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**RESEARCH ARTICLE - SYSTEMS ENGINEERING**

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# Water Demand Forecasting Based on Stepwise Multiple Nonlinear Regression Analysis

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**Abstract** The main objective of the present study is to apply the nonlinear regression (NLR) model in order to forecast water demand in Adana city of Turkey. The average monthly water bill, total subscribership, atmospheric temperature, relative humidity, rainfall, global solar radiation, sunshine duration, wind speed and atmospheric pressure are selected as independent variables. Meteorological parameters were taken from Adana meteorological station, and the other parameters such as water consumption, total subscribership and water bill values were supplied from Adana Water and Sewerage Administration during the periods of 2000–2009. In order to get a successful simulation, first, all independent variables were added to the "enter" regression model. Then, the method of stepwise multiple regression was applied for the selection of the "best" regression equation (model). Thus, the best independent variables were selected for the NLR model. Consequently, while water consumption in Adana city is 3.84 million $m^3$ at the end of 2009, it will increase up to 4.99 million $m^3$ by the year 2020.

**Keywords** Nonlinear regression · Forecasting · Stepwise multiple regression · Water demand

**الخلاصة**

إن الهدف الرئيسي لهذه الدراسة يتمثل في تطبيق أنموذج الانحدار اللاخطي (NLR) بهدف التنبوء بالطلب على المياه في مدينة أضنا التركية. وقد تم اختيار المتوسط الشهري لفاتورة الماء، وإجمالي المشتركين، ودرجة حرارة الجو، والرطوبة النسبية، والأمطار، والإشعاع الشمسي العالمي، ومدة شروق الشمس، وسرعة الرياح، والضغط الجوي كمتغيرات مستقلة. وقد تم أخذ بامترات الأرصاد الجوية من محطات الأرصاد الجوية لمدينة أضنا، والبارمترات الأخرى : مثل قيم استهلاك المياه، وإجمالي المشتركين وفاتورة الماء من إدارة المياه والصرف الصحي لمدينة أضنا في الفترة ما بين 2000-2009م. وللحصول على محاكاة ناجحة، تمت - في البداية - أضافة جميع المتغيرات المستقلة إلى أنموذج الانحدار (enter)، ومن ثم تم تطبيق طريقة الانحدار المتعدد المتدرج لذلك الاختبار لأفضل معادلة انحدار (أنموذج). وبالتالي ، فإن أفضل متغيرات مستقلة تم اختيارها لأنموذج NLR، في حين أن استهلاك المياه في مدينة أضنا 3.84 مليون متر مكعب في نهاية 2009 م، فإنه سوف يزداد إلى 4.99 مليون متر مكعب بحلول عام 2020م .

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## 1 Introduction

Changes in population of city center are forcing the construction of substantial numbers of new houses, creating a need to forecast water consumption for new housing developments. It is vital important to forecast the future water demand accurately by proper methodologies such as time extrapolation, disaggregate end-uses, single-coefficient method, multiple-coefficient method, memory-based learning technique and time-series models.

Forecasting water demand is very active nowadays. Early works addressed this question using mainly traditional statistical models. In recent years, more sophisticated modeling techniques have been applied for forecasting water demand. The forecasting performance of different regime-switching models based on non-linear time series models was compared with respect to their capabilities of forecasting monthly and seasonal flows [1]. Various artificial neural network techniques, such as generalized regression neural networks (GRNN), feed forward neural networks (FFNN) and radial basis neural networks (RBNN), were evaluated based on their performance in forecasting monthly water consumption using several socio-economic and climate factors as Fırat et al. [2] stated. Herrera et al. [3] evaluated the predictive models such as artificial neural networks (ANN), projection pursuit regression (PPR), multivariate adaptive regression splines (MARS), support vector regression (SVR), random forests (RF) and weighted pattern-based model for water demand forecasting using an experimental methodology for hourly time series data that detailed water demand in a hydraulic sector of a water supply network. The constant use rate model was used to forecast the water demand in Umm Al-Quwain Emirate for the next 20 years by Mohamed et al. [4]. The forecast was performed based on two water consumption and population databases.

