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# Time Series Modeling and Trend Detection of Streamflow and Selected Water Quality Variables in a River: Case Study, Euphrates River Monitoring Stations of 2102 and 2119

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**Abstract:** This study analyzed the data for streamflow and selected water quality variables including Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), sodium ($Na^+$), chloride ($Cl^-$) and sulfate ($SO_4^{2-}$), collected from two stations (2102 and 2119) in the Eupharates River in Turkey from 1984 to 1999 for existence of trends (using Kendall's tau test) and forecasting using a stochastic model (Thomas-Fiering). Because of EC values, the water can be used for irrigation purposes if a moderate amount of leaching occurs. In terms of SAR values, the water can be used for irrigation with little danger of the development of harmful levels of exchangeable sodium. Considering mean $Cl^-$ concentrations, no specific ion effect of $Cl^-$ is expected due to use of these waters for agricultural purposes. The quality of water at Durucasu station is also fit for irrigation in terms of $SO_4^{2-}$:$Cl^-$ ratio. Kendall's tau test results suggested an increased trend in the data record of EC and $Cl^-$ at 5% significance level and SAR and $Na^+$ at 10% significance level for the monitoring station of 2102 whereas an increased trend for the time series of SAR, $Na^+$ and $Cl^-$ at 5% and of EC at 10% significance level for the monitoring station of 2119. There was no increased or decreased trend in time series of $SO_4^{2-}$ and streamflow for both stations. The forecast values for all water quality variables and streamflow using Thomas-Fiering model are very close to the observed data and they suggest that there is no strange value for water quality variables and streamflow and the same flow pattern will continue into the near future.

**Key words:** Streamflow, water quality variables, trend, stochastic model

## INTRODUCTION

Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), sodium ($Na^+$), chloride ($Cl^-$) and sulfate ($SO_4^{2-}$) are five of the more significant water chemical quality indicators in the river systems[1]. After nineties, the increase in industrialized and urbanized areas in addition to animal husbandry without any wastewater treatment and the development of roads and airports causes pollution by the runoff and leaching of water-proof areas and degrades surface water quality. Similarly, abusive use of mineral fertilizers, soil degradation and rotation cropping system may affect surface water quality. Sodium is often indicative of development because of the elevated concentration in municipal wastewater effluent. It is one of the dominant cations in surface waters in developed parts. Chloride concentration also may indicate development. Chloride is generally low in natural waters but may be present in elevated concentrations in waters receiving industrial and municipal wastewater effluent[2].

Based on water quality data, it is important to predict the river water quality and to determine how water quality is changing over time. There is an increasing need to assess water-quality trends to provide not only a warning of the rates of water-resource degradation, but also to take adequate measures in order to keep pollutants within the permissible limits. The purpose of most water quality studies is to point out the necessary information and knowledge for the management of these precious resources; for their use, control and development. Future values of water quality variables and streamflow can be predicted using component models or autoregressive models. These anticipated future values may then aid in planning and decision-making[3].

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The present study was concerned with time-series analysis of streamflow and water quality variables, including water specific conductivity (EC), SAR, chloride, sodium and sulfate, of the Euphrates River at the measuring points Palu (2102) and Kemahboğazı (2119) for a 16-year period from 1984 to 1999. Using a nonparametrictest, we assessed the presence of trend for the observed variables and using a stochastic model predicted future values for each variable.

## MATERIALS AND METHODS

The Euphrates River flows from its origin in the highlands of Eastern Turkey through Syria into Iraq and reaches to the Persian Golf. It is the longest river in Southwestern Asia. The Euphrates basin lies 28% in Turkey (with a drainage area of 125,540 $km^2$) 17% in Syria, 40% in Iraq and 15% in Saudi Arabia. The river is about 2,700 km long, divided between Turkey (1,230 km), Syria (710 km) and Iraq (1,060 km). Contrary to this distribution, the catchment area that produces inputs into the river is situated with 62% in Turkey and 38% in Syria. It is estimated that Turkey contributes 89% of annual flow and Syria contributes 11%[4]; one expert estimates the percentage of the Euphrates flow originating in Turkey as high as 98%[5]. The remaining riparians contribute very little water. The major tributaries to the Euphrates River are Murat and Karasu in Turkey and Khabur and Balikh in Syria. Estimate on the total annual flow of Euphrates is about 35.9 billion cubic meters[5].

