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Determination of Sudden Changes in Time Series of Yeşilirmak River-durucasu Water Quality Records

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Abstract: A variety of methods and statistical tests are being used to identify existence of trends in time series of water quality parameters. In this study, it was attempted to identify trends and sudden changes for selected water quality parameters at the Yeşilirmak River-Durucasu monitoring station. For this purpose, time series of grouped time periods, which do not exhibit inhomogeneity in median and variance values among years, were constituted for each water quality parameter using graphical methods and non-parametric tests. Considering test results, even though different time periods were observed for each water quality parameter, in general, two sudden changes in time series of most water quality parameters were obtained in 1989 and 1998.

Key words: Water quality, non-parametric test, trend, Yeşilirmak river

INTRODUCTION

There is an increasing need to assess trends in water quality to provide not only a warning of the rates of water-resource degradation, but also knowledge of causal relationship to effectively manage the water resources. It is important to describe the amount or rate of that change, in terms of changes in some central value of the distribution such as mean or median[1]. Trend analyses are used to determine whether the concentrations of a water quality parameter have consistently increased or decreased during a particular time period[1-4].

In this study, water quality monitoring records (time series) in each grouped time period which do not produce visual and statistically important variation in median and variance values among years within each grouped period were examined for trend. Therefore, the study on the trend analysis of Yeşilirmak River-Durucasu water quality data has two aims: (I) by using non-parametric statistical tests, to detect time periods for each water quality parameter which do not exhibit inhomogeneity in median and variance values among years within grouped period but presents inhomogeneity in median and variance values between grouped periods and (ii) to identify trends and sudden changes within and between time series of grouped time periods for each water quality parameter.

MATERIALS AND METHODS

Description of study area and data: The Yeşilirmak Basin is one of the twenty-six major basins in Turkey. The river in the basin originates north of Sivas, flows approximately 519 km and reaches to the Black Sea. The headwaters of the river and most of its tributaries originate in the mountains that form the eastern and southern boundaries of the basin. The major tributaries to the Yeşilirmak River are Kelkit, Çekerek, Çorum Çat and Tersakan Streams[5].

Upstream of Hasan Ugurlu Dam and 33 km downstream of city of Amasya at Durucasu Hydroelectric Power Station of the Yeşilirmak River, there is a monitoring station, where the General Directorate of Electric Power Research Survey and Development Administration (EIE) measures water flow and takes water samples once every month. The geographic coordinate of the water quality monitoring station is 40° 44' 40" N latitudes and 36° 06' 43" E longitudes. The drainage area of the monitoring station is about 21,650 km^2.

Among the water quality parameters measured by EIE at Durucasu monitoring station are water specific conductivity (EC) in µS cm^{-1}, sodium (Na^+), potassium (K^+), calcium+magnesium (Ca^{2+}+Mg^{2+}), bicarbonates (HCO_3^-), chlorides (Cl^-) and sulfates (SO_4^{2-}) in mg L^{-1}. The records for these parameters available for the analysis as presented in this study are on a monthly basis for

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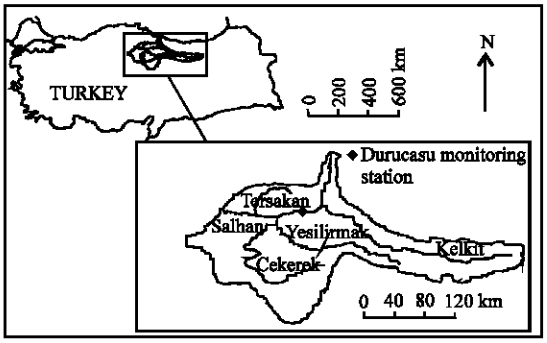

Fig. 1: Location map of the Yaşilirmak river basin and Duracasu water monitoring sation

the period 1984-2001. In addition to these water quality parameters, calculated Sodium Adsorption Rate (SAR) is also used in this study. The drainage area of the monitoring station is about 21,650 km^2 (Fig. 1).

Confirmatory data analyses: In this study, nonparametric tests including Kruskal-Wallis (to test median homogeneity) and Bartlett's statistics (to test variance homogeneity) were used to detect time periods for each water quality parameter which do not exhibit inhomogeneity in median and variance values among years within a grouped period but presents inhomogeneity in median and variance values between grouped periods.

