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Full Length Research Paper

Modeling rainfall-runoff pollution parameters using multiple linear regression technique: The case of Adana City - Turkey

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Urban rainfall-runoff pollution for Adana city was investigated experimentally. Various parameters such as electrical conductivity (EC), suspended solids (SS), volatile suspended solids (VSS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), 5-day biological oxygen demand (BOD_5), were analysed for the characterization of rainfall runoff waters in Northwest Adana Upper City Development Region. In this study, these parameters were modelled using multiple linear regression (MLR) technique. Time (T), EC, COD, and SCOD were the input parameters, while SS, VSS, and BOD_5 were the output parameters. The results proved that these output parameters can be accurately predicted using the MLR technique with R^2 values higher than 80%.

Key words: Urban runoff, water pollution, multiple linear regressions, modelling.

INTRODUCTION

The performance of sewage treatment systems especially in urban areas are generally affected by the rainfall-runoff waters containing polluting loads at a wide range. In some cases, when the treatment plants receive peak waste loads after rainfall-runoff, the treatment processes may not respond accordingly resulting in inadequate treatment performance. Some of the waste load may even be diverted to the receiving water body that may cause adverse impacts on the environment (Novotny and Ghesters, 1981). Moreover, factors such as salinity, sedimentation, dissolved oxygen, and toxic substances in urban storm water affect the quality of the water resources. With highly fluctuating pollutant contamination and flow rate, the urban runoff is more difficult to be characterized than water and wastewaters (Zoppou, 2001; Lee and Bang, 2000). Urban runoff constitutes a significant non-point source and its relation to water quality problems had not been adequately investigated until recently. Based on the realization that the rainfall runoff from urban areas contained various and high amounts of pollutant loads, this issue has attracted the attention of some researchers such as Göttle (1978), Böhnke (1979), Uchimura et al. (1997), Gromaire-Mertz et al. (1999), and Lee and Bang (2000). Most of these studies point out that rainfall runoff waters constitutes 40-60% of the total water pollution including industrial and residential wastewater. It is very likely that the contribution of urban runoff to the pollution characteristics of the sewage will increase in the future due to the various human activities and uncontrolled urbanization. Therefore, it is of paramount importance to characterize pollution stemming from storm water runoff for enhanced water quality management plans in urbanized areas (EPA, 1993). However, characterization of the urban runoff alone is not adequate to fathom the extent of the threat posed by the pollutant loads coming at unpredicted times and quantity. Hence, modelling of the urban runoff and its potential impacts on the sewage quality and the environment emerges as an important tool to constitute a proper water quality management plan. On the other hand, modelling saves the time, money, and energy to be exerted by water quality planners since water quality observation and characterization is a time-consuming and expensive act. As a modelling technique, multiple linear regressions (MLR) may be a beneficial tool in modelling the urban runoff pollution.

The present study was conducted to characterize the polluting characteristics of runoff water in Mahfesığmaz settlement area in Northwest Adana Upper City Development Region with a combined sewer system.

