of wheat (average 2012–2013) 317 \$/ton	United States Department of Agriculture (USDA)	
Price of hydropower electricity is 0.017 US\$/Kwh (2008)	Guillaume and Zytek (2008)	Government Gross Benefit of 1 kWh of energy in hydropower sector = 0.017 US\$
Price of water in industrial sector is 0.164 US\$ per cubic meter	Portal of Iran Ministry of Energy	Government Gross Benefit of 1 cubic meter of water in industrial sector = 0.164 US\$
Average of long-term annual Inflation rate for economic benefits of water in Agriculture sector = 7 %	Calculated by subtracting inflation rate of global price from domestic inflation rate	Annual Inflation rate for economic benefits of water in agriculture sector = 7 %
Average of long-term annual Inflation rate for economic benefits of water in urban, hydropower, and industrial sectors = 8 %	Calculated by subtracting inflation rate of global price from domestic inflation rate	Annual Inflation rate for economic benefits of water in urban, hydropower, and industrial sectors = 8 %

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