Calvo et al. [5] evaluated the performance of linear multiple regressions and feed forward computational neural networks (CNNs) trained with the Levenberg Marquardt algorithm for the purpose of irrigation demand modeling. The input or independent variables used in various CNN and multiple regression models were water demands from previous days and water demands and climatic data (rainfall, maximum, minimum and average temperatures, relative humidity and wind speed) from previous days. Fox et al. [6] studied how to classify properties in terms of their physical characteristics for the purpose of forecasting water demand.

Many researches were fulfilled relating the independent variables used to explain variation in house water demand such as water price, temperature, rainfall, income and household size [7–10]. However, one of the most important steps in developing a satisfactory forecasting model is the selection of the input variables. Because, these variables determine the structure of forecasting model and affect the weighted coefficient and also results of the model.

Water demand forecasting and modeling is important for planning and management of water resources and also essential for the design and operation of various water infrastructures such as reservoirs supply and distribution facilities. Water demand forecasting is of great economic and environmental importance [2].

The main goal of this study is to determine the most suitable independent variables for forecasting the monthly water demand in Adana city of Turkey. Stepwise multiple nonlinear regression method was used to develop the model. In order to get a successful simulation, first, all independent variables were added to the single regression model. Then, the method of stepwise multiple regression was applied for the selection of the "best" regression equation.

The rest of this paper is organized as follows: Section 2 describes the study area, the stepwise multiple regression method and the stepwise input variable selection procedure. Section 3 discusses results of the water demand forecasting between 2010 and 2020 in Adana city. In Sect. 4, the factors affecting the subscribership increment are presented and the precautions, taking into consideration by authorities, are discussed in detail.

## 2 Materials and Methods

### 2.1 Study Area

Adana city is one of the first industrialized city and currently one of the economically developed cities of Turkey. It is the fifth largest city of Turkey, and it is a major agricultural and commercial center. Topographically, the site is flat and grassy. This large stretch of flat, fertile land lies southeast of the Taurus Mountains, and is among the most agriculturally productive areas of the world. Topographic elevation at the site varies between 25 and 257 m. Mediterranean climate is dominant in this region, usually hot and dry in the summer season, lukewarm and rainy in the winter season. Mean temperatures are about 13–15 °C in winters and between 34 and 39 °C during summers. But, climate properties vary depending on the level of the height above the sea level. On the slope of a mountain looking at the sea, an increase of terrestrial effects on climate is observed.

