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Short communication

A simple tool for the assessment of water quality in polluted lagoon systems: A case study for Küçükçekmece Lagoon, Turkey

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ABSTRACT

Lagoon systems have particular ecological, morphological and hydrodynamic characteristics and act like transitional zones between inland and open waters. The aim of this study is to develop a Lagoon Water Quality Index (L-WQI) for environmental control of polluted lagoon systems by focusing on primary problems such as increasing stress on aquatic biota, eutrophication and organic pollution. The indicators used in L-WQI are dissolved oxygen saturation, total nitrogen to total phosphorus ratio, nitrate, orthophosphate, chlorophyll-a, chemical oxygen demand, pH, turbidity and electrical conductivity. L-WQI establishes a new normalization function for each variable and uses a modified version of the weighted aggregation method. L-WQI has been adapted to Küçükçekmece Lagoon, a highly polluted watershed located in western Istanbul. The results correlated with the observed water quality trends in this lagoon and highlighted the impact of pollution in its tributaries.

1. Introduction

Lagoons are ecotones that develop at the interface between coastal, terrestrial and marine ecosystems. On the world scale, lagoon systems comprise 13% of earth's coastline (Barnes, 1989). Each of these coastal areas is a unique, sensitive ecosystem, extremely valuable as a natural habitat for many life forms. Lagoons are also important to socio-economic structure in terms of providing opportunities for agriculture, aquaculture, tourism and recreational purposes. However the above-mentioned socio-economic advantages may become disadvantageous for the ecological environment if they are not managed and supervised with great care. Lagoons have limited water circulation to compensate for changes in water quality and are susceptible to anthropogenic pollution (Johnson et al., 2007). In lagoon systems water quality assessment is of vast importance in sustaining ecological characteristics.

Water quality in freshwater bodies is a complex issue with multiple aspects such as physical, chemical and biological processes and their interactions. In recent decades, various tools have been developed to assist water quality management including mathematical models, optimization approaches and integrated decision support systems (Huang and Xia, 2001). Along with the increasing use of these sophisticated tools, water quality indices are also being developed and used world-wide due to their simplicity, adaptability and easy-to-use nature (Kannel et al., 2007; Simoes et al., 2008). The popularity of the Water Quality Index (WQI) comes from its pragmatic structure; complex mathematical evaluations of huge quantities of water characterization data are transformed into a simple scale value. This value is easily comprehended by planners, managers and the general public (Giljanovic, 1999). Some notable implementations of WQI were by the US National Sanitary Foundation (NSF), Oregon Department of Environmental Quality, British Columbia Ministry of Environment, Canada Council of Ministers of Environment (CCME) and Environmental Protection Administration of China (Cude, 2001; Chen et al., 2006, Lumb et al., 2006). Methodologically, WQIs can be based on objective or subjective criteria. Objective WQIs make use of statistical analysis based on pre-defined threshold values set by administrative boards. Subjective WQIs are based on a parameter set, relative weights, normalization curves and aggregation algorithms (Abbasi, 2002). In recent studies, artificial neural networks and fuzzy logic have been adapted to WQIs (Khuan et al., 2002; Icaga, 2007; Nasiri et al., 2007). The common application areas of WQIs are surface waters, coastal areas or aquacultures contaminated by heavy metals and/or organic matter (Said et al., 2004; Jonnalagadda and Mhere, 2001; Liou et al., 2004; Atazadeh et al., 2007; Kaurish and Younos, 2007; Aguilera et al., 2001; Edet and Offiong, 2003).

This study develops a "Lagoon Water Quality Index" (L-WQI) to evaluate the quality of water in lagoons facing ecological problems

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such as eutrophication, organic pollution and increasing stress on aquatic biota. Küçükçekmece Lagoon was selected as the study area, showing typical characteristics of polluted lagoon systems. This lagoon once sheltered migratory birds and diverse flora and fauna. Today, however, it has vastly deteriorated as a result of extensive regional urbanization and industrialization.

2. Material and methods

2.1. The study area and sampling sites

Küçükçekmece Lagoon is located between 41°00′N and 28°45′E in the south-west of Istanbul. The lagoon's total drainage area is 340 km^2 and its surface area is approximately 15.22 km^2 with a maximum length of 7.5 km from north to south and 4 km from east to west. Maximum depth of the lagoon reaches 20 m near the Sea of Marmara shoreline. The three streams feeding the lagoon are Eşkinoz, Sazlidere and Nakkaşdere. The freshwater inflow to the lagoon was notably reduced after 1998 upon initiation of Sazlidere Dam. Currently, with an annual capacity of 85106 m^3, the dam is used for supplying potable water to Istanbul (Taner et al., 2007). The lagoon and the Sea of Marmara are connected by a channel which is 1.5 km in length. Thermal stratification of the lagoon is restricted to the summer period, whereas from November to May the lagoon shows a relatively homogenous profile. Küçükçekmece Lagoon is euthrophic and its algal blooms become explicit usually during early spring and late fall. The environmental degradation trend of the Küçükçekmece Watershed began in the 1990's as a result of rapid land-use transformations. The population of the area increased fivefold between the 1990s and 2000s. Currently, the majority of residents in the area are squatters with no access to adequate environmental infrastructure. A vast majority of industrial facilities in the region do not operate their wastewater treatment plants regularly.

