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Water Transmission Protocols and Sustainable Development in Face of Climate Change.

Case study: Urban water supply in Dez to Qomrood Water Transmission Project, Iran

Masoud Kazem

Department of Civil & Environment Engineering, AmirKabir University of Technology (Tehran Polytechnic), Tehran, Iran

Tel: 98-912-738-7851 E-mail: mas_kazem@yahoo.com

Maryam Hasanzadeh (Corresponding author)

Department of Civil Engineering, Sharif University of Technology, Tehran, Iran

Tel: 98-912-502-6397 E-mail: mary.hasanzadeh@gmail.com

Reza Maknoon (Corresponding author)

Department of Civil & Environment Engineering, AmirKabir University of Technology (Tehran Polytechnic), Tehran, Iran

Tel: 98-912-370-9254 E-mail: rmaknooon@yahoo.com

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Abstract

Central area of Iran is located in a dry- semi dry region which suffers from fresh water scarcity. Since water shortage has been known as the most important factor that threatens sustainable development, this area faces serious problem in this matter. Furthermore, growing rate of population exacerbates this critical condition. As a solution, several inter-basin water transfer projects, such as under construction Dez to Qomrood water transmission project, have been considered to overcome this difficulty. Three water allocation protocols are supposed in this project: Proportional Allocation (PA), Fix Upstream allocation

(FU), and Fix Downstream allocation (FD). This paper analyses different transmission protocols in order to minimize urban water shortage risk while considering other goals of the project such as agriculture and hydroelectricity. Moreover, to predict the change of available water resources in the basin's area, climate change effects have been predicted through an extensive collection of GCMs (Global Circulation Model) for different climate scenarios in 2050. For this purpose, two different scenarios have been used to cover the uncertainty of growing rate of population. The next step was applying a water allocation model to forecast the results of each transmission protocol, climate scenario and population combination. As the final result in the initial sustainability assessment, it can be shown that Fix Downstream allocation (FD) protocol would be the best choice supplying higher proportion of population, especially in urban water sector for a fix cost and also is the most adjusted protocol with the probable future condition.

Keywords: Water transfer, Urban water, Climate change, Water transmission protocols, Population growth rate

1. An introduction to the Problem

Despite worldwide attempts to control growing rate of population, Middle East faces a significant increasing number: from 60 million in 1950 to 277 million in 2007(Siragelding, 2002). In the same period, Iran has experienced a higher growth proportion from 16.9 million to 71.2 million which most of them have decided to live in urban regions. Furthermore, the most growing industrial districts and expanding cities are located in the arid region around central desert of Iran and an overwhelming majority of Global Climate Models (GCM) predicts more severe droughts and longer periods of low precipitation seasons in this country (Sumner, 1989; Fahimi & Kent, 2007; Maknoon et al., 2012). By considering this exacerbating condition, it can be claimed that the region actually faces a serious water shortage crisis. As a solution, Iran ministry of energy attempts to supply developing areas water demand, with water transmission from rich basins to aired regions. In the case of Dez to Qomrood project, three basic water transmission protocols have been candidated by Iranian ministry of energy. However, like many other major water resources projects in the previous century, the preliminary proceeding backs to 1960's, which results in the construction of many infrastructures of the project before the declaration of the Climate change Theory. In the frame work of sustainable development, this project and its protocols should be applied in a series of researches to evaluate their efficiency for each particular aspect. However, there are few attempts reflecting practical results in this case (Maknoon et al., 2012). This research focuses on urban water supply in Dez to Qomrood Water Transmission Project.

2. Climatic Scenarios and Water Resources Management

Young science of climate prediction contains a wide range of uncertainties derived from nature and human activities. In addition to the complicated behavior of ocean-atmosphere cycle, Greenhouse emission, as the main factor of climate change issue, has become a complex socio-economic dispute with vague effective factors. Moreover, the results of different GCMs are noticeably unequal for a definite area. Regarding these reasons, a

lucrative research must contain an extensive range of climate scenarios and GCMs to cover the most possible space of uncertainty. Multi model projection and scenario making have been used by numerous water engineering researchers such as Andersson et al. (2006), Serrat-Capdevila et al. (2007), Kunstmann et al. (2008), Maknoon et al. (2012), Van Oldenborgh et al. (2012), and Chikamoto et al. (2013).