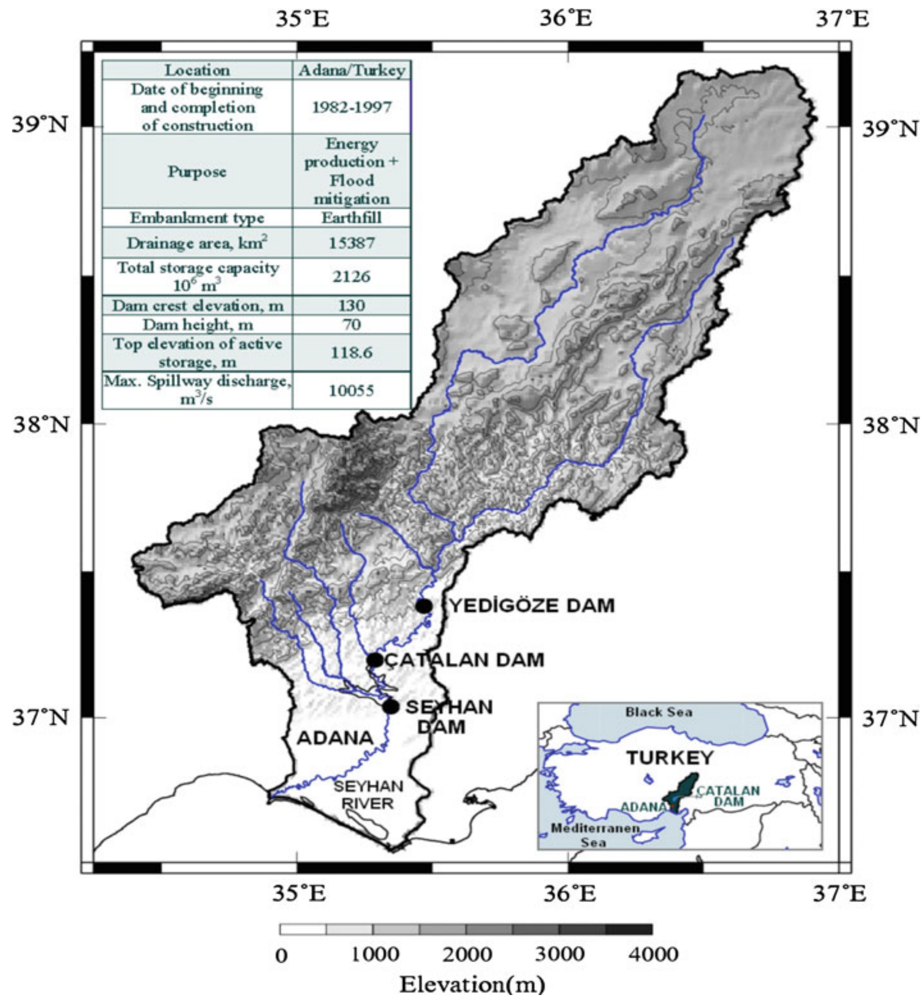


**Fig. 1** The location of the test region in Adana [12,13]

However, the weather in this region does not show intense terrestrial climate due to the Mediterranean Sea effect [11].

Seyhan Basin, with a total area of about 20,000 km$^2$, is one of the major basins in Anatolia. There are three dams in series on Seyhan River, Çatalan, Seyhan and Yedigöze Dam. Brief information about Çatalan Dam and its location in Seyhan Basin is shown in Fig. 1 [12,13]. The main water use sectors in Adana city of Turkey are the residential, industrial, commercial and governmental sectors. The total storage capacity of Çatalan Dam is 2,126 million m$^3$. The current metered consumption in Adana city was 52.012 million m$^3$/year in 2009, and respectively, 48.940 million m$^3$(88.9 %) out of this water consumption in the residential, 1.937 million m$^3$ (3.52 %) in gardens, 1.758 million m$^3$ (3.19 %) in governmental sectors and 0.385 million m$^3$ in mosques was used.

Quality control of water for 1.5 million Adanaers is measured and also is inspected periodically by Ministry of Health. Today, the quality of Çatalan freshwater used for drinking purpose, is approved by Turkish Standard Institution (TSI), European Union (EU), US Environmental Protection Agency (EPA), World Health Organization (WHO) and Regulation Concerning Water Intended for Human Consumption. However, new settlements are formed (house, school, official departments etc.) in the lands near the bank of Çatalan basin. Fertilized agriculture is started near Çatalan Dam. Furthermore, the sewage of all settlements and industrial foundations near Çatalan Dam is flowed directly into the basin. Purification of water will be more difficult and more expensive in future. Flood protection areas, which are determined in the regulation of water pollution control [14], have not been formed yet.

### 2.2 Stepwise Multiple Regression Analysis

Regression analysis is one of the most widely used methodologies for expressing the dependence of a response variable on several independent variables [15]. The first step in regression analysis is to select independent variables for constructing a model. Here, the important peculiarity is: (1) to pick out adequate dependent variables, (2) to exist linear cause–result relationship between dependent variable and independent variables, (3) to include only relevant independent variables in the model. While dealing with large number of independent variables, it is of importance to determine the best combination of these variables to predict dependent variable according to Çevik [16]. He further stated that stepwise regression served as a robust tool for the selection of best subset models, i.e. the best combination of independent variables. The determination of subset models is based on adding or deleting the variable/variables with the greatest influence on the residual sum of squares. Stepwise regression is actually a forward selection process that rechecks at each step the importance of all previously included variables. If the partial sums of squares for any previously included variables do not meet a minimum criterion to stay in the model, the selection procedure changes to backward elimination and variables are dropped once at a time until all remaining variables meet the minimum criterion.

