Urban water demand forecasting based on climatic change scenarios

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Abstract

Water resources projects, are designed to serve for many years to meet water needs. Therefore, the future water demand forecasting is of great importance for planning and management of water resources. In this study, a multi linear regression model is built to forecast urban water consumptions based a series of variables, namely the population served, monthly mean temperature and monthly total precipitation. Using the extended values of the variables up to the year 2100 based on climatic change scenarios, urban water demands are forecasted up to 2100.

Introduction

Water demand forecasting is key to design of water supply systems. Various techniques are available to forecast future water demand including time series analyses and multiple coefficient method [1] [2]. Climate change is one of the latest issues that has been considered in water resources literature. Therefore, it is not possible to avoid climatic change when forecasting future water requirements.

In this study, a multi coefficient demand model is used to forecast urban water consumptions based a series of socio-economic and climatic variables. The variables selected include the population served, monthly mean temperature and monthly total precipitation. The model used is in the form of multiple linear regressions. The variables selected are extended up until the year 2100 based on two global warming scenarios. Using the extended values of the variables, the urban water demand values are forecasted up to the same year in the case of the city of Denizli, Turkey.

Climate change

The Earth's atmosphere is polluted due to population growth, urbanization and industrialization resulting from greenhouse gases. As a result of this pollution, global climate changes occur [3].

The climate models are used to understand the climate system, to see the changes and make predictions about the future. Development of climate models started as one-dimensional models. Today, the three-dimensional general circulation models are studied.

Special Report of Emission Scenarios (SRES) was published by IPCC in 2000 [4] to be used to predict future changes in climate. How greenhouse gas emissions to be in the world with different environmental, social and economic conditions were determined by the scenarios published in this report. These scenarios were gathered into four groups;

The assumptions of A1 scenario family suppose that in the future there will be a very rapid economic growth in the world, the global population will reach its highest level in the middle of the century and then will decline, and new and efficient technologies will spread quickly.

A2 scenario defines a quite heterogeneous world. The underlying main theme of this scenario is to ensure the protection of local identities and self-confidence. Global population is expected to increase continuously. Economic development is regionally oriented. Technological developments are fragmented and slower than in other scenarios.

B1 scenario, as in the A1 scenario, assumes that the global population will peak and then decline in the middle of the century, economic embodiments will experience a rapid transformation towards service and information sectors. The density of the material will decrease and efficient technologies will be developed in resource usage.

B2 scenario assumes that economic, social and environmental sustainability are performed with local solutions in the world. Global population will increase at a slower rate than that in scenario A2. According to the scenarios B1 and A1 an average level of economic development, slower and more technological changes are assumed. This scenario is focused on the protection of the environment and social justice also draws attention to the local and regional levels.

In this study, the outputs of the project Climate Change Scenarios for Turkey supported by TUBITAK were used [5]. In this project, Echam5 general circulation model's outputs for A2 and B1 SRES scenarios were reduced to smaller scales for Turkey by using RegCM3 regional model.

Prediction of urban water consumptions between 2011-2100 years for Denizli city

As shown in Figure 1, Denizli is a city located in the south of the Aegean region. Because of its geographical location and characteristics, it has a colder climate differing from the Aegean region’s climate.

Figure 1: Denizli City

As mentioned earlier, water consumption prediction depends on economic, social, and meteorological parameters. In this study, water consumption was estimated by population, rainfall and temperature variables. The data between January 2007 and December 2010 were used to find the coefficients of the model established for prediction in the province of Denizli.

The population data is obtained through the multiplying the number of subscribers, households by 4 which is assumed to be the average number of house hold numbers.

The population of the subscribers is obtained by multiplying by 4 people which is the number of subscribers and the average number of household members. The population of the subscribers and domestic water usage data were obtained from Denizli Municipality. Rainfall and temperature data were taken from the Turkish State Meteorological Service. These data are provided in Figure 2-5.