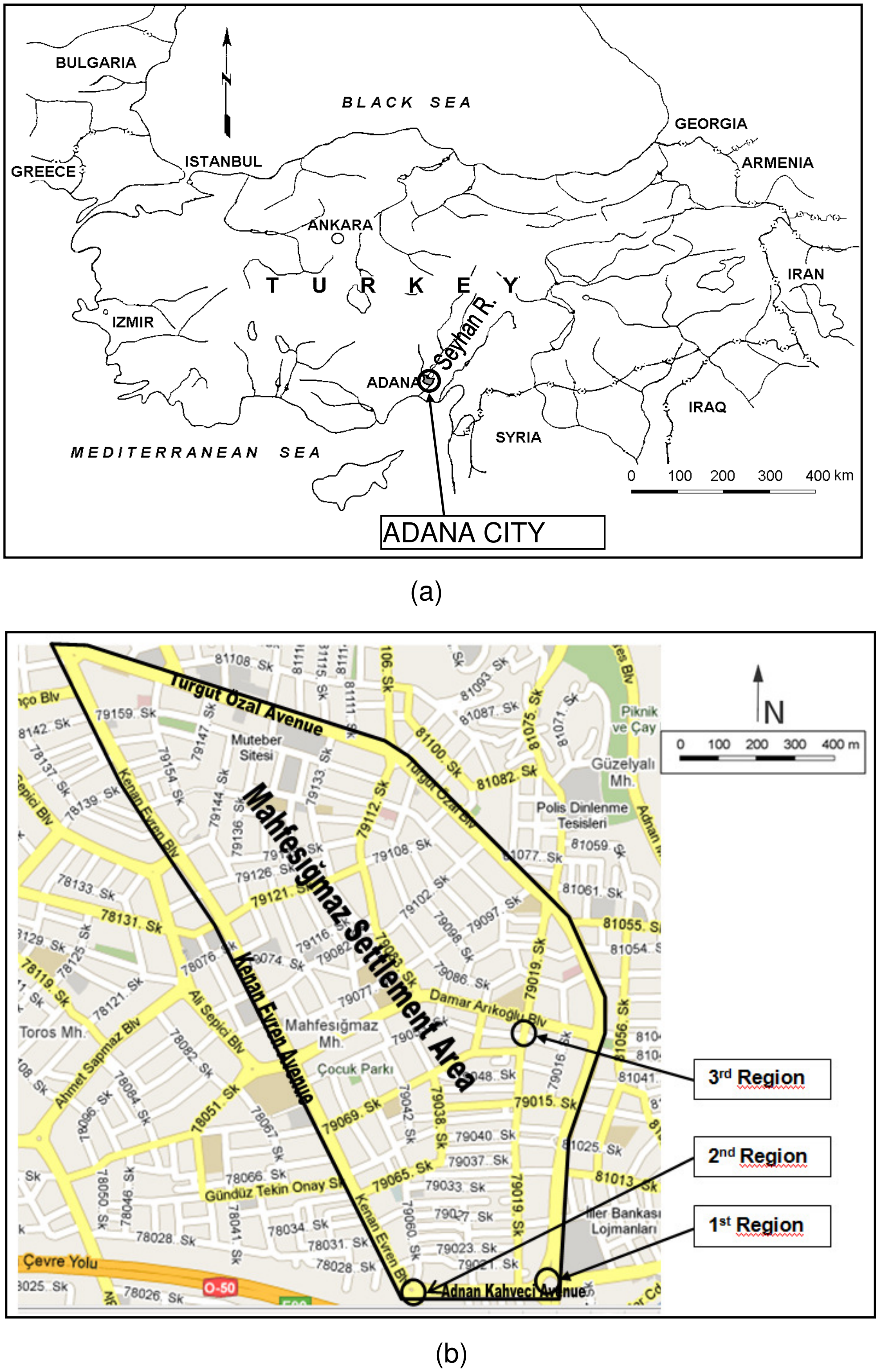

Figure 1. (a) Location map (b) Mahfesığmaz settlement area.

MATERIALS AND METHODS

The study area, Mahfesığmaz, is the highest densely populated settlement area situated in Northwest Adana Upper City Development Region (Figure 1). The details of the study area [with three regions - Turgut Özal (Region 1), Kenan Evren (Region 2)

Table 1. Minimum, maximum and median values of input and output parameters.

Parameter	Minimum value	Maximum value	Median
T (min.)	5	90	37.04082
EC (ms/cm)	6.2	635	198.0735
COD (mg/L)	16	1450	239.938776
SCOD (mg/L)	3	476	52.1734694
VSS (mg/L)	4	470	72.09184
BOD_5 (mg/L)	3	290	45.84694
SS (mg/L)	23	1620	357.3776

Table 2. Correlation coefficients of each output parameter versus input parameters changing from one to four variables.

Variable	R^2	T (min)	EC (ms/cm)	COD (mg/L)	SCOD (mg/L)
			VSS (mg/L)		
1	74.8				X
1	71.6			X	
1	48.9		X		
1	28.3	X			
2	80.9		X		X
2	77.2	X			X
2	74.9			X	X
2	73.5		X	X	
2	73.3	X		X	
3	84.8		X	X	X
3	81.2	X	X		X
3	77.2	X		X	X
3	74.3	X	X	X	
4	84.9	X	X	X	X
			BOD5 (mg/L)		
1	87.7			X	
1	75.6				X
1	57		X		
1	21.6	X			
2	89.5			X	X
2	89.4		X	X	
2	87.7	X		X	
2	85.4		X		X
2	76.2	X			X
3	89.9		X	X	X
3	89.6	X	X	X	
3	89.5	X		X	X
3	85.7	X	X		X
4	90	X	X	X	X
			SS (mg/L)		
1	65.1				X
1	62.4			X	
1	50.1		X		

Table 2. Contd.