Regression analysis consists of a collection of techniques that are used to explore relationships between variables as given in Eq. (1) [17].

$$Y = f(X_1,\ X_2, \ldots X_n) \tag{1}$$

Nonlinear regression is a form of regression analysis in which observational data are modeled by a function, which is a nonlinear combination of the model parameters and depends on one or more independent variables. Unlike traditional linear regression, which is restricted to estimating linear models, nonlinear regression can estimate models with arbitrary relationships between independent and dependent variables. The general appearance of the nonlinear relation is assumed to be:

$$Y = \alpha_0(X_1^{\alpha_1})(X_2^{\alpha_2})\ldots(X_n^{\alpha_n}) \tag{2}$$

where $\alpha_0 - \alpha_n$ are the equation parameters for the nonlinear relation [18]. Some nonlinear regression problems can be moved to a linear domain by a suitable transformation of the model formulation. Taking the log of Eq. (2), the relationship becomes linear:

$$\log(Y) = \log(\alpha_0) + \alpha_1 \log(X_1) + \alpha_2 \log(X_2) + \cdots \alpha_n \log(X_n) \tag{3}$$

and so a regression of $\log(Y)$ on $\log(X_1)$, $\log(X_2)$, …, $\log(X_n)$ is used to estimate the parameters $\alpha_0$, $\alpha_1 \ldots$, and $\alpha_n$ [17,19].

In the stepwise input variable selection procedure, first, the between-variable correlation coefficients $R_{Yi} i = 1, 2, \ldots, k$ are computed. The input variable with the largest absolute value in between variable correlation with $Y_t$, say $X_{1t}$ for simplicity, is chosen to enter Eq. (2). This variable is checked for its significance by examining the $t$ statistic of the regression coefficient $\alpha_1$. Subsequently, input variables $X_{it},\ i = 2\ldots, k$, are adjusted for $X_{1t}$ and the between-variable partial correlation $R_{Yi|1}\ i = 2\ldots, k$ is computed. The variable with the largest absolute value in between variable partial correlation, say $X_{2t}$, is then selected and inserted into the equation. The overall equation is checked for significance. The regression coefficient with a lower absolute value of $t$ statistic is tested against a pre-selected significance level, according to which the corresponding variable is retained in the equation or rejected. This test is carried out at the every iteration of the variable selection procedure. The process continues until the regression coefficient of the last entered variable is found to be statistically significant [20].

## 3 Results and Discussion

It is also well known that water demand is related to various meteorological and related statistical variables. Therefore, water consumption ($Y$) can be characterized as the function of month of the year ($X_1$), average monthly water bill, ($X_2$), total subscribership ($X_3$), atmospheric temperature ($X_4$), relative humidity ($X_5$), rainfall ($X_6$), global solar radiation ($X_7$), sunshine duration ($X_8$), wind speed ($X_9$) and atmospheric pressure ($X_{10}$). The important statistical properties such as minimum, maximum, mean, standard deviation and correlation coefficient values with water consumption of all variables are given in Table 1. Meteorological parameters used