Kruskal-Wallis tests the hypothesis that the different samples in the comparison were drawn from the same distributions or from distributions with the same median. The critical value of the Kruskal-Wallis (KW) can be calculated using the following formula[6]:

$$KW = \left[\frac{12}{N(N+1)} \sum_{i=1}^{k} n_i \bar{R}_i^2 \right] - 3(N+1) \qquad (1)$$

In equation (1); N is the total sample size, n is the sample size of the ith group, k is the number of groups and $\bar{R}_i$ is the mean rank of the ith group.

Bartlett's test is used to test if k samples have equal variances. The basic idea for this test is that the natural log of the variance is calculated for each group and then these are averaged. The variances are also averaged across groups. The average of the natural logs of the individual variances is subtracted from the natural log of the average variable. The critical value of the Bartlett's (B) can be calculated using the following formula[6]:

$$B = \frac{(N-k)\ln S_p^2 - \sum_{i=1}^{k} (n_i - 1)\ln S_i^2}{1 + \{1/[3(k-1)]\}\left\{\sum_{i=1}^{k} 1/(n_i - 1)] - 1/(N-K)\right\}} \qquad (2)$$

In equation (2); s_i^2 is the variance of the ith group and s_p^2 is the pooled variance. The pooled variance, a weighted average of the group variances, is defined as:

$$s_p^2 = \sum_{i=1} (n_i - 1) s_i^2 / (N-k) \qquad (3)$$

For both Kruskal-Wallis and Bartlett's statistics to test median and variance homogeneity within time series of grouped time periods for each water quality parameter, n is 12 (monthly data) and N is multiplicative of 12 depending on the number of year(s) in a grouped time period since there are 12 water quality records in a year for each parameter. If the P value is 0.05, there is a statistically significant difference among the variances at a 95% confidence interval.

The tested time series of possible time periods were chosen for each water quality parameter considering cumulative graph. If there is a statistically significant difference in median and/or variance values among years in time series of a possible time period decided from cumulative graph, then an appropriate time series of a new time period sequence which do not exhibit inhomogeneity ($p>0.05$) in median and variance values is selected by removing one or more year of monthly data from beginning or end of the selected possible time period. Therefore, time series of grouped time periods for each water quality parameter were constituted in this study when the time series of each grouped time period for each water quality parameter did not exhibit inhomogeneity in median and variance values among years within grouped period. In addition, existence of statistical difference ($p<0.05$) in median and/or variance values of time series between grouped time periods in each water quality parameter was tested by Kruskal-Wallis and Bartlett's statistics, respectively.

Trend analysis: For time series of grouped time periods in each water quality parameter which do not exhibit inhomogeneity in median and variance values among years within grouped period, a nonparametric, Kendall's tau test can be applied for detecting monotonic trend or change (gradual or sudden). The tau value is a measure of the correlation between the time series and time period. In this report, a trend was considered to be significant if the P value was less than or equal to 0.05 which represents a 95% confidence level. The Kendall correlation coefficient tau is defined as[7]:

$$\tau = \frac{S}{N(N-1)/2} \qquad (4)$$

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. Unless otherwise noted, all statistical tests were performed at 0.05 (95%) significance level.

RESULTS AND DISCUSSION

Confirmatory data analysis: Statistical test results for Kruskal-Wallis and Bartlett's test to observe time periods of time series, which do not exhibit inhomogeneity in median and variance values among years within grouped period for all water quality parameters are presented in Table 1. As results of these nonparametric tests within time series of grouped time period, only five time periods for EC (1984-1988, 1989-1991, 1992-1997, 1998 and 1991-2001) and HCO_3^- (1984, 1985-1988, 1989-1997, 1998 and 1999-2001), four time periods for K^+ (1984-1988, 1989-1993, 1994-1997 and 1998-2001), SO_4^{2-} (1984, 1985-1988, 1989-1990 and 1991-2001), Ca^{2+}+Mg^{2+} and SAR (1984-1988, 1989-1997, 1998 and 1999-2001) and two time periods for Na^+ and Cl^- (1984-1988 and 1989-2001) of which time series did not exhibit inhomogeneity in both median and variance values were observed. It was really interesting to see that for most of these water quality parameters, the first 5 year (1984-1988) period presented no significant evaluation in the median and variance values. In comparison, the time period of 1998 presented a significant difference from the previous (1984-1997) and following (1999-2001) time periods for most water quality parameters including EC, Ca^{2+}+Mg^{2+}, HCO_3^-, Cl-and SAR. This may due to considerable high fluctuation in discharge in 1998. Considering 18-year of time period,