Even though many researches work in the field of climate change and water resources, long term average flow is accepted as the base of the most of water allocation agreements. This might happen due to the fact that many of water transfer projects had been planned before the declaration of the Climate change Theory. In the past century, 145 international treaties on trans-boundary Rivers were taken on; and about half of these agreements focused on water allocation (Wolf, 1998). Although long term fluctuation is an inevitable characteristic of river flow, (even without bearing climate change effects in mind), a large number of these water allocation agreements do not mention the long term trend of the river flow (Giordano & Wolf, 2003).In the case of Dez to Qomrood water transfer project, economic efficiency of each protocol has been analyzed by Maknoon et al and their findings show that Fix Downstream allocation (FD) protocol is the one with the most economic efficiency (Maknoon et al., 2012). The methodology of the stated research which is presented in this paper with some applied corrections is helpful for water sector governors to face climate change and population growth. The correction applied in Maknoon method includes some statistic updates and also population growth factor. In addition, Genetic Programming (GP) has been used as the main methodology of downscaling.

3. Modeling and Scenario Combinations for Dez to Qomrood Water Transmission Project

Capturing an appropriate space of probable future leads us to use the most valid GCMs and climate scenarios. Applying a range of GCMs has a long history in hydro-climatic researches; Serrat-Capdevila et al have used this method to forecast climate change impacts on San Pedro basin (Serrat-Capdevila et al., 2007). Likewise, Andersson et al predicted climate change effects on Okavango River via a multi models system (Andersson et al., 2006). In this research, we used nineteen GCMs to capture a considerable number of predictions for this region based on the present knowledge of climate prediction. In addition to climate modeling, generating scenarios for monitoring an extensive probability domain is an accepted methodology in decision support systems of water management framework (Ito & Uchiyama, 1997; Eames, 2002; Ghanadan & Koombey, 2003; Oniszk-Poplawska & Rogulska, 2003). In this paper, four main Greenhouse emission scenarios (A1, A2, B1 and B2) had been considered. However, according to the results achieved by Maknoon et al about the similar behavior of these scenarios in this region, only A1-AIM was selected to evaluate the climate change impacts on the case region. In this paper, nineteen GCMs have been applied via A1-AIM scenario to forecast Dez and Qomrood basins hydro-climatic condition till 2050. Table 1 shows these GCMs and a five degree categorization classifies these GCMs into very optimistic, optimistic, moderate, pessimistic and very pessimistic, based on the average annual precipitation.

The location of Dez and Qomrood (Ghomrood) basins in Iran is illustrated in Figure 1. Dez basin is situated in a region with high precipitation and weighty seasonal rainfall; in contrast, Ghomrood (Qomrood) basin is located beside central desert of Iran with the lowest rate of rainfall. Under construction facilities will gather water from five local branches and transfer flow to Ghomrood River. In the destination basin, Kuchrey and Golpaygan dams reserve the flow and dispense it into demand points. A schematic view of the system as it has been modeled is shown in figure 2 and, the initial assumption and the boundary conditions of the basins are illustrated in table 2. MAGICC- SCENGEN (Model for Assessment of Green-house-gas Induced Climate Change) has been used to quantify A1-AIM climate scenario in global scale for the region. MAGICC- SCENGEN develops a mesh of 2.5×2.5 degrees cells over the region. Down scaling to a local scale has been done via reverse-distance vectors via using results of neighboring cells. Andersson et al. (2006) applied similar method to down scale rainfall changes on Okavango River basin. Monthly scaling for precipitation was performed by comparing GCMs outputs for monthly scale with historical monthly distribution to generate precipitation producer factors in monthly scale. Mitchell et al. (2004) used a similar method to forecast climate factors over the global and European scale. Down scaled values have been produced for 0.5×0.5 degree microcells covering both basins.

