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Determining spatial and temporal changes of surface water quality using principal component analysis

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ABSTRACT

Study region: Shahr Chai River, Lake Urmia basin, Iran.
Study focus: The present study investigated the ability of the Principal Component Analysis (PCA) technique in pointing the environmental effects of discharges from different activities. Major indicator parameters were extracted for water quality analysis of the Shahr Chai River located in Lake Urmia basin, Iran. The water quality parameters were measured monthly in six stream reaches and were affected by discharges from intensive recreational centers and rural and agricultural activities.
New hydrological insights: The results showed that the NSFWQI and the $WQI_{min\text{-}p}$ could not distinguish between highly impacted stream reaches, while the calculated WQImin-c with two parameters including turbidity and fecal coliforms could meaningfully classify the sampling stations. These two parameters were selected based on results from correlation matrix. This study showed that calculation of the $WQI_{min\text{-}c}$ was an effective and easily applicable assessment method for different effluents' impacts on stream water quality. The PCA technique could justifiably show different landscape effects on river water quality whereby the river downstream was found to experience decreased water quality.

1. Introduction

In recent years, developments in agriculture, industry, and urban activities, especially around rivers, have effected significant changes in quality and quantity of these water resources. Changes in rivers' water quality, mostly due to dramatically increased chemicals and nutrient materials, threaten aquatic ecosystems and river downstream environmental conditions. Further, it is rarely possible to present the best allocation option for water resources without monitoring water quality. Monitoring network analysis can be helpful to prevent river pollution and to apply remedial policies (Debels et al., 2005). A reliable monitoring of surface water quality seems to be critical in water resource modeling (Massoud, 2010). As there are numerous physical, biological, and chemical water quality parameters, researchers have proposed a simple expression of the general quality conditions of surface waters called the Water Quality Index (WQI).

WQI summarizes numerically the information from multiple water quality parameters such as Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), and Turbidity (TUR) into one single value. This single value can be used to compare water quality conditions among sites and to investigate their trends over a given period of time. There are various WQIs across the world that use different parameters depending on water quality objectives (CCME, 2001; Debels et al., 2005). Pesce and

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Wunderlin (2000) compared the objective WQI (WQI_{obj}) on the basis of 20 parameters and the minimum WQI (WQI_{min}) on three parameters (DO, EC or total dissolved solids, and TUR) to assess the effects of urban discharge on the quality of river water. According to their analyses, they suggested that the WQI_{min} is as efficient as the WQI_{obj} is. Using the WQI_{min} resulted in decreased analytical cost, which is a determining factor in water quality studies.

In a study conducted on water quality of Bagmati river, Kannel et al. (2007) compared the results of WQI (considering 18 water quality parameters), WQI_m (as a regression analysis result between WQI and WQI_{min} values), WQI_{min} (considering five water quality parameters: temperature (T), pH, DO, EC and Total suspended solids (TSS)), and WQI_{DO} (considering a single parameter, DO). Their results showed that WQI_{min} was overestimated in comparison with other indices, whereas both WQI and WQI_{min} trends were similar. In addition, they emphasized WQI_{min} for periodic monitoring programs. Moscuzza et al. (2007) analyzed the impact of different agroindustry effluents on water quality of Salado River by applying WQI_{min}. In their study, WQI_{min} was calculated using only two parameters (DO and EC) which can be determined easily in situ. Focusing on the effects of meat industry as the most pollutant source, they proposed WQI_{min} as a useful index for river management decisions. Sharma and Kansal (2011) used WQI for Yamuna River in order to study the aftereffects of the projects implemented during Yamuna Action Plan phase I and II. They indicated that BOD, DO, total coliforms (TC), fecal coliforms (FC) and free ammonia were the most important parameters to investigate the water quality of Yamuna River. TuranKoÇer and Sevgili (2014) suggested that the calculated WQI_{min} using NH_4^+-N and total organic nitrogen could be applied to survey the impacts of trout farm effluents on the quality of stream water.