Table 1: Kruskal-Wallis, Bartlett's and Kendall's tau statistical test results within time periods

Constant	Period	KW stat.	P value	Dec.[a]	Bartlett stat.	P value	Dec.	Kendall tau-stat.	P value	Dec.
EC	1984-1988	5.353	0.253	ND	6.635	0.156	ND	-0.027	0.766	NS
	1989-1991	0.235	0.889	ND	1.938	0.379	ND	0.024	0.820	NS
	1992-1997	5.741	0.332	ND	3.427	0.634	ND	-0.006	0.947	NS
	1998	*	*	*	*	*	*	-0.152	0.534	NS
	1999-2001	1.903	0.386	ND	0.819	0.664	ND	-0.135	0.226	NS
	1984-2001	61.042	0.000	SD	26.651	0.063	ND	0.098	0.032	IT
Na	1984-1988	3.377	0.497	ND	8.468	0.076	ND	0.010	0.906	NS
	1989-2001	19.146	0.085	ND	7.493	0.823	ND	-0.084	0.119	NS
	1984-2001	74.686	0.000	SD	37.104	0.003	SD	0.226	0.000	IT
K	1984-1988	3.447	0.486	ND	1.261	0.868	ND	-0.044	0.664	NS
	1989-1993	0.535	0.970	ND	1.743	0.783	ND	0.090	0.317	NS
	1994-1997	4.396	0.222	ND	29.428	0.000	SD[1]	-0.097	0.436	NS
	1998-2001	5.598	0.133	ND	5.232	0.156	ND	0.059	0.595	NS
	1984-2001	38.478	0.002	SD	105.602	0.000	SD	0.133	0.004	IT
Ca+Mg	1984-1988	5.240	0.264	ND	4.028	0.402	ND	-0.034	0.721	NS
	1989-1997	11.877	0.151	ND	2.908	0.940	ND	-0.105	0.108	NS
	1998	*	*	*	*	*	*	-0.303	0.164	NS
	1999-2001	1.447	0.485	ND	0.593	0.744	ND	-0.114	0.317	NS
	1984-2001	42.177	0.001	SD	25.839	0.077	ND	0.067	0.138	NS
HCO_3	1984	*	*	*	*	*	*	-0.046	0.882	NS
	1985-1988	1.933	0.586	ND	0.902	0.825	ND	-0.128	0.216	NS
	1989-1997	3.215	0.920	ND	7.788	0.454	ND	-0.021	0.739	NS
	1998	*	*	*	*	*	*	-0.485	0.032	DT
	1999-2001	2.092	0.351	ND	0.588	0.745	ND	-0.162	0.175	NS
	1984-2001	32.223	0.014	SD	40.576	0.001	SD	-0.015	0.720	NS
Cl	1984-1988	6.845	0.144	ND	0.880	0.927	ND	0.133	0.097	NS
	1989-2001	74.856	0.000	SD[2]	9.273	0.679	ND	-0.037	0.706	NS
	1984-2001	82.445	0.000	SD	16.818	0.467	ND	0.234	0.000	IT
SO_4	1984	*	*	*	*	*	*	-0.260	0.222	NS
	1985-1988	4.666	0.198	ND	5.983	0.112	ND	0.157	0.130	NS
	1989-1990	0.802	0.371	ND	0.000	0.986	ND	-0.036	0.812	NS
	1991-2001	12.623	0.245	ND	6.725	0.751	ND	0.056	0.344	NS
	1984-2001	55.868	0.000	SD	21.984	0.185	ND	0.202	0.000	IT
SAR	1984-1988	5.933	0.204	ND	9.333	0.057	ND	0.052	0.554	NS
	1989-1997	11.471	0.176	ND	10.406	0.238	ND	0.017	0.811	NS
	1998	*	*	*	*	*	*	0.534	0.000	IT
	1999-2001	2.411	0.299	ND	1.266	0.531	ND	-0.162	0.137	NS
	1984-2001	77.270	0.000	SD	54.900	0.000	SD	0.273	0.000	IT

Notes: [a]: Decision, Test interpretation for a 95% confidence level; ND: no difference; SD: significantly different; NT: not a significant trend; IT: increased trend; DT: decreased trend; *: no determination because there is no other series to compare; [1]: 1995 is different. The test values become: KW = 1.707 (P value = 0.426), Bartlett's stat = 5.175 (P value = 0.075), Kendall's tau = -0.073 (P value = 0.584); [2]: 1998 is different. The test values become: KW = 18.785 (P value = 0.065), Bartlett's stat = 8.536 (P value = 0.665), Kendall's tau = -0.079 (P value = 0.148)