**Table 1** The statistical parameters of all data

| Input and output variables | Unit | $X_{min}$ | $X_{max}$ | $X_{mean}$ | $X_{SD}$ | Correlation with $Y$ |
|---|---|---|---|---|---|---|
| $Y$ | $m^3$ | 2482408.000 | 4538769.000 | 3536344.807 | 472388.201 | 1.000 |
| $X_1$ | month | 1.000 | 12.000 | 6.454 | 3.444 | 0.174 |
| $X_2$ | Turkish Lira/$m^3$ | 0.312 | 2.470 | 1.285 | 0.650 | 0.390 |
| $X_3$ | Number | 312254.000 | 439454.000 | 374156.866 | 32063.322 | 0.357 |
| $X_4$ | °C | 6.700 | 29.800 | 19.296 | 7.279 | 0.696 |
| $X_5$ | % | 56.100 | 80.000 | 68.761 | 5.618 | 0.224 |
| $X_6$ | mm | 0.000 | 320.900 | 48.690 | 53.990 | −0.440 |
| $X_7$ | kcal/$m^2$ | 0.129 | 0.652 | 0.372 | 0.136 | 0.577 |
| $X_8$ | h | 2.200 | 11.300 | 7.295 | 2.334 | 0.665 |
| $X_9$ | m/s | 0.300 | 1.600 | 1.128 | 0.294 | 0.116 |
| $X_{10}$ | Bar | 1.001 | 1.021 | 1.010 | 0.005 | −0.648 |

**Table 2** Nonlinear regression with constant using enter method

| Model | Unstandardized coefficients | | Standardized coefficients | t | Sig. |
|---|---|---|---|---|---|
| | $\alpha$ | Std. error | Alpha | | |
| 1 | | | | | |
| Constant | 1458.814 | 2.155 | | 1.468 | 0.145 |
| $X_1$ | −0.018 | 0.018 | −0.105 | −0.986 | 0.326 |
| $X_2$ | −0.009 | 0.055 | −0.040 | −0.156 | 0.877 |
| $X_3$ | 0.507 | 0.404 | 0.318 | 1.254 | 0.213 |
| $X_4$ | 0.173 | 0.073 | 0.543 | 2.358 | 0.020 |
| $X_5$ | 0.133 | 0.156 | 0.081 | 0.856 | 0.394 |
| $X_6$ | 0.010 | 0.009 | 0.100 | 1.083 | 0.281 |
| $X_7$ | −0.024 | 0.069 | −0.072 | −0.342 | 0.733 |
| $X_8$ | 0.103 | 0.069 | 0.274 | 1.496 | 0.138 |
| $X_9$ | 0.036 | 0.034 | 0.080 | 1.056 | 0.294 |
| $X_{10}$ | −1.686 | 5.606 | −0.057 | −0.301 | 0.764 |

$Y$ dependent variable
$R = 0.773$

in this model were taken from Adana meteorological station, and the other parameters such as water consumption, total subscribership and water bill values were supplied from Adana Water and Sewerage Administration during the periods 2000–2009. The relationship between water demand and input variables can be expressed as,

$$Y = f(X_1,\ X_2,\ X_3,\ X_4, X_5,\ X_6, X_7,\ X_8, X_9,\ X_{10}) \tag{4}$$

For the development of forecasting models, the total 119 data records were collected in the period 2000–2009 for the city of Adana, Turkey. In the nonlinear regression method, the most significant point is to select the predictor variables that provide the best prediction equation for modeling of dependent variable. For instance, first, the multiple nonlinear regression analysis was performed with the enter method in the Statistical Packages for the Social Sciences (SPSS) program. Table 2 shows the summary of the method. It seems that the enter method did not give a good result. This can be seen when comparing the last column of Table 2. All significance values are very much higher than 0.05 except for $X_4$. Therefore, this model estimates from enter method have been rejected. According to the enter method, the following model was obtained as,

$$Y = 1458.814X_1^{-0.018}X_2^{-0.009}X_3^{0.507}X_4^{0.173}X_5^{0.133}X_6^{0.01}X_7^{-0.024}X_8^{0.103}X_9^{0.036}X_{10}^{-1,686} \tag{5}$$

