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Modeling nutrient loads to the northern Adriatic

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SUMMARY

The northern Adriatic (NA) is one of the most productive areas of the Mediterranean Sea with a watershed area spread over four neighboring countries, Italy, Slovenia, Switzerland and Croatia. Up to date research include mainly the nutrient load estimations from the biggest nutrients sources, like the Po River watershed (Italian part). This research aims to estimate the loads from nearly the entire contributing area, including the Italian, the Slovenian and the Croatian part. The ArcView Generalized Watershed Loading Function (AVGWLF) model was applied to simulate nutrient loads from the NA watershed. The model can simulate runoff, sediment and nutrients (nitrogen and phosphorus) loads from the watershed, by taking dispersed and point sources into account. Calibration and validation of the model were performed on the data from 1999 to 2002 and 2003 to 2007, respectively. Comparison between the simulated and measured loads in the Po River watershed shows a good match and thus high reliability of the model. As expected, the Po River dominated the nutrient loads to the NA. However, the results also point to other contributing areas, e.g. smaller watersheds with high intensity of nutrient loads, causing significant local impacts (e.g. Lagoon of Venice). The model also shows that the major sources of nutrients are not only agricultural but also urban areas without proper wastewater treatment (secondary at present). Proper management of these areas, such as introducing suitable (tertiary) wastewater treatment, or other nutrient management measures shall reduce the nutrient loadings to the NA.

Further work is focused to use the model for optimizing the control and management of the activities in the contributing areas, smaller as well as bigger sub-watersheds.

1. Introduction

Increased nutrient concentrations in rivers, lakes and coastal seas as a consequence of various human activities such as agriculture or wastewater discharges have several undesirable effects, most of which are related to the increased growth of phytoplankton and other aquatic plants. These effects are more expressed in shallow water bodies with poor water exchange, such is the northern part of the Adriatic Sea. Additionally, its northwestern part is one of the most productive areas in the Adriatic Sea, as well as in the Mediterranean Sea (e.g. Sournia, 1973; Mozetič et al., 2009). Numerous rivers and streams discharge nutrient rich freshwaters into the NA shallow waters (Raicich, 1996). These rivers play important role in sustaining the marine productivity in the NA. Changes in the NA riverine inputs are therefore potential drivers for long-term changes in the marine ecosystem. For many years the NA has been recognized as a region of high marine production at several trophic levels from phytoplankton to fish, but recently the external nutrient input is thought by some authors to be the source of the eutrophication problem of this area (Degobbis, 1989).

The majority of the nutrients surely come with the Po River, which is the biggest contributing watershed to the NA. Thus, most of the latest studies are focused to the Po River watershed (de Wit and Bendoricchio, 2001; Palmeri et al., 2005; Spillman et al., 2007), while very few (Degobbis, 1988; Ludwig et al., 2009; UNEP, 1995; Strobl et al., 2009; Cozzi and Giani, 2011) have been done for the entire NA watershed. Degobbis (1988) in his Ph.D. Thesis presents cycle and balance of nutrients in the NA. Ludwig et al. (2009) studied the Mediterranean and Black Sea and also presented nutrient loads for several bigger rivers in the NA (Po River, Adige, etc.), but many smaller rivers (like Dragonja or Mirna) were missed due to lack of data. UNEP study from 1995 deals with eutrophication, nutrient loads, source types, load assessment and effects on marine life, where nutrient loads and source types have been taken from several older papers and studies, and thus, cannot be reliable for present state. Cozzi and Giani (2011) present the analysis of the runoff and nutrient loads by the NA rivers, in order to point out their current impact on the NA marine ecosystem. Nutrient loads were calculated from measured data only, where different types

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of land uses in the watersheds were not taken into account. None of these studies included modeling approach, where different land uses, soil maps, elevation map, point sources (e.g. wastewater treatment plants (WWTP) and urban systems (US)) are taken into account. Strobl et al. (2009) have calculated nutrient loads for the Mediterranean region using AVGWLF simulation model, however the input data taken into account are in a less detail, e.g. smaller watersheds and WWTPs were roughly aggregated into the bigger watersheds.

In this work a modeling approach was used to simulate the nutrients loads to the NA from the entire watershed by addressing also smaller sub-watersheds and including higher resolution data (e.g. for land use, wastewater treatment, soil characteristics), as opposed to most of the studies which focus either on the Po River sub-watershed, as the biggest contributing watershed to the NA or several bigger contributing rivers to the NA. We believe that such quantification of nutrients loads for all sub-watersheds is very important, as smaller sub-watersheds may have significant impact. It also enables better management of the NA water quality at local scale. For this task we use the Geographic Information System (GIS) based nutrient loading model, AVGWLF (Evans et al., 2002) to simulate the nutrient loadings in the given period from diffuse non-point (different land uses) and point sources (wastewater treatment plants and urban drainage systems). Compared to other watershed-oriented water quality models such as SWAT, SWMM, MONERIS and HSPF; AVGWLF model is relatively easy to use due to its 'modest' requirements on data input and at the same time complex enough for our research goals. The model is capable of simulating most of the key mechanisms controlling nutrient fluxes within a watershed.

