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Investigation of priorities in water quality management based on correlations and variations

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ABSTRACT

The development of water quality assessment strategies investigating spatial and temporal changes caused by natural and anthropogenic phenomena is an important tool in management practices. This paper used cluster analysis, water quality index method, sensitivity analysis and canonical correlation analysis to investigate priorities in pollution control activities. Data sets representing 22 surface water quality parameters were subject to analysis. Results revealed that organic pollution was serious threat for overall water quality in the region. Besides, oil and grease, lead and mercury were the critical variables violating the standard. In contrast to inorganic variables, organic and physical-inorganic chemical parameters were influenced by variations in physical conditions (discharge, temperature). This study showed that information produced based on the variations and correlations in water quality data sets can be helpful to investigate priorities in water management activities. Moreover statistical techniques and index methods are useful tools in data – information transformation process.

1. Introduction

Surface waters are the most vulnerable sources to pollution due to their easy accessibility for wastewater disposal. Both the natural processes as well as the anthropogenic influences together determine the quality of surface water (Singh et al., 2004; Simeonov et al., 2003).

Water quality can be thought as a measure of suitability of water for a particular use based on selected physical, chemical, and biological characteristics (USGS, 2001). During the last decades, river water quality monitoring by measurement of quality parameters has been increasing. Creating a water quality monitoring system with appropriate efficiency and to extract useful information from complex data sets may require application of multivariate statistical tools due to multivariate nature of the ecological systems. The application of multivariate techniques (cluster analysis-CA, canonical correlation analysis-CCA, etc.) offers better understanding of water quality and ecological status of the studied systems. Moreover, water quality indices, which have been formulated all over the world can easily judge out the overall water quality within a particular area promptly and efficiently. These methods allow identification of the possible factors influencing the water systems. Therefore they are valuable tools for reliable management of water resources as well as rapid solutions on pollution problems (Noori et al., 2010; Simeonov et al., 2003; Spanos et al., 2007; Bharti and Katyal, 2011; Horton, 1965).

The research aimed: (1) to calculate water quality index-WQI to interpret overall water quality instead of evaluating variable-by-variable basis, (2) to examine parameter contribution to index score and sensitivity of the variables and (3) to analyze strength of the relationship between "physical" and "water quality" parameters. The overall objective was to investigate priorities in water quality management practices in the case of Gediz River Basin, Turkey.

2. Study area

The Gediz River Basin is one of the most important agricultural areas in the western part of Turkey (see Fig. 1). Gediz River with about 401 km length and 17,200 sq km drainage area flows from east to west into the Aegean Sea just north of Izmir (MoEF, 2008). The basin approaches a total population of 2 million. The region has hot dry summers, cool winters and average annual rainfall amount is 500–530 mm (Loon et al., 2007). The primary issues in the basin are water shortage, competing use, and high levels of pollution, etc. The major water pollutant sources are point (untreated wastewater discharges from organized industrial districts and municipal sewage treatment plants) and diffuse sources (mainly runoff from agricultural, forest areas, and domestic–industrial

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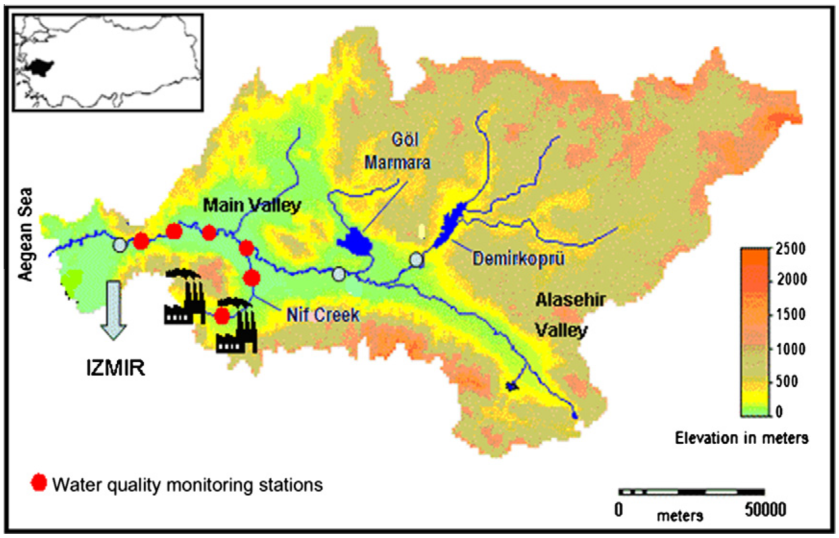