During the development of L-WQI, water and sediment quality was monitored periodically (Üstün et al., 2005). Our monitoring program was carried out from November 2005 to March 2008 at nine sampling stations. Stations 10–13 are located in the lagoon; Stations E2 and E3 are located on Eşkinoz Stream; Station D3 is in Sazlidere Dam; and Stations D1 and D2 are located on Sazlidere Stream (Fig. 1). During monitoring studies: dissolved oxygen (DO), pH, electrical conductivity (EC) and salinity are measured *in situ* by using WTW Oxi 330i/set; chemical oxygen demand (COD) by the open reflux method; turbidity, orthophosphate, nitrate and chlorophyll-a by spectrophotometric methods (APHA, 1995). We also benefited from an additional set of data collected by the Turkish State Hydraulic Works (DSI) from sampling stations S1 (from May 1994 to December 1998), S2 (from February 1990 to October 1996), S3 (from February 1999 to December 2006), S4 (from February 1999 to October 2006) and S5 (from January 1990 to May 1994) on Sazlidere Dam (Fig. 1).

2.2. Index methodology

This study introduces a general framework for water quality indices consisting of five primary phases: determination of objectives, selection, normalization and aggregation of variables and validation (Fig. 2). The first phase is the determination of index objectives based on unique characteristics of the water body (e.g. lagoons, coastal waters, lakes). These objectives should be related to all living species' life sustainability and beneficial use for human beings. Water quality variables are then selected based on these pre-defined objectives as well as data availability and financial constraints. Subsequently, variables are normalized according to certain water quality standards and thresholds in parallel with index objectives. Then follows the aggregation phase where selected water quality parameters are aggregated to express the final water quality score in the most appropriate way. The first four phases of the above framework was given below for L-WQI, while the index validity was discussed in the results section.

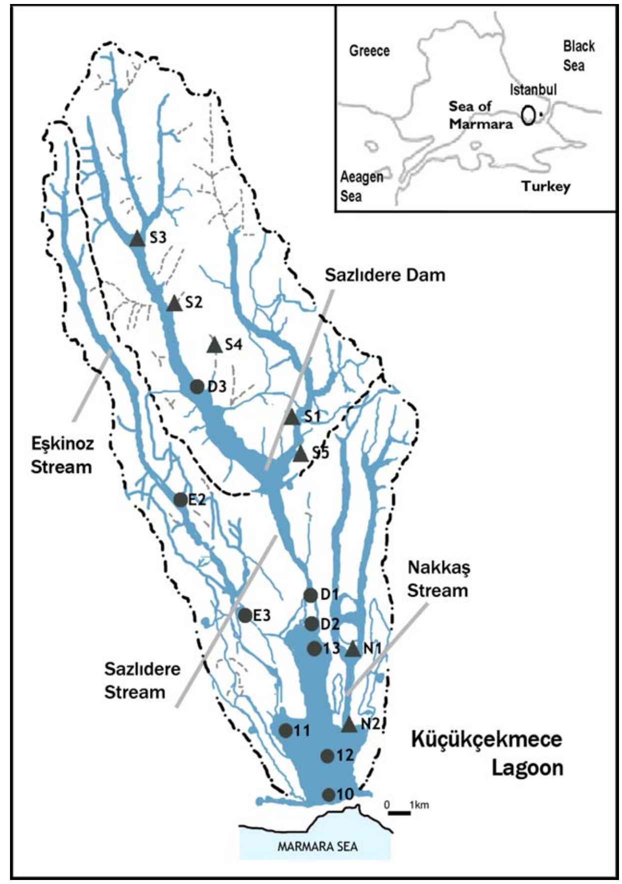

Fig. 1. Küçükçekmece Watershed and Water Quality Monitoring Stations. Our team's sampling stations on Eşkinoz Creek (Stations D1–D3), Sazlidere Creek (Station E2 and E3) and Kucukcekme Lagoon (Stations 10–13) are marked with ●. The additional data set of State Hydraulic Works' (DSI) on Sazlidere Dam (stations S1–S5) are marked with ▲.

2.2.1. Index objectives and variable selection

The objective of L-WQI is to evaluate critical stress on aquatic biota i.e. eutrophication and decreases in oxygen levels of ecosystems as a result of organic pollution by anthropogenic sources. To complete the evaluation, the following parameters were selected as water quality variables to be used in the index: dissolved oxygen (mg/L), DO (saturation ratio); temperature (°C); salinity (ppt); total nitrogen to total phosphorus ratio (TN:TP); orthophosphate, O-PO_4, (mg/L); nitrate, NO_3 (mg/L); chlorophyll-a, Chl-a, (μg/L); chemical oxygen demand, COD (mg/L); ph; turbidity (NTU); and electrical conductivity, EC, (mS/cm). DO is a basic indicator of aquatic stress in water bodies for L-WQI. DO is measured in terms of saturation ratio which is an attribute of in-stream temperature and salinity. COD is an effective indicator of organic pollution load especially in water bodies receiving excessive industrial discharges. TN:TP, Redfield Ratio, indicates the limiting nutrient in the environment for algal growth (Wetzel, 2001). Determination of the limiting nutrient is particularly vital for lagoon systems as they exhibit a transitional character between inland and marine waters. NO_3 and O-PO_4 are soluble and readily found forms of primary nutrient species in freshwaters. Chlorophyll-a, a vital pigment for photosynthesis, is present in most plants and algae. Nutri-