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ESTIMATION OF MISSING SEDIMENT CONCENTRATION DATA IN AGRICULTURAL DRAINAGE BASINS AND DETECTION OF SEASONAL VARIATION

ABSTRACT

In this study, it was aimed at determining the seasonal variability in the sediment concentrations observed in an agricultural drainage basin. This research was carried out in an agricultural basin of 9 495 ha, located in the Cukurova region within the borders of Adana province, in Turkey. In order to determine the sediment concentrations, an automatic water sampler was set at the outlet (L4) of the main drainage channel (YD2) that provides drainage of the basin. Drainage water samples with 250 ml volume were taken on a daily time step. Sediment concentration values of the water samples taken were determined in the laboratory by the drying and evaporation method. The sediment concentration series observed in the 2020 hydrological year were directly associated with the sediment data observed simultaneously at the drainage flow observation station located in the Sirkenli village, downstream of the YD2. Daily sediment concentration series in L4 was disaggregated by months and seasons of the hydrologic year 2020 to make a temporal comparison among the data. Temporal analysis showed that the sediment concentration values have been prone to an increase in heavily rainy periods as well as in irrigation season. Additionally, it was determined that the correlation between sediment concentration values and drainage water depths in the main drainage channel was statistically insignificant during the peak irrigation season. The insignificant corre-

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lation between sediment concentration and drainage water depth might be ascribed to the direct by-pass irrigation flows to the drainage system of the agricultural basin.

Keywords: *Missing sediment concentration, agricultural drainage basin, drainage flow rates, Lower Seyhan Plain (LSP), agricultural water management*

INTRODUCTION

Water is a precious value for all living creatures, and it is needed for the continuation of vital activities. Today, the rapidly increasing population growth and the decrease in renewable water resources have brought the importance of water to the top of the international agenda (Akuzum et al., 2010). In addition to being an indispensable part of life, excessive use of water has also seriously detrimental effects on living things as well as the environment. Although there exists a growing need for water in the other sectors of domestic, energy supply, municipality, etc., the agricultural sector recklessly consumes water resources in irrigation schemes, both wasting water and causing soil erosion by water. In turn, irrigation operations in large-scale catchments exercise a significant influence on the hydrologic response of the watersheds. Soil erosion by water may be defined as 'the movement of soil fragments by precipitation and runoff'.

Additionally, precipitation intensity, soil physical characteristics, the topography of the catchment, land use and land cover types, etc. affect the severity and the degree of water erosion (Karakaplan, 2010). This event, defined as soil loss, has negative impacts on all areas that affect the life of living things. These negative impacts have been seen more particularly in areas where agricultural activities are carried out. The increase in surface runoff resulting from precipitation regimes and excessive irrigation practices accelerate soil loss from agricultural catchments, resulting in irreparable results on agricultural production and the national economy. A number of researchers have researched how to reduce soil loss from agricultural catchments, to reveal the measures to be taken and the plans to be made. While Lutz and Hargrove (1944) investigated the effects of surface runoff on sediment, many researchers shed light on this issue with different methods and techniques (Podmore and Merva, 1971; Irvem and Tulucu, 2004; Guvel, 2007; Terzi and Baykal, 2015; Demir et al., 2017; Opan et al., 2017; Ulke et al., 2011). Among the research, few studies have attempted to quantify irrigation-induced soil loss from large-scale agricultural drainage basins. This may be due to the lack of sufficient drainage flow rate observation data, i.e. incoming and outgoing drainage amounts, in irrigation catchments. The aims of this study are three-fold:

a) to complete missing sediment concentration data, if any, observed at the main drainage outlet of the basin by using data from the contiguous catchment,

b) to figure out seasonal variations of sediment concentration data, and to test whether there is a time-dependent difference in the data,

c) to make comparisons between sediment concentrations of the rainy season, irrigation season and non-irrigation season.