Then, stepwise regression technique was applied. The stepwise regression analysis in this study was performed by SPSS, which is a well-known statistical and data management software package. $R$ (correlation coefficient) values and significant levels ($P$ values) were used to evaluate estimator performance of the regression methods. Comparing stepwise regression and the enter method, the stepwise method is more accurate due to lower significant levels ($P$ values). As seen from the last column of Table 3, the significance values are lower than 0.01. Thus, the best independent variables were selected for the NLR model, and the following model was obtained as,

$$Y = 4405.5486X_4^{0.207}X_3^{0.474} \tag{6}$$

**Table 3** Nonlinear regression with constant using stepwise method

| Model | Unstandardized coefficients | | Standardized coefficients | $t$ | Sig. |
|---|---|---|---|---|---|
| | $\alpha$ | Std. error | Alpha | | |
| 1 | | | | | |
| Constant | 1870682.14 | 0.028 | | 220.410 | 0.000 |
| $X_4$ | 0.217 | 0.023 | 0.681 | 9.450 | 0.000 |
| 2 | | | | | |
| Constant | 4405.5486 | 0.589 | | 6.183 | 0.000 |
| $X_4$ | 0.207 | 0.021 | 0.650 | 9.757 | 0.000 |
| $X_3$ | 0.474 | 0.106 | 0.297 | 4.462 | 0.000 |

$Y$ dependent variable
$R = 0.681$ (Model 1), $R = 0.743$ (Model 2)

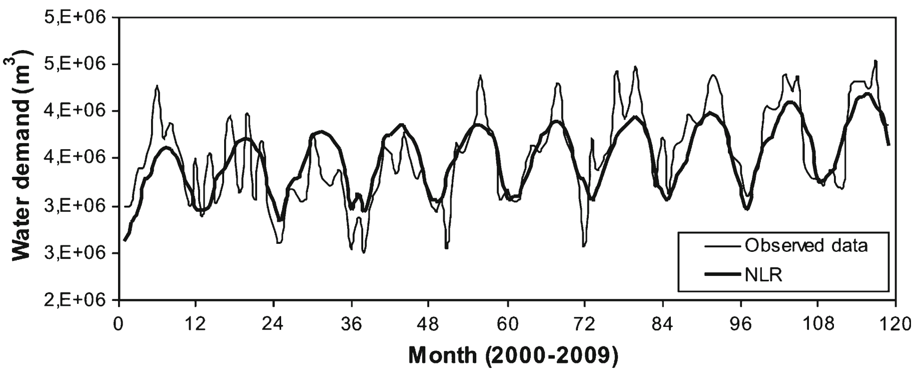


**Fig. 2** The comparison between prediction of NLR and observed data

According to Eq. (6), two independent variables ($X_4$ and $X_3$) were used. The other potential independent variables did not have the opportunity to be properly evaluated. Thus, the other variables were ignored except for $X_4$ and $X_3$. In Eq. (6), the dimensions of variables such as water demand ($Y$), atmospheric temperature ($X_4$) and total subscribership ($X_3$) are taken as $m^3$, °C and number, respectively.

The monthly water demands were predicted using Eq. (6). The scatter diagrams of the regression predictions against the observed data were drawn to indicate the performances of the NLR model. The evaluation results are presented in Fig. 2.

The mean absolute percentage error (MAPE) and correlation coefficient ($R$) were used to see the convergence between the observed data and the NLR predictions. MAPE and $R$ are defined as follows [21]:

$$\text{MAPE} = \frac{1}{n} \sum \left| \frac{p_i - o_i}{p_i} \right| \times 100 \quad (7)$$

$$R = \frac{\overline{o.p} - \overline{o}.\overline{p}}{\sqrt{\left[\overline{o^2} - (\overline{o})^2\right] \times \left[\overline{p^2} - (\overline{p})^2\right]}} \quad (8)$$

where, $o$ is the observed value, $p$ is the prediction value and $n$ is the total number of months. The performance values of the NLR model, such as MAPE and $R$ are given in Table 4. The maximum MAPE value was obtained for 2000 as 9.72 %. On the other hand, the best result of MAPE was found to be 4.80 % for 2005. According to the evaluation of the period 2000–2009, the MAPE value was determined as 6.96 %.