Time series of streamflow ($m^3\ s^{-1}$) and water quality variables including EC (dS $m^{-1}$), SAR, $Na^+$ (mg $L^{-1}$), $Cl^-$ (mg $L^{-1}$) and $SO_4^{2-}$ (mg $L^{-1}$) from two monitoring stations in the Eupharates River basin were used as a material for this study. The General Directorate of Electric Power Research Survey and Development Administration (EIE) measures water flow and takes water samples once every month from these stations. The geographic coordinate of the water quality monitoring stations is 38°41'49"N latitudes and 39°56'22" E longitudes for the 2102 and 39°41'00" N latitudes and 39°23'36" E longitudes for the 2119 monitoring station. The drainage area of the monitoring stations is about 25,415 and 10,356 $km^2$, respectively. These stations were chosen for the study since they have the longest observation periods than the other stations. Figure 1 shows the location of the monitoring stations in the basin.

The records for the selected variables available for the analysis as presented in this paper are on a monthly basis for the period 1970-1999. Since there are many missing values between 1970-1983, the data were examined only for the period 1984 to 1999.

**Trend analysis:** For time series of each water quality parameter and streamflow, a nonparametric, Kendall's tau test can be applied for detecting monotonic trend. The tau value is a measure of the correlation between the time series and time period. The following is the method for Kendall's tau value[6]: (1) The N data pairs $(x_1, y_1)$, $(x_2, y_2)$ … $(x_N\ y_N)$ are indexed according to the magnitude of the x value, such that $x_1 \le x_2 \le \dots \le x_N$ and $y_i$ is the dependent variable value that corresponds to $x_i$, (2) Examine all N(N-1)/2 ordered pairs of $y_i$ values. Let P be the number of cases where, $y_i > y_j$ $(i > j)$ and let M be the number of cases where, $y_i < y_j$ $(i > j)$, 3) Define the test statistics S = P-M and (4) The Kendall correlation coefficient tau is defined as:

$$\tau = \frac{S}{N(N-1)/2}$$

In this report, a trend was considered to be significant if the P value was less than or equal to 0.10 which represents a 90% confidence level. As with other types of correlation coefficients, tau can only take on values between -1 and 1, its sign indicates the sign of the slope of the relationship and the absolute value indicates the strength of the relationship.

**Thomas-Fiering (T-F) model:** In order to forecast time series for water quality and streamflow records, T-F modeling approach was used in this study. Thomas-Fiering model presents a set of 12 regression equations. A well-known T-F model equation can be given as[7]:

$$Y_{i+1} = \bar{Y}_{j+1} + r_j \frac{S_{j+1}\left(Y_i - \bar{Y}_j\right)}{S_j} + U_i S_{j+1}\sqrt{\left(1 - r_j^2\right)}$$

where, $Y_i$ is last observed value for the ith month, $Y_{i+1}$ is the value to be simulated for the I+1th month from the ith month, $\bar{Y}_j$ and $\bar{Y}_{j+1}$ are mean monthly values during the jth and j+1th month, respectively, $r_j$ is serial correlation coefficient between values in the jth and j+1th months, $S_j$ and $S_{j+1}$ are standard deviations of monthly values during the jth and j+1th month, respectively; $U_i$ is a random normal deviate with zero mean and unit variance.

Thomas-Fiering model accounts the effects of seasonality on the variability of the data by considering month to month variation in the average value and month to month coefficient of correlation between the data[7].