MATERIALS AND METHODS

MATERIALS

This work was conducted in an irrigation basin covering a total area of 9 495 ha, located in the Lower Seyhan Plain of the Cilician Plain, i.e. the Cukurova Plain or Cilicia Pedias in antiquity. The study area is situated in the Mediterranean region of Turkey and is located between the geographical coordinates 36º51′46′ - 36º57′00′ N latitude and from 35º24′10′ to 35º36′34′ E longitude. It is surrounded by Abdioglu residential area and Ceyhan River in the east, Cotlu and Herekli settlements in the south, Yakapinari in the north, Camili village in the west (Figure 1). In order to determine temporal sediment concentrations generated by the research catchment, an automatic water sampler was installed at the outlet (L4) of the main drainage channel of YD2, which provides the drainage of the basin. In addition, missing sediment observation data of L4 in the 2020 hydrological year, i.e. October 1st, 2019 to September 30th, 2020, was completed by using sediment observation data of L12 -located 19.2 km downstream from L4- on YD2 channel in Sirkenli settlement (Figure 1).

METHODS

Determining Sediment Concentrations

Water samples of 250 ml were taken on a daily basis using an automatic water sampler installed at the outlet of the basin (L4 in Figure 1). The sediment concentration values of the water samples were obtained in the laboratory by the drying (evaporation) method (Bilgin, 2015; Ibrikci et al., 2016). Water samples were processed as the following:

- Sterilization of glass beakers used for samples, determining the tares of beakers with precision scales,
- Filling in the beakers with 250 ml water sample by using a graded cylinder,
- Putting the glass beakers filled with water samples into the oven of 103-105 °C (Bilgin, 2015) and waiting until the water completely evaporates (drying the samples),
- Removing the dried samples from the oven and weighing the dried samples; then, calculating the difference between the dry weight and tare weight to get the sediment weight in the 250 ml water,
- Calculating sediment concentrations of samples in the unit of mg/l.

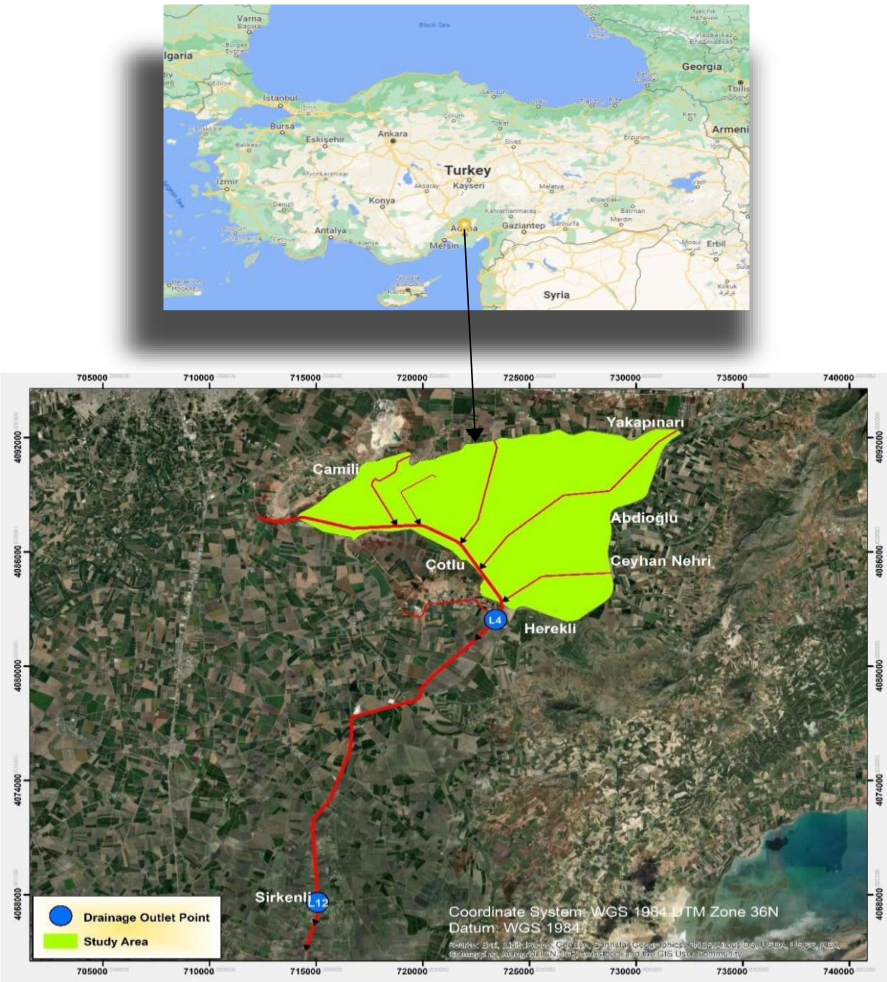

Figure 1. Location of L4 and L12 drainage outlets in the YD2 channel and the study area in Turkey

