Ecological Indicators 36 (2014) 672–681

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Parameters selection for water quality index in the assessment of the environmental impacts of land-based trout farms

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ARTICLE INFO

Article history:
Received 17 February 2013
Received in revised form
25 September 2013
Accepted 28 September 2013

Keywords:
Water quality index
Aquaculture
Environmental impact
Indicator parameters
Ammonia
Organic nitrogen

ABSTRACT

This study aimed to check the effectiveness of water quality indices (WQIs) in the specific assessment of trout culture impacts on a stream water quality by selecting the parameters in various approaches. Water quality was monitored monthly for a period of 1 year in one reference point and four affected stream reaches in which discharges from intensive trout farms, and rural and agricultural activities were present. The objective WQI calculation using 24 parameters and the minimum WQI (WQI_{min}) using dissolved oxygen, biochemical oxygen demand, total suspended solids, total phosphorus, ammonia nitrogen (NH_4^+-N), and total nitrogen as major indicators in trout farm effluents could not distinguish the aquaculture-impacted stream reaches. However, WQI_{min} calculation with NH_4^+-N, total organic nitrogen (TON), soluble reactive phosphorus, and total organic phosphorus which were selected using the principal component analysis findings meaningfully classified the sampling points. Further reduction of parameters to NH_4^+-N and TON in WQI_{min} calculation achieved a similar successful classification of the sampling points. This study showed that WQI_{min} calculated using NH_4^+-N and TON is a useful and easily applicable methodology in the assessment of the impacts of trout farm effluents on the stream water quality.

1. Introduction

The use of surface waters for various purposes threatens the integrity of aquatic ecosystems as a result of changing its quality and quantity. Therefore, representative and reliable monitoring and assessment of water quality are critical (Massoud, 2010). Surface water quality is traditionally assessed by water quality standards and objectives (Rosemond et al., 2009). However, this traditional approach cannot provide sufficient information on the overall quality of water or the spatial and temporal trends (Kannel et al., 2007). Although dynamic mathematical modeling or multivariate statistics are the best approaches to determine these trends (Boyacıoğlu and Boyacıoğlu, 2007), they require overmuch effort, financial resource, and expertness and they are not easily applicable or cognizable. Therefore, researchers and/or environmental authorities have strived to derive a simple expression of the general quality of surface waters by a single number, that is, the water quality index (WQI) (Debels et al., 2005).

There are several WQIs using different parameters depending on the water quality objectives all over the world (CCME, 2001; Debels et al., 2005). The WQIs are commonly used in either the classification of surface waters (Boyacıoğlu, 2010; Lermontov et al., 2011) or the assessment of beneficial use (Said et al., 2004) and water pollution (Akkoyunlu and Akıner, 2012; Bakan et al., 2010; Kannel et al., 2007; Zhang and Zhang, 2007). For instance, Pesce and Wunderlin (2000) calculated the objective WQI (WQI_{obj}) on 20 parameters and the minimum WQI (WQI_{min}) on three key parameters (dissolved oxygen, electrical conductivity or total dissolved solids, and turbidity) to assess the effect of urban discharge on a receiving river water quality. They suggested that the latter was sufficient as much as the former in the assessment, resulting in a decrease in analytical cost, which is a limiting factor in water quality assessments. Kannel et al. (2007) also showed that the WQI_{min} on five parameters (temperature, pH, dissolved oxygen, electrical conductivity and total dissolved solids) could be useful for the periodic routine monitoring program of urban impacts on a river.

The environmental sustainability of aquaculture, the fastest-growing food industry due to the expansion of an annual average growth of 8.3% for the past three decades (FAO, 2010), is a concern because it can have serious negative impacts on aquatic ecosystems as a result of nutrient and organic matter enrichment (Folke and Kautsky, 1992). The impacts may show clear temporal and spatial variations depending on species, culture method, stocking density, feed type, hydrologic properties, farm capacity and husbandry practices (O'Bryen and Lee, 2003; Tacon and Forster, 2003; Wu, 1995). There are some studies using the WQIs in the assessment of environmental impacts of aquacultural activities.

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1470-160X/$ – see front matter
http://dx.doi.org/10.1016/j.ecolind.2013.09.034

Ferreira et al. (2011) applied the Canadian WQI to assess the effects of shrimp farm activities on two coastal environments using 18 parameters representing physicochemical and biological variations and bacteriological contamination. The investigators did not detect a significant influence in the sites. Simões et al. (2008) used U.S. National Sanitation Foundation WQI, the minimum operator concept, and the WQI_{min} in the assessment of the effects of pond aquaculture effluents on stream ecosystem and suggested that the deterioration due to aquacultural activity can be easily inferred with WQI_{min} on three parameters: dissolved oxygen, turbidity and total phosphorus. The question of which parameters should be considered and how they are selected in the calculation of WQI for specific assessments of the impacts of aquaculture effluents on stream water quality remains to be answered. Therefore, the objectives of this study were to determine the water quality of stream reaches exposed to point discharges of flow-through trout farms and diffuse discharges of rural community and agricultural activities and to show a way of selecting the indicator parameters for the WQIs to assess the trout farming impacts.