Stochastic series of runoff have been generated via stochastic series of rain fall derived from historical data, monthly downscaled forecasted factors and a linear rainfall- runoff model. There are outstanding researches that utilized similar linear and none-linear downscaling factors. Gardner utilized exponential factors to evaluate annual runoff with a various range of climatic conditions (Gardner, 2009). There are also other noticeable cases in current researches such as Maknoon et al, Graham, Chen, Benestad and Carter (Carter et al., 2001; Benestad, 2004; Chen et al., 2006; Graham et al., 2007; Maknoon et al., 2012).

As a standpoint factor of this research, population growth has been considered via two different scenarios including a controlled rate of 1.4 percent and a normal growth of 1.7 percent. These two scenarios have been the predominant projections for urban population of Iran (Sumner, 1998; Fahimi & Kent, 2007).

In this paper, three sharing rules have been used to define water transfer protocols. These three rules were defined by Ansink & Ruijs (2008). We can develop a mathematic definition for each protocol as shown below.

Proportional Allocation (PA): upstream receives αQt and downstream receives $(1 - \alpha)\ Qt$, with $0 < \alpha < 1$;

Fixed Upstream Allocation (FU): upstream receives Min $\{\beta, Qt\}$ and downstream receives Max $\{Qt - \beta\ \_, 0\}$, with $0 < \beta < E\ (Qt)$;

Fixed Downstream Allocation (FD): upstream receives max $\{Qt - \gamma, 0\}$ and downstream receives Min $\{\gamma, Qt\}$, with $0 < \gamma < E\ (Qt)$.

Obviously, water transmission projects are very political dependent plans in which the definition of upstream and downstream is different from engineering field. Therefore, The

upstream definition is strongly related to this question: "who can control water?". This fact obviously can be seen in huge and national projects in which the government financial support is the most important related factor (Gumbo & Van der Zaag, 2002). Thus in this case, all allocations are under domination of central government. However, in this research we assume Dez basin as the upstream and Qomrood basin as the downstream. It seems that this assumption is appropriate to the real condition of these basins and was used in the current research by Maknoon et al (Maknoon et al., 2012).

In conclusion, three main factors of modeling and their scenarios are illustrated in table 3. As it can be seen in this table, Transmission protocol is the only real controllable factor. Owing to 38 possible outcomes for each Transmission protocol in this system, the best basic protocol weighted by the proportion of suitable results for each one is predicted.