Kruskal-Wallis test results showed that there was significant differences in times series of all water quality parameters. This conclusion was also confirmed by Bartlett's test for Na^+, K^+, HCO_3^- and SAR. There were two unusual cases in nonparametric tests of times series. Even though there was no inhomogeneity in median values among years in time series of 1994-1997 period for K^+, variance value for 1995 showed a significant difference from median values of other years in time period. Similarly, there was no inhomogeneity in variance values among years in time series of 1989-2001 period for Cl^- but median value for 1998 showed a significant difference from median values of other years in time period (Table 1).

In order to confirm these results, Kruskal-Wallis and Bartlett's test were also applied to show inhomogeneity in median and variance values between time series of grouped time periods for each water quality parameter (Table 2). For this reason, time series in a grouped time period for a parameter were compared with the following time series of grouped time period for the same parameter. Kruskal-Wallis and/or Bartlett's test showed that there were significant differences (inhomogeneity) between time series of grouped time periods for each parameter. Therefore, the grouped time periods for each water quality parameter (Table 1) can be used for the trend analysis.

Trend analysis: Kendall's tau test results were presented in Table 1 (within time series of grouped time periods) and Table 2 (between time series of grouped time periods). Considering 18-year of time period, Kendall tau test results showed that there was an increased trend in times series of EC, Na^+, K^+, Cl^-, SO_4^{2-} and SAR whereas not a increased or decreased trend in times series of Ca^{2+}+Mg^{2+}, HCO_3^- was observed. For the time series of grouped time periods, which did not exhibit inhomogeneity in median and variance values among years for all water quality parameters, not a significant trend was observed except time series in 1998 for HCO_3^- (decreased trend) and for SAR (increased trend) (Table 1). Monthly measured values of water quality parameters and their trend lines for the grouped time periods were demonstrated in Fig. 2. The slope of the trend lines for time series of each grouped time period in Fig. 2 represents the magnitude of Kendall's tau value from Table 1. In some cases, even though there were inhomogeneity in median and/or variance values between two time series of grouped time periods (for EC the time periods of II-III and, IV-V; for K^+ and SAR the time periods of II-III and III-IV; for Ca^{2+}+Mg^{2+} and SO_4^{2+} the time periods of III-IV; for HCO_3-the time periods of III-IV and IV-V), not a significant trend was observed between these data series (Table 2). In general, considering the nonparametric test results for all water quality parameters, the dates of sudden changes were occurred in 1989 and 1998.

Nevertheless, some socio-economic evolution in the Yeşilirmak river basin may explain the dates of changes and tendencies. 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 the Yeşilirmak river water quality. Similarly, abusive use of

Table 2: Kruskal-Wallis, Bartlett's and Kendall's tau statistical test results between time periods

Constant	Period	KW stat.	P value	Dec.[a]	Bartlett stat.	P value	Dec.	Kendall tau-stat.	P value	Dec.
EC	I-II	33.836	0.000	SD	9.675	0.002	SD	0.331	0.000	IT
	II-III	5.567	0.018	SD	0.130	0.718	ND	-0.126	0.051	NT
	III-IV	11.781	0.001	SD	0.155	0.694	ND	-0.161	0.045	DT
	IV-V	10.028	0.002	SD	0.688	0.407	ND	0.152	0.156	NT
Na	I-II	57.142	0.000	SD	26.202	0.000	SD	0.226	0.000	IT
K	I-II	16.600	0.000	SD	43.785	0.000	SD	0.240	0.000	IT
	II-III[1]	0.756	0.385	ND	10.556	0.001	SD	0.076	0.287	NT
	III-IV[1]	4.894	0.027	SD	7.406	0.006	SD	-0.139	0.056	NT
Ca+Mg	I-II	18.177	0.000	SD	13.867	0.000	SD	0.146	0.004	IT
	II-III	11.095	0.001	SD	2.348	0.125	ND	-0.197	0.002	DT
	III-IV	8.300	0.004	SD	4.334	0.037	SD	0.133	0.198	NT
HCO_3	I-II	14.017	0.000	SD	0.174	0.677	ND	-0.314	0.000	DT
	II-III	13.989	0.000	SD	7.331	0.007	SD	0.140	0.005	IT
	III-IV	8.717	0.003	SD	10.201	0.001	SD	-0.116	0.065	NT
	IV-V	4.491	0.034	SD	20.223	0.000	SD	0.039	0.726	NT
Cl	I-II[2]	62.956	0.000	SD	6.533	0.011	SD	0.271	0.000	IT
SO_4	I-II	7.946	0.005	SD	0.081	0.776	ND	0.263	0.000	IT
	II-III	19.648	0.000	SD	3.014	0.083	ND	0.357	0.000	IT
	III-IV	4.640	0.031	SD	0.079	0.943	ND	-0.034	0.541	NT
SAR	I-II	61.510	0.000	SD	11.525	0.000	SD	0.354	0.000	IT
	II-III	0.015	0.902	ND	14.355	0.000	SD	0.015	0.834	NT
	III-IV	0.051	0.821	ND	10.285	0.001	SD	-0.076	0.482	NT