Estimating Missing Sediment Data

Missing sediment data, if any, at the L4 observation location is estimated by the following methodology:

a) Sediment concentration values observed both at the catchment outlet, i.e. L4, and Sirkenli drainage gauging station, i.e. L12, in 2019 and 2020 were subjected to correlation analysis (Hogg and Craig, 1995) using SPSS statistical package program (Equation 1).

b) After being assessed the correlations between the data sets, various regression models were tried to get a suitable model for estimating missing sediment data. In this regard, Hogg and Craig (1995) point out that the exponential regression model types

(Equation 2, Equation 3) might be one of the promising models for completing missing data. Therefore, exponential models were adopted and model parameters were estimated by *Curve Expert* software.

c) Finally, the exponential regression model and its determined parameters were employed to estimate any missing data of L4 sediment observation station from L12 data.

$$r_{xy} = \frac{\mathrm{Cov}[X,Y]}{\sqrt{\mathrm{Var}[X]\mathrm{Var}[Y]}} = \frac{\sum[x_i-\bar{x}][y_i-\bar{y}]}{\sqrt{\sum[x_i-\bar{x}]^2\sum[y_i-\bar{y}]^2}} \quad (1)$$

where X and Y stand for variables of sediment concentrations observed at two different locations. *Cov(X, Y), Var(X)* and *Var(Y)* stand for the covariance between the two variables, variances of *X* and *Y*, respectively.

$$y = a\, e^{\left[\frac{b}{x}\right]} \quad (2)$$

$$y = a\, e^{b[x]} \quad (3)$$

where *a* and *b* are the regression coefficients; *e* is the base of the natural logarithm (natural number) or known as Euler's number.

RESULTS AND DISCUSSION

Visual Diagnostics and Correlation Analysis Results

Suspended sediment concentration values of drainage water samples taken from the drainage outlet (L4 in Figure 1) in the research area were obtained in the laboratory by following the methodology explained. The plot of suspended sediment data time series was visually checked to provide insight into the data. Visual diagnostic checks revealed that the sampling was regular but there were a modest number of missing values. Examination of cautionary notes for L4 indicated that flood events due to heavy rains, solar energy failure and system errors in the automatic sampler device have caused the automatic water sampler to stop collecting data, resulting in a gap in suspended sediment concentrations data in winter and summer months, i.e. in the period from 01.11.2019 to 29.02.2020 in winter and 01.06.2020 to 20.07.2020 in summer of 2020 hydrological year. Suspended sediment observations of L12 which is located 19.2 km downstream from L4 (Figure 1) were used to fill in the missing sediment data of L4. To that end, the correlation analysis technique (Koklu et al., 2006) was employed to measure the strength of association between suspended sediment data of L12 and L4 stations. The plot of L4 versus L12 sediment concentrations observed from November 2019 to February 2020 showed a nonmonotonic behaviour (Figure 2) as in Helsel et al. (2020), indicating evidence of some kind of correlation. In this regard, correlation analysis resulted in positive correlation coefficients between L4 and L12. As seen in Table 1, a moderate correlation (r=0.654) exists between suspended sediment data observed from November to February. However, the correlation coefficient decreases remarkably to r=0.344, indicating a weak correlation, in peak irrigation season, i.e. in June and July (Table 1). This decrease in correlation coefficient might be attributed to the anthropological aspects of agriculture such as irrigation, cultivation, poor irrigation water management, and bypass of irrigation water directly into drainage channels. These intervened hydrological processes might have distorted the anticipated strong association between sediment data observed at the outlet of the catchment (L4) and downstream of YD2 (L12).

Regression Analysis Results and Infilling of Missing Records

After determining the level of relationship between stations with correlation analysis, the "*curve expert*" statistical program was employed to determine the best regression model for filling the gap in the data. After having been assessed the periods of missing observations, regression analysis was performed using relevant data as shown in Figure 2 and Figure 3. Results led us to conclude that the exponential regression model is the most likely model to be used for completing missing sediment data. The resultant regression coefficient of the exponential models was given in Figure 2 and Figure 3. The regression model and its relevant coefficients were applied to complete missing sediment data in L4, and then the correlation coefficient for the time series of full data, i.e. including observed and completed data in the period considered, was recalculated as seen in (Figure 2, Figure 3). As seen in Table 1, when the completed data series of L4 was used in the correlation coefficient calculation, the correlation coefficient increased from 0.344 (weak correlation) to 0.488 (moderate correlation) in the summertime. However, completion of sediment data conduced to a small increase in the correlation coefficient (from 0.654 to 0.724) in the autumn and winter months (Table 1).