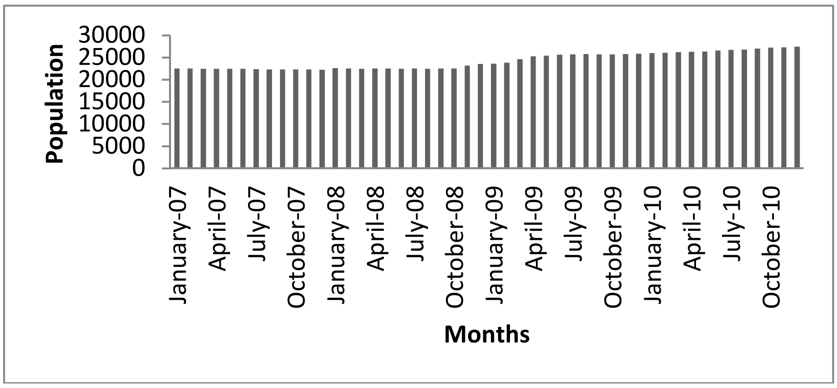

Figure 3. Temperature between the years of 2007-2010

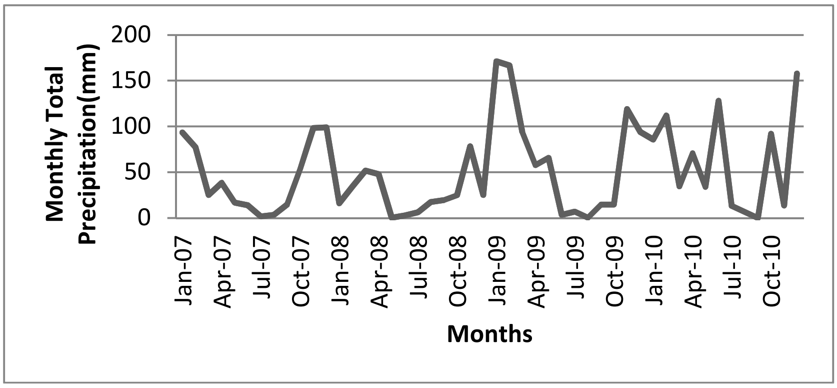

Figure 4. Monthly total precipitation between the years of 2007-2010

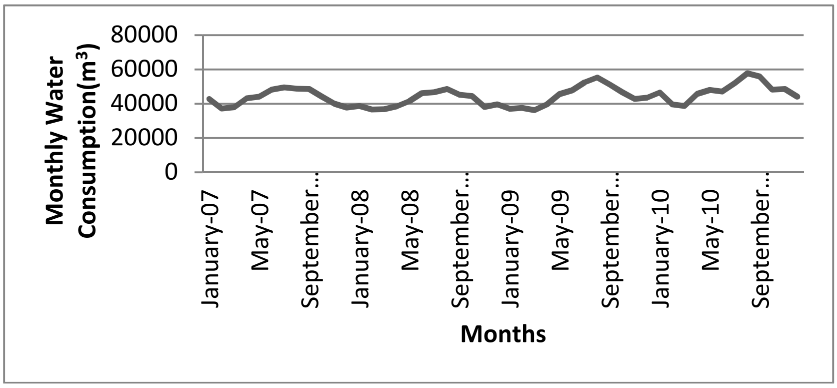

Figure 5: Monthly water consumption between the years of 2007-2010

Population data for estimation of water consumption between the years of 2011-2100 were obtained by the exponential method given Eq. 1.

$$P_{t+n} = P_t e^{rn} \qquad (1)$$

where P_{t+n} is the population in the last census, P_t is the population in the previous census, r is the population growth rate, and n is the period between two censuses.

The rate of population growth was calculated by using the population values between the years of 2007-2010, and then the Eq. 2 was obtained.

$$P_{t+n} = P_t e^{0,058179\,n} \tag{2}$$

Population of Denizli City between the years 2011 and 2100 estimated by Eq.2. These values are shown in Figure 6.

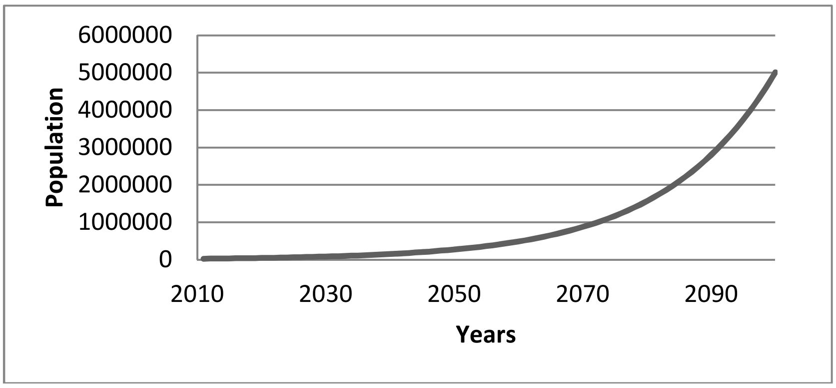

Figure 6: Estimated population between the years of 2007-2010

Temperature and precipitation values were taken from the project's website of Climate Change Scenarios for Turkey project supported by TUBITAK [5]. Temperature and rainfall data in A2 and B1 scenarios between the years of 2011-2100 obtained from the website are provided in Figure 7-10.