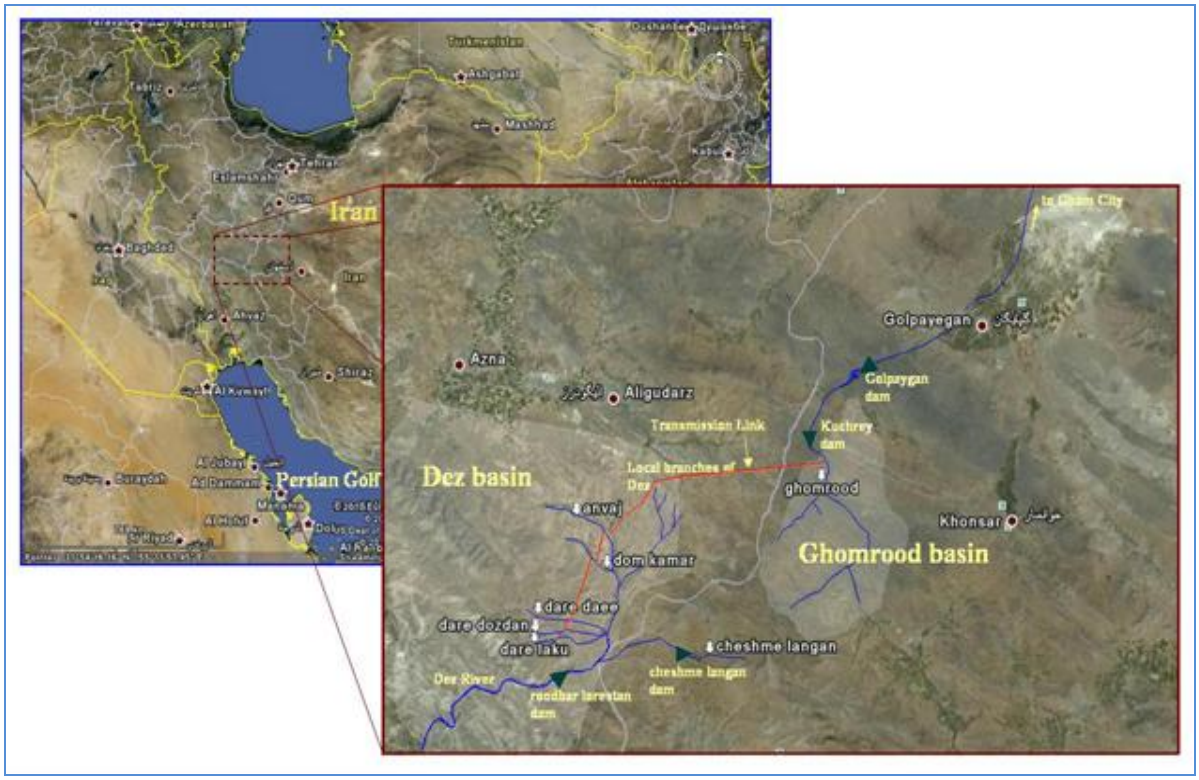

Figure 1. Geographic location of Dez and Qomrood basins and the water transfer link connecting Dez branches to Qomrood River.

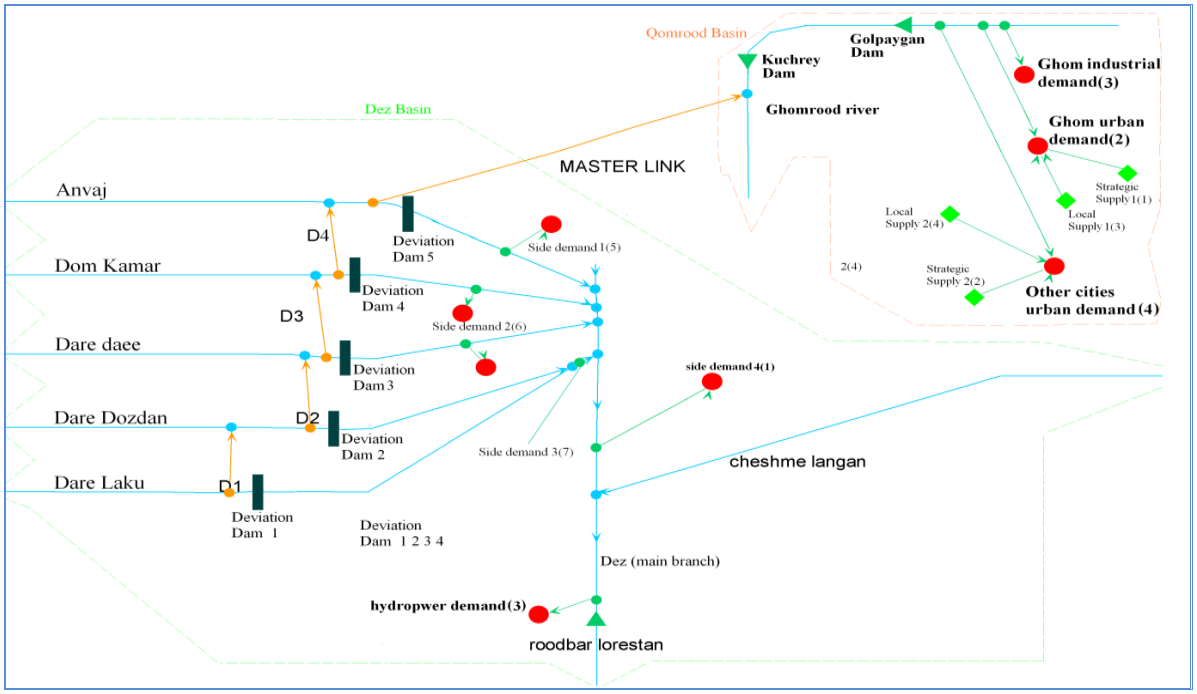

Figure 2. Schematic view of developed model for Dez and Qomrood systems including transfer links, more information are shown in table 1.