The model was used to estimate: (1) the quantities of nutrients released from each sub-watershed and thus providing an estimate of the importance of all watersheds compared to the biggest nutrient contributor, e.g. the Po River watershed, (2) quantities of major sources of nitrogen and phosphorus in the NA watershed and each sub-watershed regarding the type of anthropogenic activity, enabling their control in watershed management.

The paper is organized as follows: Section 1 states the objectives of this research and provides some background and relation to previous research. Section 2 describes the AVGWLF application used in modeling exercise. Section 3 describes case study area and datasets used for the modeling tasks. Model setup and calibration is described in Section 4. Section 5 gives the results of the model and their discussion and finally Section 6 contains the conclusions of this paper.

2. AVGWLF simulation model

Data manipulation between the GIS software package (ArcView) and the Generalized Watershed Loading Function model (GWLF; Haith and Shoemaker, 1987) and subsequent simulation modeling in this study is managed via the interface AVGWLF (Evans et al., 2002).

The core watershed simulation model for AVGWLF GIS based application is the GWLF model. GWLF is a lumped, non-point source nutrient loading model in which the loading functions provide a practical compromise between simple empirical export coefficients that predict annual losses of nutrients from river watersheds at various points throughout a drainage system (The annual load delivered to a water body is calculated as the sum of the individual loads exported from each nutrient source within a watershed.) and complex chemical simulation models that require unrealistically large amounts of detailed data for most practical applications at the catchment scale. GWLF was originally developed by Haith and Tubbs (1981) and validated by Haith and Shoemaker (1987) to simulate sediment, dissolved and total phosphorus and nitrogen loads from a watershed given different size and land use areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge like wastewater treatment plants (WWTP). It is a continuous simulation model which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values.

GWLF calculates dissolved liquid and solid phase nitrogen and phosphorous in stream flow using equations *1* and *2*. Dissolved nutrient load is transported in runoff and eroded soil from various source areas, each of which is considered uniform with respect to soil and land cover.

$$\mathrm{LD}_n = \mathrm{DP}_n + \mathrm{DR}_n + \mathrm{DG}_n + \mathrm{DS}_n \quad (1)$$

$$\mathrm{LS}_n = \mathrm{SP}_n + \mathrm{SR}_n + \mathrm{SU}_n \quad (2)$$

where LD_n and LS_n are the dissolved and solid phase nutrient load respectively (kg), DP_n and SP_n are the point source dissolved and solid phase nutrient load respectively (kg), DR_n and SR_n are the rural runoff dissolved and solid phase nutrient load respectively (kg), DG_n is the ground water dissolved nutrient load (kg), DS_n is the septic system dissolved nutrient load (kg), SU_n is the urban runoff nutrient load (kg).

For execution, the AVGWLF model requires three separate input files containing the transport, nutrient, and weather-related data. The transport file defines the necessary parameters for each source area to be considered (e.g., area size, curve number, etc.) as well as global parameters (e.g., initial storage, sediment delivery ratio, etc.). The nutrient file specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, urban source area accumulation rates, manure concentrations, etc.). The weather file contains daily average temperature and total precipitation values for each simulated year. Additionally we use the retention file for nutrient retention in the basin. The retention file allows users to account for the pollutant, attenuating effect of lakes, ponds and wetlands within the watershed being simulated (Evans et al., 2002).

3. Case study and dataset description

3.1. Study area description

The NA watershed (Fig. 1) measures approximately 110,600 km^2 and is spread over four neighboring countries, Italy, Slovenia, Croatia and Switzerland. These surrounding countries are characterized by different anthropogenic pressures and levels of urbanization, ranging from the strongly inhabited Po River watershed in Italy to the Croatian and Slovenian natural areas. Part of the Po River watershed which belongs to the Switzerland was not modeled due to lack of data. The NA watershed is consisted of the following sub-watersheds: Po River, Adige, Piave, Livenza, Tagliamento, Isonzo, Dragonja, Mirna, Brenta-Bacchiglione, tributary of lagune Marano-Grado, south-western Istrian tributary and other smaller watersheds.

Some details about the major sub-watersheds (rivers) of the NA watershed can be found in Table 1.

The biggest watershed represent the Po River one and embraces an area of approximately 71,000 km^2 (64% of the whole NA watershed). Population in watershed is approximately 16,000,000 inhabitants. The river is 652 km long. The average annual rainfall in the area is about 980 mm/yr, with minimal values of 700 to 900 mm/yr, and maximal of 1400 to 1600 mm/yr. The average