The monthly atmospheric temperature ($X_4$) and total subscribership ($X_3$) should be known to forecast the water demand between 2010 and 2020. For this reason, the monthly increment proportion of subscribership was calculated as 0.29 %. The subscribership data were computed applying the increment ratio between 2010 and 2020. The increase of total subscribership was shown in Fig. 3 between 2000 and 2020. Figure 3 shows that the subscribership will be 645,585 at the end of 2020, whereas it is 439,454 at the end of 2009.

Freshwater need of Adana has been provided from Çatalan Dam since November, 2002. As seen in Figs. 2 and 3, while the increase of the number of subscribers has displayed parallelism since 2003 with the previous years, a distinct increase on freshwater consumption has been determined.

**Table 4** The performance values of the NLR model

| Year | MAPE (%) | *R* |
|---|---|---|
| 2000 | 9.72 | 0.7807 |
| 2001 | 8.87 | 0.4966 |
| 2002 | 8.61 | 0.8289 |
| 2003 | 6.00 | 0.9062 |
| 2004 | 5.64 | 0.8191 |
| 2005 | 4.80 | 0.8563 |
| 2006 | 8.32 | 0.7012 |
| 2007 | 6.04 | 0.8639 |
| 2008 | 5.64 | 0.8501 |
| 2009 | 5.83 | 0.8625 |
| The period of 2000–2009 | 6.96 | 0.7611 |

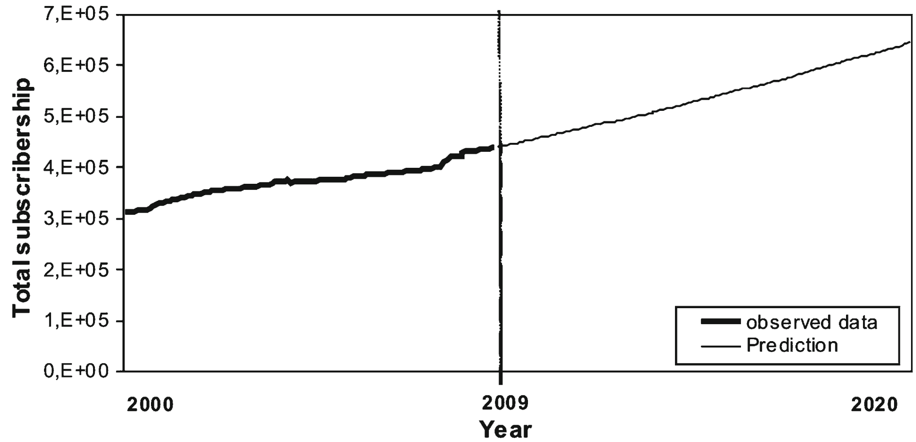


**Fig. 3** Total subscribership and its corresponding fitted linear trends

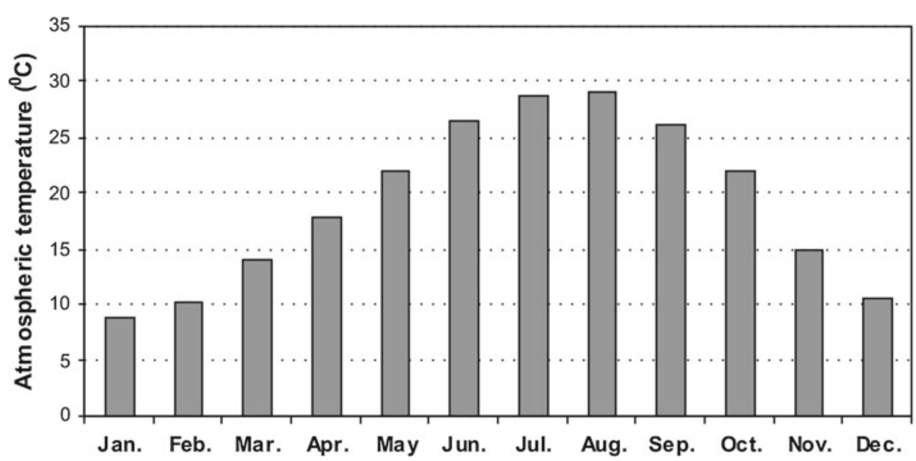


**Fig. 4** Monthly average atmospheric temperature values of the last 10 years

The average monthly atmospheric temperature values between 2000 and 2009 have been used as an independent variable of conjectural water demand which is observed between 2010 and 2020. The monthly average atmospheric temperature values were shown in Fig. 4.