Table 1. GCMs categories and their behaviors in the objective region

GCMs family	Family Behavior	Involved GCMs	Typify GCM
Very optimistic	rainfall raises in objective cells	CNRM-CM3, CSIRO-30, GFDLCM-2.0	GFDLCM-2.0
Optimistic	rainfall declines in objective cells from 0% to 10%	ECHO-G, GISS-EH, INMCM-30, MICRO-HI, MRI-232A, UKHADCM3, MPI-ECH5	GISS-EH
Moderate	Rainfall declines in objective cells from 10% to 20%	BCCRBCM2, CCCMA-31, CCSM-30, UKHADGEM, MICRO-CMED,NCARPCM1	UKHADGEM
Pessimistic	Rainfall declines in objective cells from 20% to 30%	GFDLCM-2.1	GFDLCM-2.1
Very Pessimistic	Rainfall declines in object cells more than 30%	FGOALS-1G, IPSL-CM4	FGOALS-1G

4. Projection for Run-off and Results of Water Allocation Model

Final runoff projection results appropriately match TAR assessment and were in the same order of Maknoon et al results (Bates et al, 2008; Maknoon et al., 2012). This fact can be considered as a great confirmation of general results given by medium of GCMs. Table 4 illustrates the changes of average annual runoff in the basin for five categories of GCMs and for A1-AIM scenario. One GCM of each family is selected as the index of the group behavior. As it is shown in the table 24, GCMs that we used in research are: GFDLCM-2.0, GISS-EH, UKHAD-GEM, GFDLCM-2.1 and FGOALS-1G.

Per-capita urban water use is a major item playing a significant role in sustainable development context. As it can be seen in table 5, two main theme of SDI (Sustainable Development Indicator) and the sub-theme are directly related to urban water supply. In this research, as long as the indexes are based on water and energy themes of CSD Indicators of Sustainable Development of UN with considering total population who gain benefits from the project (UN, Indicators of Sustainable Development, 2007), we have focused on a tangible figure of total urban demand coverage by applying the transfer project. As a result, an index for per-capita urban water use seems necessary. Due to the lack of a reliable index for per-capita urban water use, three values have been identified in order to calculate the supply coverage of urban population. The first value (180 liter per person per day) is defined by Iran ministry of Energy, the second one (210 liter per person per day) is evaluated in Egypt, a country with similar life style and climate, and the last one (121.7 liter per person per day) is an optimum value considered in Fars province, located near to the case study region (Fry & Martin, 2005; Keshavarzi et al, 2006).

Final results for supplied urban demand in 2050 are shown in table 6. The final row of the table illustrates weighted results of each protocol based on the number of GCMs in each category. The values of table 6 have been generated via coverage graphs. Figure 3 shows the coverage graphs for five GCMs in 2050. As it is expected, by 157 million cubic meters in 2050, FD protocol can transfer much more water for urban usage in comparison with other protocols. However, a question still remains which ask whether or not these figures are enough for different scenarios of population growth.

Table 1. Initial Suppositions, historical statistics and boundary conditions applied for modeling the basins and water transfer system.

Model modules	Applied figures/ amounts/statistics
Urban demand of Qom city	**Total= 150MCM/year (estimated), 120 MCM/year (supported by transmission link), 20MCM/year (supported by local resources) , 16MCM/year (strategic reservoirs)**
Industrial demand	**Total= 20MCM/year (estimated for Qom industrial suburbs)**
Urban demand of neighbor cities in the objective region	**Total= 52.25MCM/year, 20 MCM/year (supported by transmission link), 20MCM/year (supported by local resources), 20MCM/year (strategic reservoirs).**
Kuchrey Dam	**Reservoir capacity is 207MCM. Initial storage = 50% at the beginning of the period**
Golpaygan Dam	**Reservoir capacity is 200MCM. Initial storage = 50% at the beginning of the period**
Annual flow of local branches in Dez basin	**230CMC/year by average rate of 7.29 CM/second (according to the historical data from Iran ministry of energy). Annual and Monthly oscillations are considered.**
Annual inflow of Anvaj river	**19.8MC/year (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Annual inflow of Domkamar river	**14.67MC/year (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Annual inflow of dare daee river	**46.55MC/year (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Annual inflow of dare dozdan river	**129.07MC/year (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Annual inflow of dare laku river	**98.90MC/year (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Transmission capacity of master link between Dez and	**23CM/second (Maximum capacity of the transmission tunnel)**
Annual incoming of Cheshme langan river	**700CMC/year by average rate of 22.19 CM/second. (according to the historical data from Iran ministry of energy)Annual and Monthly oscillations are considered**
Rudbar Loresatan Dam	**Reservoir capacity= 228MCM and peak hydropower production= 450MW**
Side river demand	**60MCM/year.**
PA Protocol	**50% allocation to downstream/ 50% allocation to upstream**
FD protocol	**Minimum allocation to Downstream = 160 MCM/y**
FU protocol	**Minimum allocation to Upstream = 160 MCM/y**