2. Materials and methods

2.1. Study site and sampling points

Eşen Stream, one of the main running waters of the western Mediterranean basin in Turkey, discharges into the Mediterranean Sea. The streamflow has been altered markedly for the purposes of hydroelectric power generation, flood control and irrigation. The flow is diverted into two hydroelectric power plants (HEPPs) from the upstream with a water pipeline. The upper reach of the midstream is mainly fed by a ground water resource (Çaygözü). A common outlet of the HEPPs is added below 1 km from the resource. At approximately 1 km below this point, a control gate (Regulator) dams up the stream and diverts the water into an open channel for agricultural irrigation and a third HEPP. An overflow of the open channel capacity discharges into the main streambed. The stream taking tributaries of the midstream and the downstream finally runs into the sea (Fig. 1).

The basin of the stream is a significant land-based trout culture site. There are more than 50 flow-through rainbow trout farms, with a total licensed capacity of 7700 tons per year of market size and 213 million fry per year. However, the farms with high production capacities are generally located near the main stream channel around the midstream region. Their effluents were directly discharged to the stream without any solid removal and treatment during the study period. Nine single-pass flow-through trout farms with a total capacity of 4400 tons per year are located along a reach of 2 km between Çaygözü and Regulator. Çaygözü represents the unaffected reference sampling point (S1), whereas the regulator site represents stream reach (S2) affected by nine intensive trout farms. The third sampling point (S3) is fed by a few brooks and the overflow of the open channel. S3 is largely under the effects of rural activities. There is a tributary with steep slope (Sögütlüdere Brook) discharges between S3 and the fourth sampling point (S4) where a trout farm with a capacity of 950 tons per year is located. Therefore, S4 represents a combined effect of steep environmental gradients and the trout farm discharges. The fifth (S5) was selected from downstream reaches as a self-purification zone, which is within the vicinity of intensive agricultural areas plus rural settlements (Fig. 1).

2.2. Water quality analysis

The samples were taken monthly between March 2008 and February 2009. Temperature (*T*), dissolved oxygen (DO), oxygen saturation (SAT), pH and electrical conductivity (EC) were measured in situ by YSI 55 and YSI 63 field instruments (Yellow Springs Instrument Co., Yellow Springs, OH). Turbidity (TUR) was measured using Hach 2100AN model benchtop turbidimeter (Hach Company, Loveland, CO).

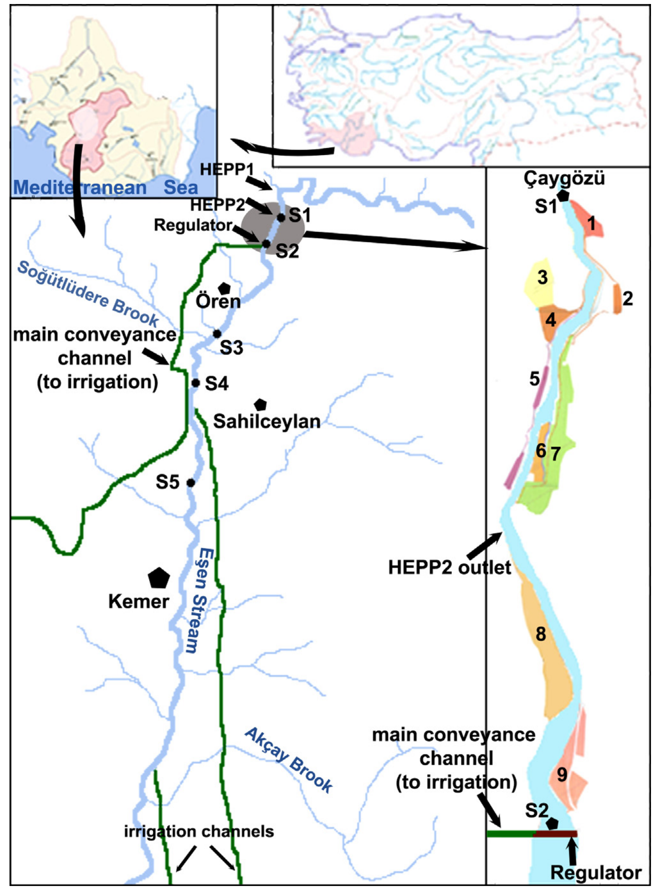

Fig. 1. Location of Eşen Stream and sampling points (map on left), and a schematic view of the nine flow-through trout farms between first and second sampling points (plot on right).

Total suspended solids (TSS) and total dissolved solids (TDS) were determined by filtration and then dried at 103–105 °C. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^{-}) were determined by volumetric titrimetry, and sulphate (SO_4^{2-}) was determined by spectrophotometry using the turbidimetric method. Ammonia nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N) and nitrate nitrogen (NO_3^--N) were determined by phenate, colorimetric, and cadmium reduction methods, respectively. Total nitrogen (TN) was analyzed by cadmium reduction after persulfate digestion. Soluble reactive phosphorus (SRP) in filtered samples and total inorganic phosphorus and total phosphorus (TP) after hydrolysis and digestion in unfiltered samples, respectively, were determined by ascorbic acid method. Total organic nitrogen (TON) and total organic phosphorus (TOP) were calculated by subtracting the inorganic fractions from total concentrations. The Helios-α model UV–vis spectrophotometer (Thermo Scientific, Cambridge, United Kingdom) was used for analyzing of nutrient forms. Biochemical oxygen demand (BOD_5) was determined by five days incubation and chemical oxygen demand (COD) with open reflux method. Total coliforms (TC) and fecal coliforms (FC) were determined using membrane filtration methods. All water quality analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 1998).