A review of the recent studies reveal that different WQI indices have been efficient for identification of pollution sources/factors and understanding temporal/spatial variations in river water quality management (Kannel et al., 2007). However, the questions that may remain to be a matter of problem include which parameters to consider and how to select them. In the present study, the Principal Component Analysis (PCA) technique was evaluated and attempts were made to extract the most important indicator parameters for assessment of water quality variations in the Shahr Chai River.

2. Materials and methods

2.1. Study site and sampling points

The Shahr Chai River is one of the main running waters of Lake Urmia basin in Iran (located at 37°24′–37°34′N, 45°35′–45° 16′E). The River is 72.5 km long. It originates from the Zagros mountain range and passes through the Urmia plain with different landscapes and is mostly diverted for urban, agricultural, industrial and domestic use along its way. The average annual flow of the river is about 170 Million Cubic Meter (MCM) at Band hydrometric station (BHS). The 170 MCM represents the potential inflows to the river mainstream (Fig. 1). With a capacity of 220 MCM, Shahr Chai Dam was constructed on the river not only to control floods but also to supply agricultural and domestic water consumption. Among the significant river contamination sources are the most populated centers in urban and rural regions as well as waste from industrial and agricultural activities, especially in the vicinity of Urmia city.

According to a study conducted by the Iranian Ministry of Energy in 2011, there are more than 5600 industrial centers in urban and rural areas of Urmia region. Furthermore, these centers are generally located around the main stream channel, particularly the Shahr Chai River downstream. To locate the monitoring stations, the sites with high pollution potential were identified (Energy Ministry, 2011) (Fig. 1). The stations were selected such that could both provide access to the river and offer representative samples of water quality all along the river length. For this purpose, six stations were selected. The first (SH1) and the second (SH2) stations were located at the upstream of the Shahr Chai dam. The river flow and water quality parameters at the third station (SH3) was under the effect of dam water release schedules (Fig. 1). The forth sampling point (SH4) is largely fed by more than 50 restaurant wastes that were located at the Band recreational region, between the dam and Urmia city entrance. Most of the waste from these restaurants

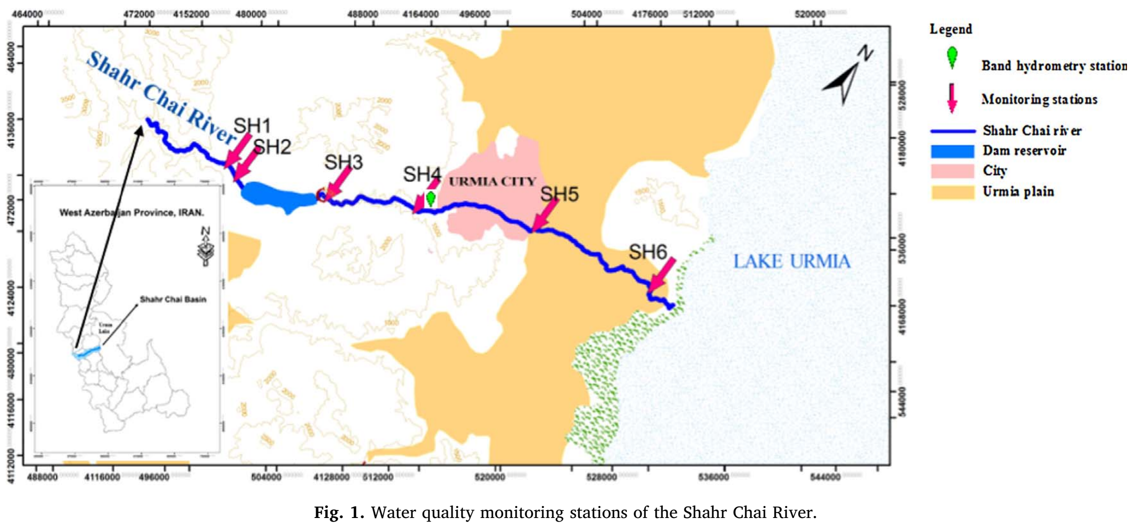

Fig. 1. Water quality monitoring stations of the Shahr Chai River.