1	30.2	X			
2	74		X		X
2	69.3	X			X
2	66.8		X	X	
2	65.7	X		X	
2	65.3			X	X
3	80.5		X	X	X
3	74.8	X	X		X
3	69.3	X		X	X
3	68.1	X	X	X	
4	80.9	X	X	X	X

and Adnan Kahveci (Region 3)], meteorological information (1989 through 2000), sampling (between October 1999 and May 2000), analyses [electrical conductivity (EC), pH, suspended solids (SS), volatile suspended solids (VSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldhal nitrogen (TKN), and total phosphorus (TP)], and the modelling set-up were provided by Selek at al. (2003).

RESULTS AND DISCUSSION

The data for predicting the maximum discharge through modeling used in this study were obtained from our previous work (Selek et al., 2003). Output variables used to estimate the SS, VSS and BOD_5 were selected according to three criteria; 1) A relatively small set of variables must be used in the MLR analysis; 2) Variables must provide a good statistical fit; and 3) Variables must represent a rainfall-runoff pollution model. In the light of these statements, the SS, VSS, and BOD_5 values have been estimated by means of four independent variables, that is time (T), EI, COD and SCOD using multiple linear regression (MLR) technique. Minimum, maximum and median values of each parameter used herein are given in Table 1.

MLR is a method used to model the linear relationship between a dependent variable and one or more independent variables. There is a dependent variable, y, a number of independent variables, $x_1, x_2, \ldots, x_p$, and the model is defined in general terms by:

$$y=\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_j x_j+\ldots+\beta_p x_p+\varepsilon \qquad (1)$$

where ε, the "noise" variable, is a normally distributed random variable with a mean equaling zero and a standard deviation of σ, whose magnitude is not known. The values of the coefficients $\beta_0, \beta_1, \beta_2, \ldots, \beta_p$ are to be estimated so as to minimize the sum of squares of differences between the observed *y* values in the data and the ones predicted by Equation (1). MLR technique was applied to each input and output dataset to determine best correlation between parameters. For each output parameter (SS, VSS, and BOD_5), input parameters (T, EI, COD and SCOD) changing from one to four variables were tried to obtain best correlation between them as shown in Table 2. As seen in Table 2, best correlations were obtained using four input parameters for each output parameter. When applied to the input data, MLR technique produced the Equations 2 to 4 for the VSS, SS and BOD_5, respectively:

$$VSS = -18.0886-0.15\ T + 0.36\ EI - 0.33\ COD + 2.01\ SCOD\ (R^2 = 0.85) \qquad (2)$$

$$SS = 19.74-0.964\ T + 1.63\ EI - 1.59\ COD + 8.28\ SCOD\ (R^2 = 0.81) \qquad (3)$$

$$BOD_5 = -10.14 + 0.102\ T + 0.057\ EI + 0.225\ COD - 0.248\ SCOD\ (R^2 = 0.90) \qquad (4)$$

Figure 2 plots the measured versus predicted SS, VSS and BOD_5 values for MLR technique. When the data points on and around the lines of equality were assessed, it is apparent that the data points fell on the line for the MLR model suggest linear relationship between the observed and predicted data.