Notes: [a]: Decision, Test interpretation for a 95% confidence level; ND: no difference; SD: significantly different; NT: not a significant trend; IT: increased trend; DT: decreased trend. [1]: without 1995 series. [2]: without 1998 series

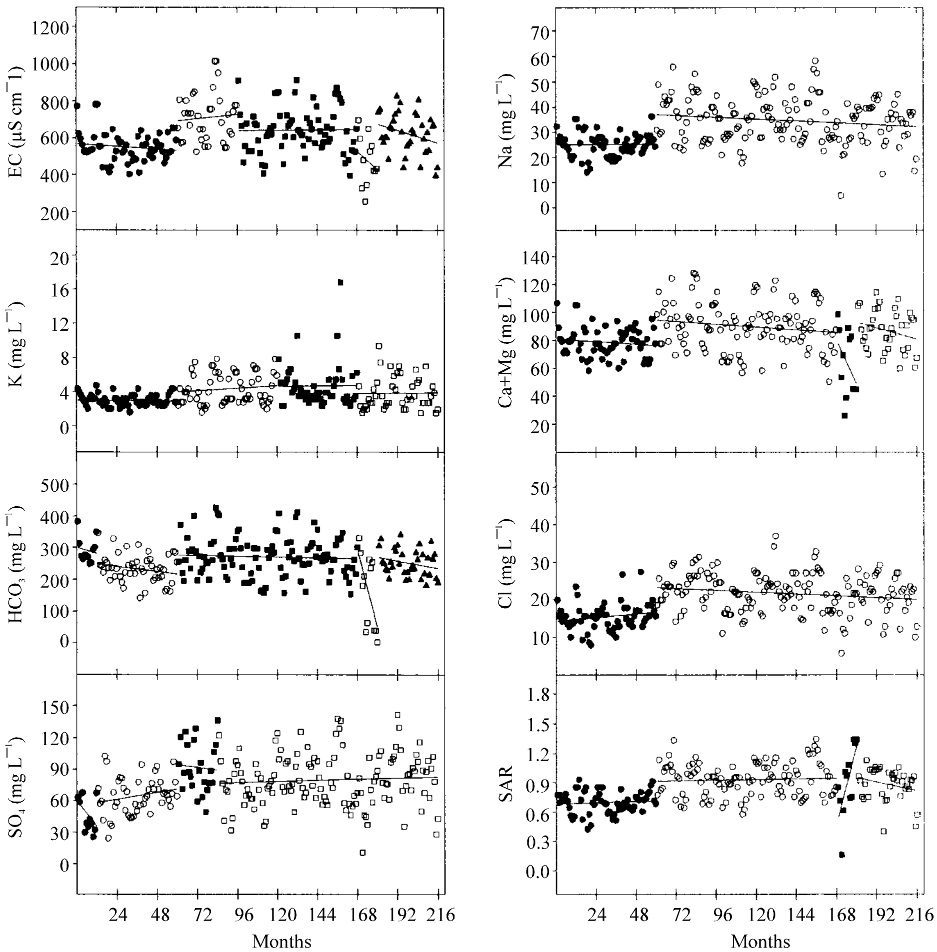

Fig. 2: Monthly measured values of water quality parameters and trend lines for the grouped time periods at Durucasu station of the Yeşilırmak river

mineral fertilizers, soil degradation and rotation cropping system were very important in the basin and have led to a slight increase in concentration of some water quality parameters.

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