Table 1: Basic statistics for the studied water quality monitoring stations in the Euphrates River

| Parameters | Sample size | Mean | Median | Min. | Max. | SD |
|---|---|---|---|---|---|---|
| Monitoring station 2102S | | | | | | |
| treamflow ($m^3$ $s^{-1}$) | 192 | 263.2 | 104.0 | 17 | 2289 | 390.73 |
| EC (dS $m^{-1}$) | 192 | 448.9 | 473.5 | 140 | 653 | 118.65 |
| SAR | 192 | 1.3 | 1.3 | 0.3 | 2.3 | 0.47 |
| $Na^+$ (mg $L^{-1}$) | 192 | 37.1 | 39.2 | 5.3 | 66.4 | 15.28 |
| $Cl^-$ (mg $L^{-1}$) | 192 | 44.8 | 46.8 | 7.8 | 90.8 | 20.99 |
| $SO_4^{2-}$ (mg $L^{-1}$) | 192 | 18.9 | 16.3 | 1.0 | 70.6 | 12.52 |
| Monitoring station 2119S | | | | | | |
| treamflow ($m^3$ $s^{-1}$) | 192 | 87.5 | 48.9 | 13 | 524 | 94.77 |
| EC (dS $m^{-1}$) | 192 | 500.2 | 522.5 | 175 | 680 | 103.27 |
| SAR | 192 | 0.8 | 0.8 | 0.2 | 1.3 | 0.18 |
| $Na^+$ (mg $L^{-1}$) | 192 | 27.0 | 28.5 | 5.1 | 43.2 | 7.18 |
| $Cl^-$ (mg $L^{-1}$) | 192 | 31.0 | 32.6 | 4.3 | 58.9 | 10.02 |
| $SO_4^{2-}$ (mg $L^{-1}$) | 192 | 29.2 | 28.3 | 2.9 | 134.5 | 15.59 |

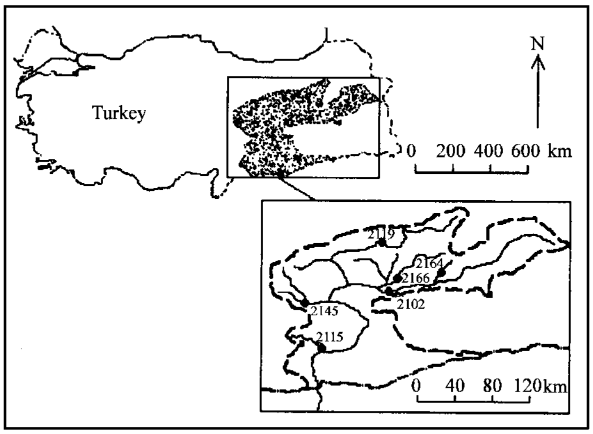


Fig. 1: Location map of water quality monitoring stations in the Euphrates River

## RESULTS AND DISCUSSION

The ratio of the highest to lowest concentration was very large for $SO_4^{2-}$ (70.6:1 for 2102 and 46.4:1 for 2119) (Table 1). There was low ratio for $Cl^-$ (11.6:1 for 2102 and 13.7:1 for 2119), $Na^+$ (12.5:1 for 2102 and 8.47:1 for 2119), SAR (7.7:1 for 2102 and 6.5:1 for 2119) and EC (4.7:1 for 2102 and 3.9:1 for 2119) (Table 1).

The water of Euphrates River is mostly used for irrigation. From agricultural standpoint, a number of classification systems of irrigation waters have been proposed which, in general based on the assumption of average conditions of good management[8]. A widely used classification system is the one suggested by the US Salinity Laboratory Staff[9]. This classification system is based on EC and SAR of the water. Considering mean and median values of EC and SAR for Euphrates River at Palu and Kemahboğazı (Table 1), the quality of water can be classified as C2-S1 (medium salinity-low sodium water). Because of EC values, the water can be used for irrigation purposes if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control. In terms of SAR values, the water can be used for irrigation with little danger of the development of harmful levels of exchangeable sodium. However, extremely sodium sensitive crops such as deciduous fruits and nuts may accumulate injurious concentrations of sodium[8,9].

Among the anions presented in macro levels, the main concern goes to $Cl^-$ and $SO_4^{2-}$. Even the low concentrations of $Cl^-$ (70-100 mg $L^{-1}$) may cause leaf damage on fruit plants. Waters in high $SO_4^{2-}$, commonly having $SO_4^{2-}$:$Cl^-$ ratio 3:1 or higher and known as $SO_4^{2-}$-water, are more deleterious than $Cl^-$ waters because high concentration of $SO_4^{2-}$ is more injurious to roots and disturbs the internal metabolism of the plants. At the same time, continuous use of such waters leads to precipitation of $Ca^{2+}$ as $CaSO_4$, causing rise in pH and Exchangeable Sodium Percentage (ESP) of the soil[8]. Considering mean $Cl^-$ concentrations, no specific ion effect of $Cl^-$ is expected due to use of these waters for agricultural purposes. The quality of water at Durucasu station is also fit for irrigation in terms of $SO_4^{2-}$:$Cl^-$ ratio. Relatively low $SO_4^{2-}$:$Cl^-$ ratios (0.42 for 2102 and 0.94 for 2119) were observed for both stations.