Table 2. Scenario producer factors for water supply: two population scenarios, nineteen GCMs, and three allocation protocol (possible scenarios= 2×19×3= 114)

Factor	Population	Available water	Transmission Protocol
Number of scenarios	2	19	3
Uncertainty sources	Socio-economic condition	GCMs and Climate scenarios	Government decision policy

Table 3. Predicted flow variation till 2050 for each GCMs class

GCMs class	Typify GCM	predicted Change of annual flow in the basin - A1 scenario
Very optimistic	GFDLCM-2.0	+13.10
Optimistic	GISS-E	-6.06
Moderate	UKHADGEM	-23.25
Pessimistic	GFDLCM-2.1	-37.95
Very Pessimistic	FGOALS-1G	-51.60

Table 4. Sustainable development indexes for urban water considered in this research, based on "UN: Indicators of Sustainable Development (2007)" definitions. Per-capita indexes are shown in the last column are taken from different resources.

Theme	Sub-Theme	Indicator description in UN guideline 2007	Inclusive Indexes which considered in model outputs	Per-Capita Index
Poverty	Sanitation	Proportion of population using an improved sanitation facility	**Total population receive standard per-capita urban water**	180 liters/day Defined by Iran ministry of Energy
	Drinking water	Proportion of population using an improved water source		210 liter/day (Egypt as a similar condition)
Freshwater	Water quantity	Proportion of total water resources used		121.7 liter/day (a similar study in the adjacent providence)

Table 5. Results for supplied urban demand in 2050 horizon for five categories of GCMs and three transmission protocols

Forecast category	Weight of assessment based on 19	Supplied urban demand (Million Cubic Meter/ Year)		
		Protocol FD	Protocol PA	Protocol FU
Very optimistic	3	168	162	159
Optimistic	7	163	159	143
Moderate	6	156	124	126
Pessimistic	1	145	110	99
Very Pessimistic	2	130	84	77
Weighted average		**157**	**137**	**131**