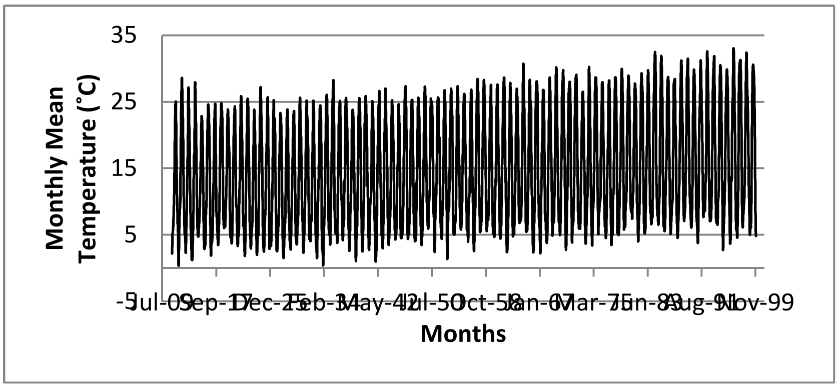

Figure 7: Monthly mean temperature between the years of 2007-2010 for A2 scenario

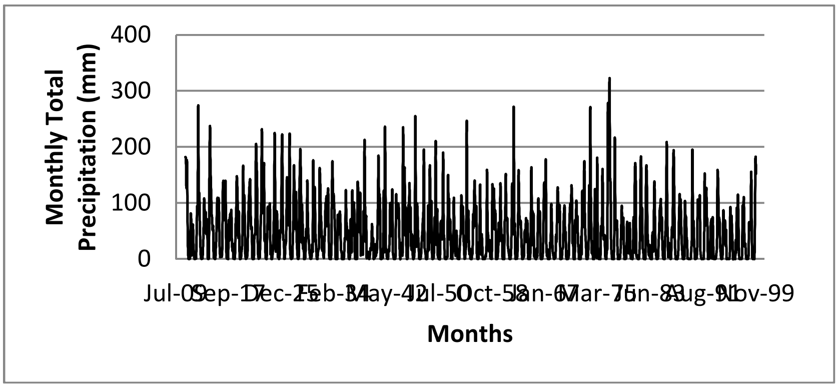

Figure 8: Monthly total precipitation between the years of 2007-2010 for A2 scenario

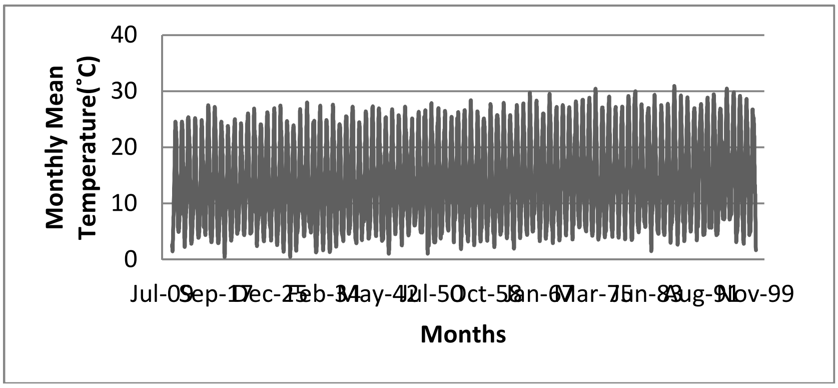

Figure 9: Monthly mean temperature between the years of 2007-2010 for B1 scenario

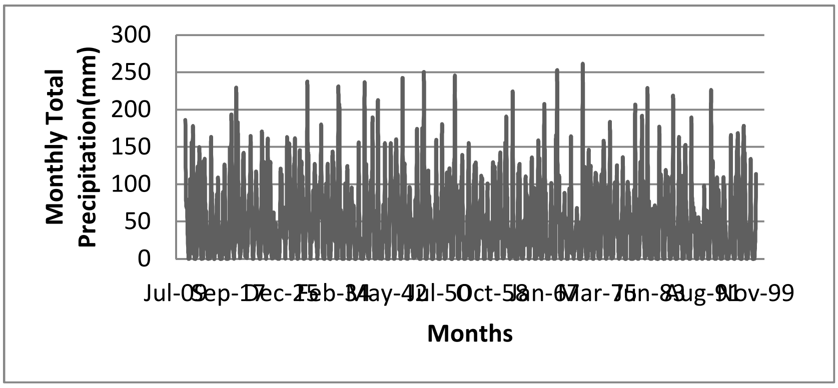

Figure 10: Monthly total precipitation between the years of 2007-2010 for B1 scenario

Application

In this study, water demand forecasting is performed by multivariate regression method whose is general structure is given in Eq. 3

$$ST = f(N,S,Y) \quad \textbf{(3)}$$

where, ST is the water consumption, N is the population, S is the temperature, and Y is the precipitation.