Conclusions

Comprehensive field urban runoff data obtained from the work of Selek et al. (2003) were used in developing models to predict the pollution characteristics of the urban runoff from three regions in Mahfesığmaz settlement area. The content of the urban runoff were estimated in terms of SS, VSS, and BOD_5 using Equations 2 to 4 obtained as a result of the application of MLR technique. These equations can be used for the interval of minimum and maximum value of SS, VSS and BOD_5 which are 23 - 1620, 4 - 470 and 3 - 290 respectively. It was observed that the MLR model

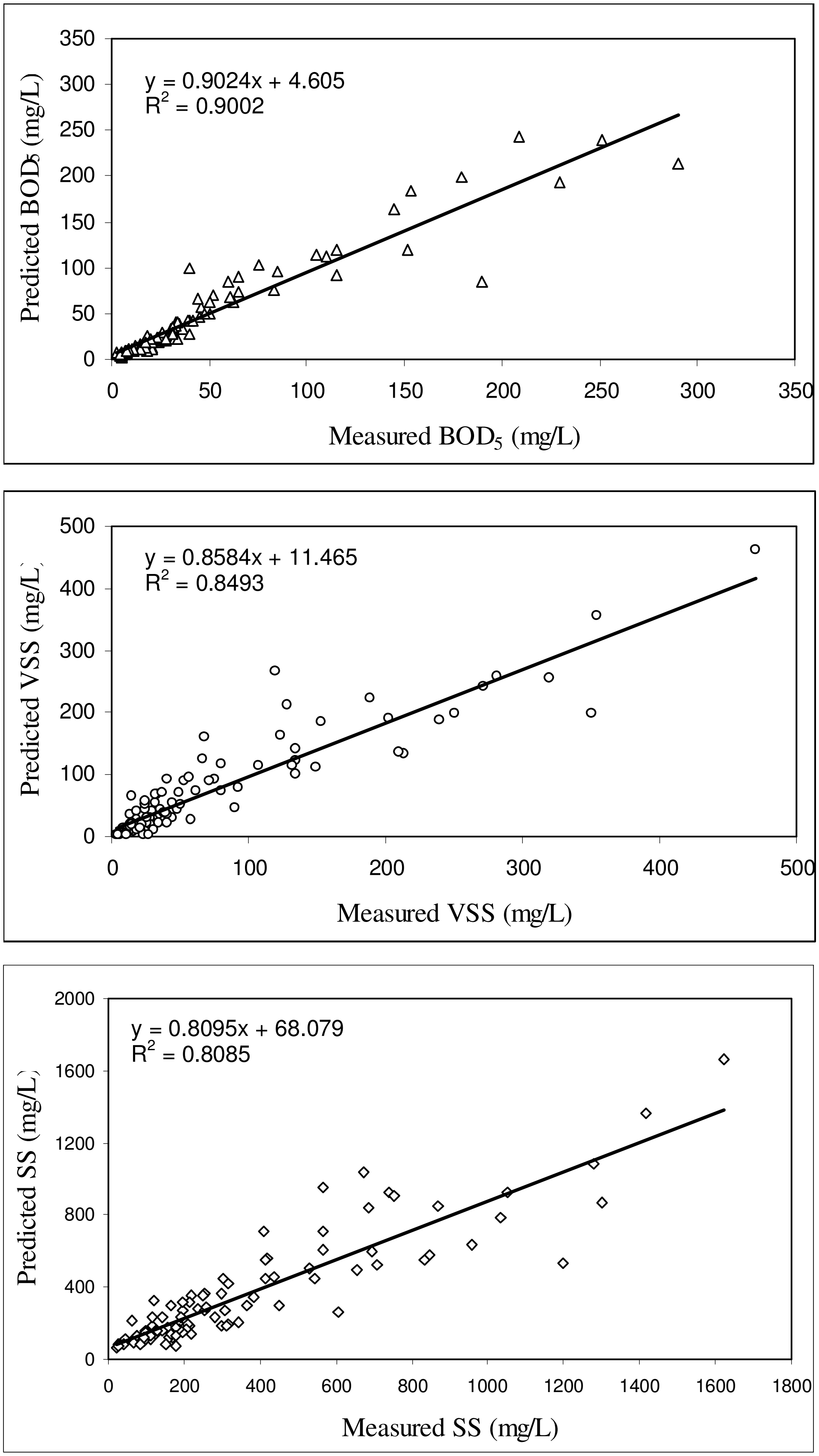

Figure 2. Output parameters predicted by MLR technique versus measured parameters: (a) BOD_5 (b) VSS (c) SS.

provided quite close estimations to the observed rainfall runoff pollution data with R^2 values higher than 80%.

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