The nonparametric Kendall's tau test statistics for all variables results suggested an increased trend in the data record of EC and $Cl^-$ at 5% significance level and SAR and $Na^+$ at 10% significance level for the monitoring station of 2102 whereas an increased trend for the time series of SAR, $Na^+$ and $Cl^-$ at 5% and of EC at 10% significance level for the monitoring station of 2119 (Table 2). There was no increased or decreased trend in time series of $SO_4^{2-}$ and streamflow for both stations. It is suggested that the necessary precautions should be

Table 2: Kendall's tau statistical test results for the studied water quality monitoring stations in the Euphrates River

| | Monitoring station 2102 | | | Monitoring station 2119 | | |
|---|---|---|---|---|---|---|
| Parameters | Kendall's tau-statistic | P-value | Decision* | Kendall's tau-statistic | P value | Decision* |
| Streamflow ($m^3$ $s^{-1}$) | -0.055 | 0.269 | NS | 0.044 | 0.358 | NS |
| EC (dS $m^{-1}$) | 0.105 | 0.023 | IT | 0.086 | 0.070 | IT |
| SAR | 0.086 | 0.080 | IT | 0.157 | 0.001 | IT |
| $Na^+$ (mg $L^{-1}$) | 0.080 | 0.099 | IT | 0.170 | 0.000 | IT |
| $Cl^-$ (mg $L^{-1}$) | 0.097 | 0.040 | IT | 0.188 | 0.000 | IT |
| $SO_4^{2-}$ (mg $L^{-1}$) | -0.034 | 0.532 | NS | -0.015 | 0.773 | NS |

Notes: *: Test interpretation for a 90% confidence level; NS: not a significant trend; IT: increased trend

Table 3: Set of Thomas-Fiering models fitted to the time series of selected water quality constituents and streamflow for each month at Palu monitoring station

| Streamflow | EC | Chloride |
|---|---|---|
| $Y_J = 481.4+0.13\ (Y_D-515.6)+64.2U$ | $Y_J = 481.4+0.13\ (Y_D-515.6)+64.2U$ | $Y_J = 47.0+0.22\ (Y_D-58.3)+6.7U$ |
| $Y_F = 459.4+\ 0.05\ (Y_J-481.4)+80.2U$ | $Y_F = 459.4+0.05\ (Y_J-481.4)+80.2U$ | $Y_F = 43.0+0.53\ (Y_J-47.0)+11.7U$ |
| $Y_M = 387.6+0.26\ (Y_F-459.4)+60.3U$ | $Y_M = 387.6+0.26\ (Y_F-459.4)+60.3U$ | $Y_M = 27.4+0.34\ (Y_F-43.0)+11.2U$ |
| $Y_A = 298.8-0.31\ (Y_M-387.6)+46.0U$ | $Y_A = 298.8+0.31\ (Y_M-387.6)+46.0U$ | $Y_A = 18.7+0.05\ (Y_M-27.4)+4.8U$ |
| $Y_M = 257.8-0.49\ (Y_A-298.8)+54.4U$ | $Y_M = 257.8+0.49\ (Y_A-298.8)+54.4U$ | $Y_M = 16.7+0.16\ (Y_A-18.7)+6.3U$ |
| $Y_J = 346.8+0.71\ (Y_M-257.8)+87.5U$ | $Y_J = 346.8+0.71\ (Y_M-257.8)+87.5U$ | $Y_J = 27.2+0.70\ (Y_M-16.7)+12.9U$ |
| $Y_J = 460.3+0.41\ (Y_J-346.8)+57.0U$ | $Y_J = 460.3+0.41\ (Y_J-346.8)+57.0U$ | $Y_J = 51.4+0.57\ (Y_J-27.2)+12.4U$ |
| $Y_A = 546.9+0.50\ (Y_J-460.3)+37.5U$ | $Y_A = 546.9+0.50\ (Y_J-460.3)+37.5U$ | $Y_A = 68.3+0.65\ (Y_J-51.4)+12.2U$ |
| $Y_S = 580.7+0.58\ (Y_A-546.9)+34.7U$ | $Y_S = 580.7+0.58\ (Y_A-546.9)+34.7U$ | $Y_S = 71.4+0.53\ (Y_A-68.3)+7.7U$ |
| $Y_O = 555.1-0.19\ (Y_S-580.7)+85.5U$ | $Y_O = 555.1+0.19\ (Y_S-580.7)+85.5U$ | $Y_O = 63.2+0.77\ (Y_S-71.4)+16.5U$ |
| $Y_N = 496.5-0.13\ (Y_O-555.1)+91.3U$ | $Y_N = 496.5+0.13\ (Y_O-555.1)+91.3U$ | $Y_N = 51.4-0.02\ (Y_O-63.2)+15.9U$ |
| $Y_D = 515.6+0.07\ (Y_N-496.5)+58.3U$ | $Y_D = 515.6+0.07\ (Y_N-496.5)+58.3U$ | $Y_D = 51.7+0.24\ (Y_N-51.4)+10.1U$ |