Table 1. The correlation matrix of the data of the observation points in the missing months

Period	Observation Points	L4	L12	L4-completed
01.11.2019-29.02.2020	L4	1		
	L12	0.654	1	
	L4-completed	1	0.724	1
01.06.2020-20.07.2020	L4	1		
	L12	0.344	1	
	L4-completed	1	0.488	1

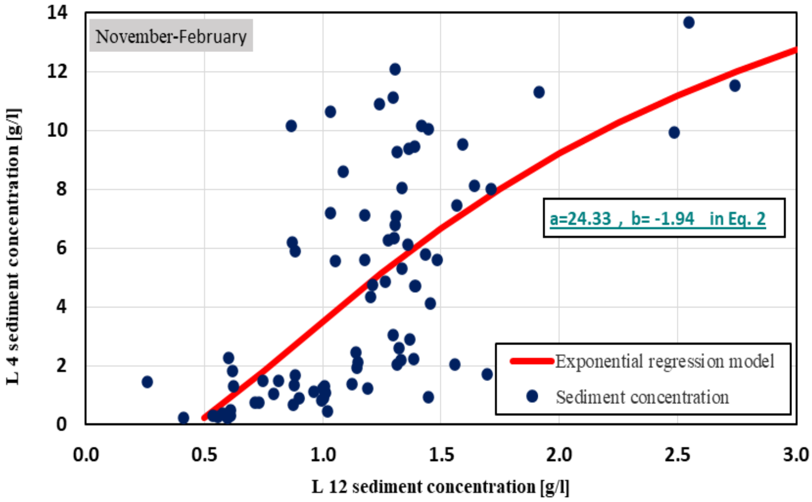

Figure 2. Scatterplot of sediment concentrations observed in L12 versus L4 in autumn and winter months, and plot of the exponential regression model fit to the same data

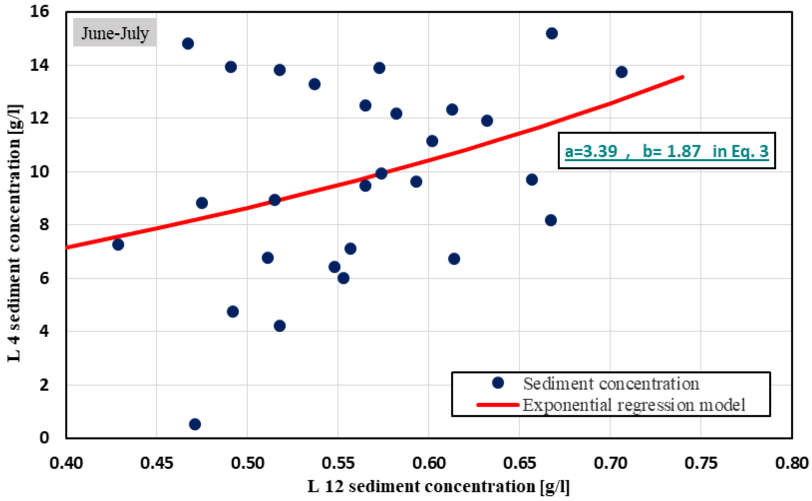

Figure 3. Scatterplot of sediment concentrations observed in L12 versus L4 in the peak irrigation season, i.e. summer months (June-July), and plot of the exponential regression model fitted to the same data

Observed suspended sediment concentration data at the drainage outlet (L4) of the research area in the 2020 hydrology year and filled in missing records were plotted as a time series in Figure 4.