Eight different models are tried in order to find the best multivariate regression model structure for the relationship between the water consumption and the population, the temperature and the precipitation variables. This eight model structures in Table 1 are provided.

Table 1. Structure of Models

Models	**Structure of Models**
M1	$ST = {}_0 + {}_1N + {}_2S + {}_3Y$
M2	$ST = {}_0 + {}_1\ln(N) + {}_2S + {}_3Y$
M3	$ST = {}_0 + {}_1\ln(N) + {}_2\ln(S) + {}_3Y$
M4	$ST = {}_0 + {}_1\ln(N) + {}_2\ln(S) + {}_3\ln(Y)$
M5	$ST = {}_0 + {}_1N + {}_2\ln(S) + {}_3Y$
M6	$ST = {}_0 + {}_1N + {}_2\ln(S) + {}_3\ln(Y)$
M7	$ST = {}_0 + {}_1N + {}_2S + {}_3\ln(Y)$
M8	$ST = {}_0 + {}_1\ln(N) + {}_2S + {}_3\ln(Y)$

The coefficients of the models are calculated by the method of least squares with water consumption, population, and temperature and precipitation data between January 2007 and December 2010. The models' correlation coefficients (*r*) can be seen in Table 2.

Table 2: Models Performance

Model	**r**	**Model**	**r**
M1	**0,8937**	M5	0,8597
M2	0,8923	M6	0,8657
M3	0,8584	**M7**	**0,8957**
M4	0,8644	M8	0,8945

As can be seen in Table 2, the model which has best correlation is M7 (r = 0.8957). But M1 model was chosen as the most appropriate model which has very close correlation value to M7 model and obtained without any conversions to the data. M1 model is provided in Eq. 4.

$$ST = 6926{,}85 + 1{,}23N + 474{,}57S - 14{,}93Y \qquad \textbf{(4)}$$

The water consumption between the years 2007-2010 and the result of M1 model are drawn in Figure 11. As can be seen from the figure, the consistence between the results of M1 model and the water consumption value is high.

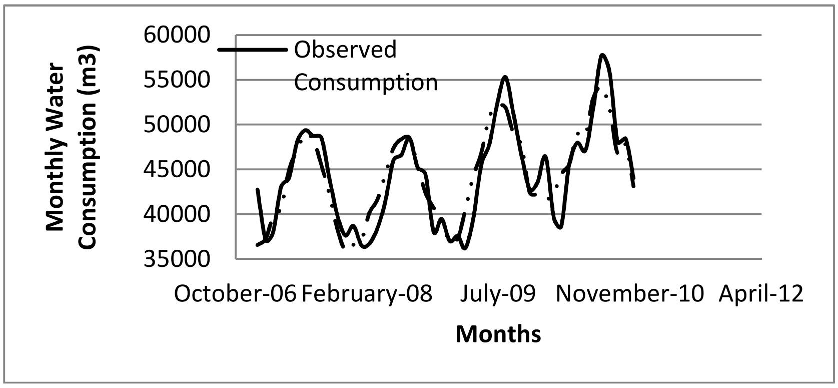

Figure 11: Results of M1 model and observed water consumption value between the years of 2007-2010

After the selection of the model, the predicted values obtained by using M1 model according to the A2 and B1 scenarios in Denizli are provided in Figure 12. In addition, the estimates of water consumption in the month of January of the last decade are given in Table 3.