Notes: $Y_J$, $Y_F$, ..., $Y_D$, on the left-hand side of the equations are the values to be simulated for the months of January, February, ..., December; $Y_D$, $Y_J$, ..., $Y_N$, on the left-hand side of the equations are the observed values for the month of December, January, ... , November; U is the Gaussian random number with zero mean and Unit variance

Table 4: Statistical comparison of observed and forecasted values for the studied water quality monitoring stations in the Euphrates River

| | 2102 | | 2119 | |
|---|---|---|---|---|
| Parameters | $F_{cal}$ | $z_{cal}$ | $F_{cal}$ | $z_{cal}$ |
| Streamflow ($m^3$ $s^{-1}$) | 0.78 | -0.03 | 0.88 | -0.03 |
| EC (dS $m^{-1}$) | 0.86 | 0.02 | 0.72 | 0.02 |
| SAR | 0.86 | 0.02 | 0.70 | 0.03 |
| $Na^+$ (mg $L^{-1}$) | 0.89 | 0.02 | 0.76 | 0.04 |
| $Cl^-$ (mg $L^{-1}$) | 0.88 | 0.01 | 0.71 | 0.05 |
| $SO_4^{2-}$ (mg $L^{-1}$) | 0.50 | 0.01 | 0.47 | 0.03 |

taken to prevent trend increases for the mentioned variables for both stations.

Thomas-Fiering model was used to develop a stochastic model to predict the future values of the water quality variables and streamflow. Most of the water quality variables and streamflow showed seasonal pattern. As an example, model equations for the streamflow and selected water quality variables from monitoring station 2102 are presented in Table 3. The z-test (for mean) and F-test (for variance) were used as forecast accuracy measures in order to compare the observed and forecasted data of each variable. The test results for both forecast accuracy measures are presented in Table 4. Since the calculated F ($F_{cal}$) values of the observed and forecasted data were smaller than the F critical value of 1.27 at a 5% significance level, it can be concluded that there is no statistical difference between the variances of observed data and forecasted values from the model. Similarly, considering the z-test, it is concluded that the forecasted values of each water quality variables and streamflow from T-F approach preserve the basic statistics of the observed values in terms of mean since the calculated z ($z_{cal}$) values for these parameters were between the critical value (±1.96) at a 5% significance level. Therefore, it can be concluded that, the T-F modeling approach can give reliable forecasts of water quality constituents and streamflow time series of a river.

The forecast values for all water quality variables and streamflow using Thomas-Fiering model are very close to the observed data. Also, the forecasts suggest that there is no strange value for water quality variables and streamflow and the same flow pattern will continue into the near future (Fig. 2).

The findings have important ramifications for monitoring plans. The analysis suggests that there are currently increased trends in EC, SAR, $Na^+$ and $Cl^-$ taking place. The chemistry of river water is the result of the hydrologic processes active in the watershed. The seasonal processes cause the variation in water quality variables and in streamflow.