The average monthly atmospheric temperature was observed as the highest degree in August and as the lowest degree in January, as 29.1 and 8.9 °C, respectively. Thus, the water demand of Adana city between 2010 and 2020 was forecasted using Eq. (6) and was shown in Fig. 5. As seen from Fig. 5, while the water demand of Adana city is 3.84 million $m^3$ at the end of 2009, it will be 4.99 million $m^3$ in 2020.

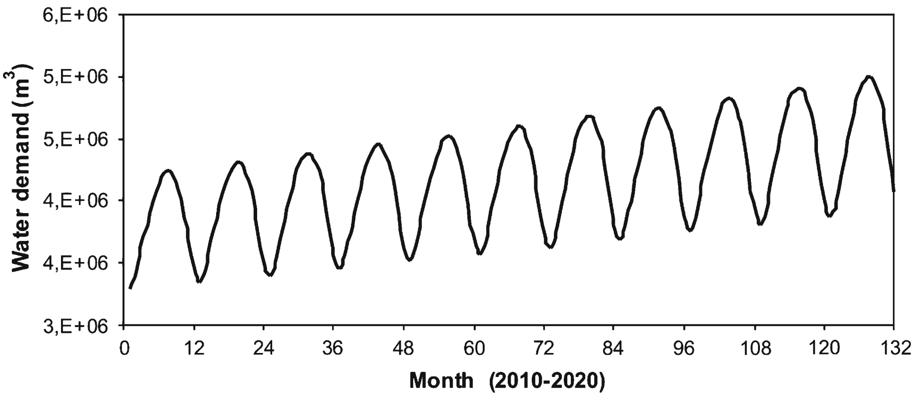


**Fig. 5** The water demand in Adana city for the period of 2010–2020

## 4 Conclusions

This study determines the most suitable independent variable for forecasting the water demand in Adana city of Turkey. According to the results obtained from the stepwise multiple regression analysis, the monthly water demand is directly related to the total number of subscribers and atmospheric temperature. The water demand of Adana is estimated to reach around 4.99 million $m^3$ in 2020.

The following results and recommendations can be drawn from the present study:

- The greatest effect of increase of migration and the population growth in Adana city is that the fields in this region which are suitable for agriculture and the number of the employees who are able to work in these fields is too many.
- Agricultural industry is quite developed in this region and the need for qualified employees in this sector has attracted immigrants from the other regions in Turkey.
- Some people living in other regions with severe winter conditions and paying a considerable amount on heating could choose to immigrate to warmer parts of Turkey like Adana.
- The population growth because of the migration in Adana city, spoiling the quality of the underground water and the cost of energy resulting from pumping the underground water into the system has revealed that the freshwater need of the city has to be met from the freshwater on surface.
- The greatest effect of the increase of using water is that the water in Çatalan Dam, which is maintained between minimum 118 m and maximum 130 m codes comes from Taurus Mountains and is used as freshwater without being polluted; the water quality is analyzed as per world standards.
- The code difference between the dam and the city has provided the water to be pumped in sufficient pressure. For this reason, pressure tanks are not used in high-floored buildings. So, this is an advantage of energy saving.
- The decrease of usable water reserves resulting from the population growth in Turkey like all around the world will not affect Adana city in 2020. Today, Çatalan Dam is capable of meeting this capacity.
- Excess amounts of water could be exported in bottles to areas in need of potable water until 2020.

To conclude, the water quality is adequate at the moment. But, if the precautions, specified in water pollution control regulations, are not taken, water pollution in Çatalan Dam will grow at an alarming rate in future. The authorities should be warned to take necessary precautions as per the above-mentioned regulations.

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