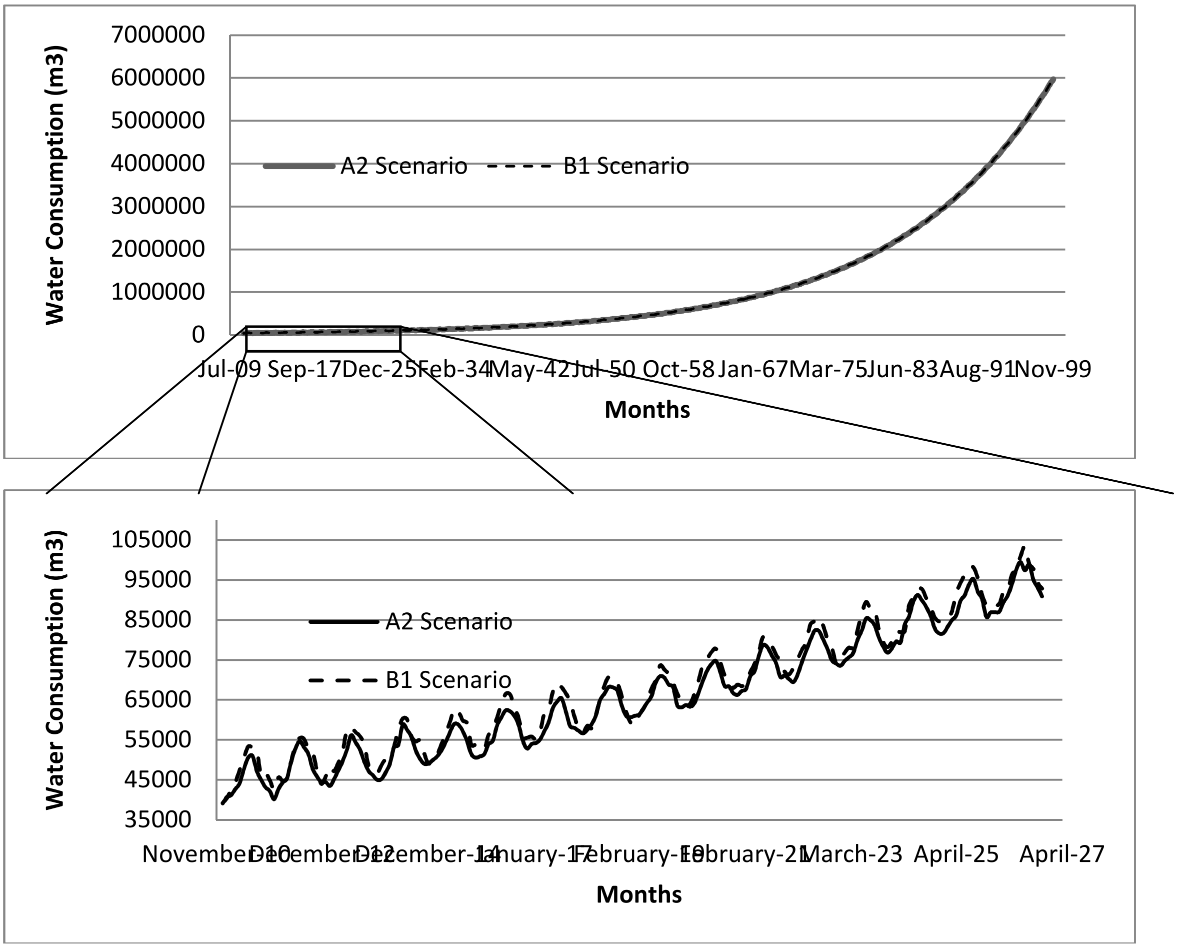

Figure 12: Results of M1 model water consumption value between the years of 2011-2100

Table 3: Water consumptions between the years of 2080-2099

Months	**A2 Scenario (m^3)**	**B1 Scenario (m^3)**	**Months**	**A2 Scenario (m^3)**	**B1 Scenario (m^3)**
Jan.2080	1878580	1878730	Jan.2090	3356216	3356594
Jan.2081	1992125	1991461	Jan.2091	3556090	3559141
Jan.2082	2108477	2111411	Jan.2092	3770028	3770013
Jan.2083	2234995	2234861	Jan.2093	3994564	3996021
Jan.2084	2369141	2368600	Jan.2094	4233519	4234175
Jan.2085	2511095	2511371	Jan.2095	4485928	4488070
Jan.2086	2660090	2661696	Jan.2096	4753259	4755337
Jan.2087	2819328	2818521	Jan.2097	5038871	5038602
Jan.2088	2987007	2987559	Jan.2098	5341096	5339082
Jan.208	3166780	3166542	Jan.209	5659191	5661597

9			9		

Conclusions

Water resources development has been conventionally a source-based and investment-focused process. As such, it can be stated to be somewhat unsustainable. More demand-based approaches are needed to sustain limited sources to serve for growing population and industry. Moreover, water resources are under additional stres due to the climate change, which should be taken into consideration in any water resources design.

A multiple linear regression model is proposed to predict future water requirements, in which water consumptions are modeled based on population, monthly mean temperature and monthly total precipitation. The extended values of climatic variables are obtained based on the climatic change scenarios, A2 and B1. The regression model is run using the extended population and the climatic values to obtain the future water demand values. It is observed that the model predicts are compatible with the real values observed in the case study area considered. It is, therefore, concluded that the use of such models are encouraging. However, such models are highly dependent upon the healthy data, which could sometimes be difficult to obtain. It is recommended that water authorities keep the records continuously and reliably and are willing to share them.

Acknowledgement

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