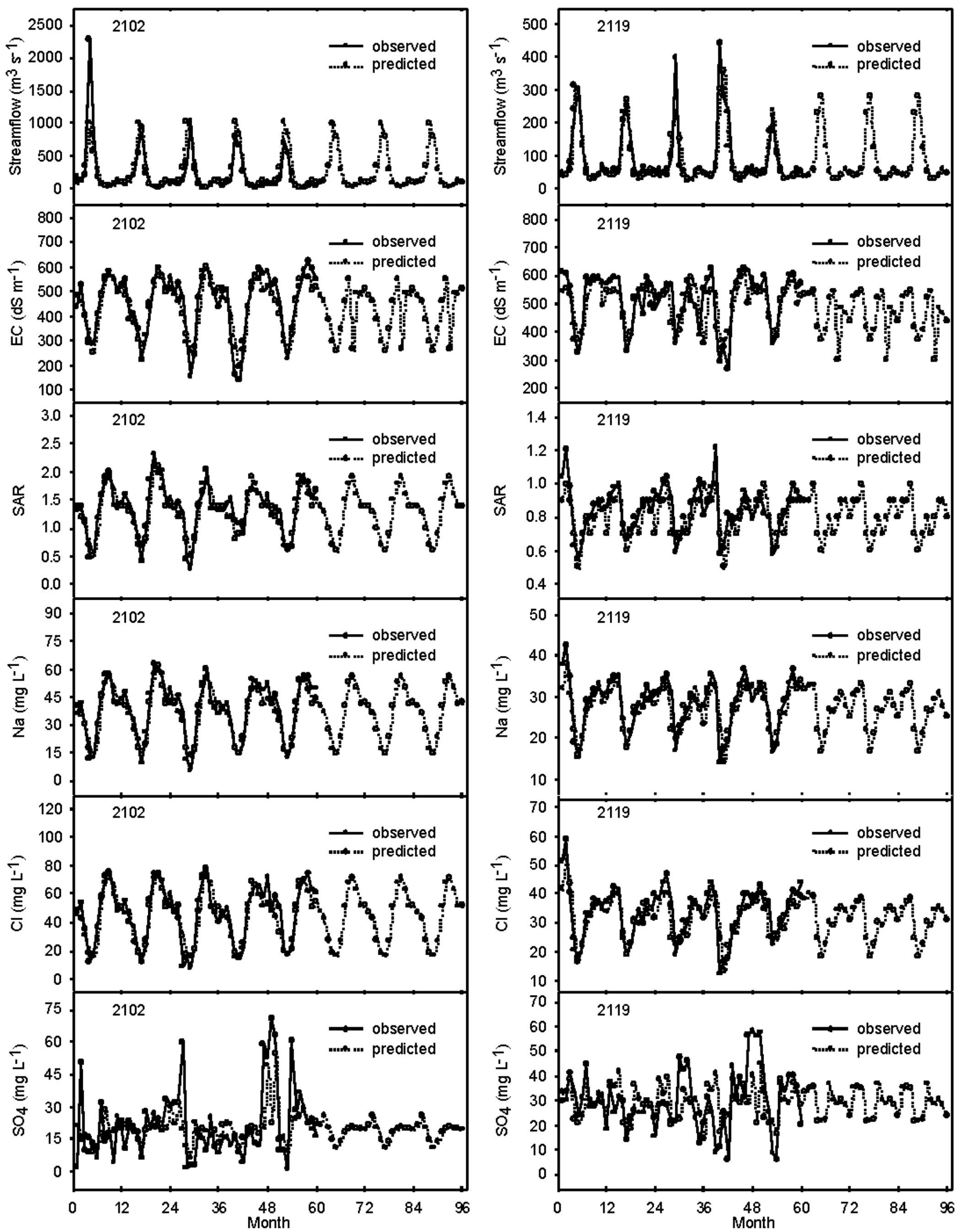


Fig. 2: Comparison of 5 year (1995-99) observed vs. simulated data for water quality variables and streamflow for the selected monitoring stations in the Euphrates River at River

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