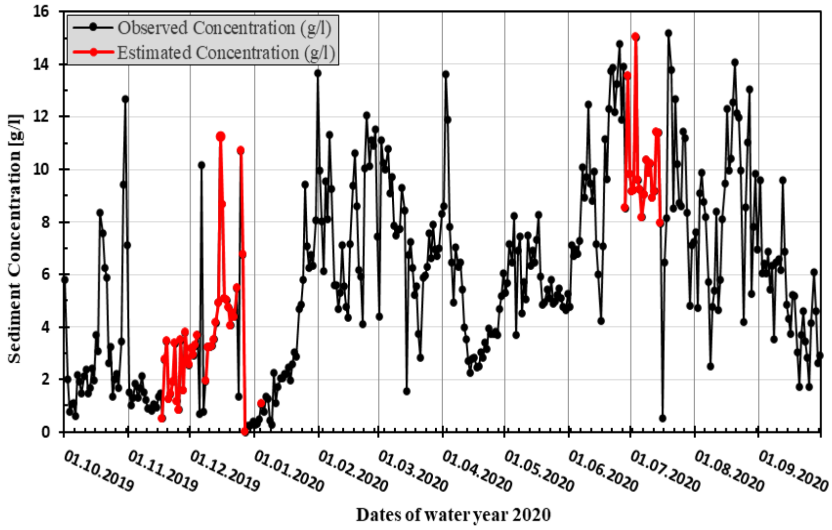

Figure 4. Observed and estimated sediment concentrations at the L4 location

As seen from Figure 4, the lowest suspended sediment concentration was observed on the 27th of December 2019, while the highest three values, including one value estimated, (>14.5 g/l) were in July 2020. This means that the highest sediment concentration in the drainage waters is observed in the peak irrigation season, indicating the direct impacts of irrigation practices on sediment transport in semi-arid landscapes of the Mediterranean region. On the other hand, mean sediment concentrations were obtained as 9.21, 6.01, 5.04 and 3.43 g/l in summer, spring, winter and autumn, respectively, in the irrigation catchment. As such, the mean sediment concentration is the highest in the summer season. It is clear from Figure 4 that irrigation practices realized in June, July and August have been staple causes of sediment transportation from the catchment because surface irrigation methods such as uncontrolled flooding, furrow and basin prevail in more or less 60% of the catchment and, in turn, district irrigation efficiency is low (≈40%). The intensity of irrigation gets lower and lower in autumn and the soil is generally covered by crop residuals. Therefore, average sediment concentrations, as well as drainage flow rates, are the lowest in autumn. However, sediment concentration starts to increase in the wintertime if there exists precipitation because heavy winter rainfalls inherently have a high erosive effect in the Mediterranean region and the soil surface is generally barren during winter.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the study and interpretations of scatterplots of the suspended sediment data observed at the outlet of an irrigation basin -located in the Mediterranean region of Turkey basin- in the 2020 water year, the following conclusions may be drawn and recommendations might be made:

- In practice, cautionary notes for sediment observation station are of great importance to find out scientific reasoning why the automatic water sampler stopped taking water samples. In this particular research site, flood events due to heavy rains, solar energy failure and system errors in the automatic sampler device have caused the automatic water sampler to stop collecting data, resulting in a gap in suspended sediment concentrations data in the winter and summer months.
- Visual diagnostic checks of the data help the analyst a) to summarize succinctly the information on sediment data, to reveal if the sampling is regular or not and if there exists any missing value in the data set. Downstream or upstream sediment observation stations are key stations to fill in missing records if there exists a strong association between the two stations. In this context, regression analysis might be a remedy for the analyst as in this study.
- Suspended sediment data are subject to temporal variations in the irrigation catchment. In this regard, it was observed that the sediment concentration in the drainage channels increased with precipitation events in wintertime. Mean sediment concentrations were 9.21, 6.01, 5.04 and 3.43 g/l in summer, spring, winter and autumn, respectively, in the irrigation catchment. Mean sediment concentration was found the highest during the peak irrigation season, indicating the evidence of sediment transportation by irrigation practices, and consequently, irrigation return flows.
- Irrigation bypass flows into the drainage canals had a dilution effect on sediment concentrations.
- Although precipitation events and irrigation applications have had a significant effect on the sediment concentration in drainage, it was concluded that the application of surface irrigation methods in the catchment has accelerated the increase of sediment concentrations in the summertime.
- To mitigate the soil loos induced by irrigation practices, pressurized irrigation methods such as drip irrigation, sprinkler irrigation, etc., should be encouraged. In addition, poor irrigation efficiencies, as well as poor water management regimes, should be improved by taking tangible measurements at the irrigation scheme level. Furthermore, the polluter pays policy might be implemented or incentive measures might be taken on the farm and at the irrigation scheme level.

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