Fig. 1. Gediz Basin Map (after Harmancioglu et al. (2008)).

wastewaters not connected to sewers). Heavily-polluted wastewater discharges from urban areas and industries within the basin seriously degrade the quality of surface water particularly in the low-flow summer months (Izsu, 2008).

3. Study method

In the study water quality samples collected from six monitoring stations over 2 years on monthly basis along the Gediz River and its tributaries (see Fig. 1) and analyzed for biochemical oxygen demand-BOD, chemical oxygen demand-COD, kjehldahl nitrogen-KN, oil and grease-O&G, chloride-Cl, sodium-Na, boron-B, sulfate-SO_4, pH, dissolved oxygen-DO, total phosphorus-TP, suspended solids-SS, nitrate nitrogen-NO_3-N, nitrite nitrogen-NO_2-N, iron-Fe, aluminum-Al, nickel-Ni, lead-Pb, zinc-Zn, chromium-Cr, mercury-Hg and cadmium-Cd were assessed. Water samples have been analyzed according to "Standard Methods for the Examination of Water and Wastewater (APHA, 2005)" at the laboratory.

Variables were divided into three classes as:

- organic (BOD, COD, KN, O&G),
- physical-inorganic chemical (Cl, Na, B, SO_4, pH, DO, TP, SS, NO_3-N, NO_2-N)
- inorganic pollution (Fe, Al, Ni, Pb, Zn, Cr, Hg and Cd).

Cluster analysis, water quality index method, sensitivity analysis and canonical correlation analysis were applied to improve understanding of water quality phenomena caused by natural and anthropogenic forces in the region. Each analysis technique was performed for three groups distinctly.

Water quality index: A water quality index is used to summarize large amounts of water quality data into simple terms (e.g. good or fair) for reporting to management and the public in a consistent manner. In the study the method was applied to summarize complex data sets instead of trying to interpret quality on a variable-by-variable basis. In order to determine index parameters cluster analysis was applied. This provided classification of water quality variables based on their similarities; therefore elimination of some variables (which were highly correlated each other) from calculations.

For three groups of variables "Canadian Council of Ministers of the Environment Water Quality Index-CCME WQI method" was performed. CCME WQI relates water quality data to a selected beneficial water use using relevant water quality guidelines as benchmarks. In this method the percentage of parameters and tests that fail to meet the guidelines, the deviation from the guideline for tests that do not meet guidelines, are captured in three factors (scope-F_1, frequency-F_2, and amplitude-F_3). The index yields a number between 0 and 100. A higher number indicates better water quality (Lumb et al., 2006; CCME, 2001; Khan et al., 2005).

Scope (F_1): The scope factor represents the percentage of the total number of parameters that fail to meet the water quality guidelines at any time over the time period of interest.

$$F_1 = \left[\frac{\text{Number of failed parameters}}{\text{Total number of parameters}}\right] * 100$$

Frequency (F_2): The measure for frequency is F_2. It represents the percentage of individual tests that fail to meet the water quality guidelines.

$$F_2 = \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right] * 100$$

Amplitude (F_3): The amplitude factor represents the average deviation of failed test values from their respective guidelines. The relative deviation of a failed test from the guideline is termed an excursion and is calculated as follows:

When the test value must not exceed the guideline:

$$\text{Excursion} = \left[\frac{\text{Failed test value}}{\text{Guideline value}}\right] - 1$$

When the test value must not fall below the guideline:

$$\text{Excursion} = \left[\frac{\text{Guideline value}}{\text{Failed test value}}\right] - 1$$

The collective amount by which individual tests are out of compliance is calculated as follows:

$$\text{nse} = \left[\frac{\sum \text{Excursion}}{\text{Total number of tests}}\right] - 1$$

where nse is the normalized sum of the excursions from the guidelines.

F_3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.