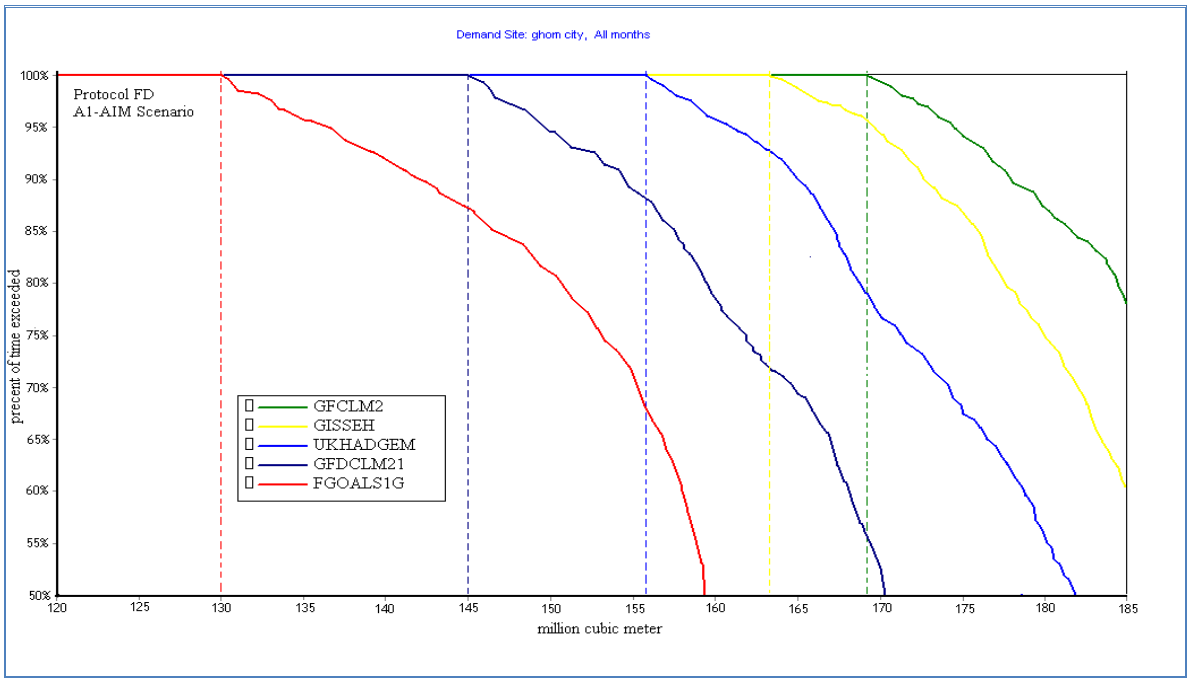

Figure 3. Urban supply/ demand ratio predicted via five GCMs in 2050 (FD Protocol).figures of table 6 have been produced by similar graphs for FU and PA protocols.

5. Population Growth and Urban Water Supply in Qomrood Basin

As it was mentioned in the first chapter, population growth is a challenging issue in Iran. By considering two different scenarios of low and normal growth rate, supply proportion for urban sector was calculated for each Protocol. The results are shown in table 7. As it can be clearly seen from the graph, even FD protocol never meets one hundred percent coverage unless for an optimum per-capita index (121.7 liter per person per capita). This forecasting indicates that there exists a considerable uncertainty about the urban water supply which leads to a wide band from 48% coverage for the worst condition of FU protocol to 113% of coverage for FD protocol in a low population growth rate and for an optimum water usage. In addition, sensitivity analysis of results shows that the role of the protocols is obviously more important than the population growth scenarios.

Table 6. Supply/ Demand proportion for urban water usage in 2050 for cities situated in Qomrood basin

Per Capita urban water use Index	Supply/Demand for urban sector in 2050					
	Protocol FD		Protocol PA		Protocol FD	
	Population growth rate 1.4	Population growth rate 1.7	Population growth rate 1.4	Population growth rate 1.7	Population growth rate 1.4	Population growth rate 1.7
IRAN Ministry of Energy (180 Liter/person/day)	0.76	0.68	0.67	0.59	0.64	0.57
Average for Egypt (210 Liter/person/day)	0.65	0.58	0.57	0.51	0.55	0.48
Similar value in adjacent providence (121.7 Liter/person/day)	1.13	1.00	0.98	0.87	0.94	0.84

6. Conclusion

Final results of the model indicate that Fix Downstream water transmission protocol can supply a higher proportion of urban demand in 2050 as the target year (between 68% to 113%. depends on the population scenario and consumption pattern).This result is valuable in the first round of a sustainable development evaluation. The results also show the importance of determining a suitable per-capita urban water use indicator for this region. It seems that we should put more emphasis on the case of water transmission to improve assessment procedure. As a case, hydrologic conductivity is a changing factor in long term; planet cover will vary by climatic changes. Moreover, human activities such as river engineering can change the parameters of the rainfall-runoff model. In addition to this, a wide range of under construction projects is located in this region which will certainly influence the water balance. Hydropower projects, developing irrigation and industrial zones are typical factors that usually planed by social and political forces than technical factors. These factors can be considered in future researches to produce more reliable predictions in such basins. It`s also recommended to future researchers to focus on the next layer of socio-economic issues and the behavior of consumers in long term.

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Glossary

GCM: General Circulation Model

MAGICC- SCENGEN: Model for Assessment of Green-house-gas Induced Climate Change-Scenario Generator

FD protocol: Fix Downstream water allocation Protocol

FU protocol: Fix Upstream water allocation Protocol

PA protocol: Proportional water Allocation Protocol

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