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MATHEMATICAL MODELING OF WATER QUALITY CHANGE IN EASTERN EUROPEAN RIVER

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Abstract: The professional assessment of often performed stream water quality change (most likely the result of pollution sources) is derived from the so-called "screening modeling" results. This paper aims to show some stream water quality screening-modelling technique in order to point out related problems and to suggest their solution. The main goal is to achieve relevant and sufficiently accurate results and to present them representatively at the limited time, data, and money conditions.

Keywords: water, pollution, stream water quality mathematical model, hydroecology.

1. Introduction

Water quality reflects the state of the environment and the quality of farming. The surface water ponds and their pools are mostly influenced by human activities (Tumas, 1997). Agriculture has the greatest impact on water quality. As the result, most of the rivers are polluted with nitrogen materials leaching from the farmland. Mineral and organic resource growth in water bodies cause their eutrophication. Biogenic materials (nitrogen and phosphorus) promote algae (phytoplankton) growth. Flushed plants consume more oxygen and its shortage appear. Ammonia and hydrogen sulphide are produced in bottom sediments of anaerobic environment during the decomposition of organic matter. The change in water clarity, color, odor and other physical, chemical and biological indicators can be seen.

Although during the recent years the environment is less polluted in East Europe, the fertilizers due to the high cost are used moderately, the negative effect of the fertilizers and their consequences will be felt for a long time (Paulukevicius, 2001).

The investigated river Liedas belongs to Susve basin (Lithuania) and it is in the area of intensive farming. The Liedas is assigned to a low aqueous rivers dominating in the plain region and are the tributaries of the larger rivers (ME R.L., 2002). Moreover, the river water quality has not been observed so far. Therefore, the comprehensive research will help to regulate the river water pollution, to propose measures to reduce the pollution or to avoid it.

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Used in the paper model was performed by the computer by a special software QUAL2E for equations solution, and developed by the U.S. Environmental Protection Agency (U.S. EPA, 2014). Some modeling results were given there. The model will help to explore various water pollution scenarios and solve water quality planning and forecasting tasks.

2. Mathematical Model

The mathematical model of the stream water quality (Sileika, 1996) is based on the solution of the mass balance equation expressed for particular pollution parameter along the selected stream. The effect of reservoir on pollution was expressed by regression equations obtained from the simplified evaluation of the long-term monitoring at upstream and downstream of the reservoirs.

The following assumptions after derivation of the general stream mass-balance equation were made:

- the flow and pollution transport is one dimensional (in the direction of the stream longitudinal axis);
- the suspended solids do not affect water-pollution mixture density, water is incompressible;
- the concentration of the solid through the river cross section is constant, the suspension is well mixed.

The basic equation is the following:

$$\frac{\partial(A \cdot c)}{\partial t} = \frac{\partial(A \cdot v \cdot c)}{\partial x} + \frac{\partial(A \cdot D_L \frac{\partial c}{\partial x})}{\partial x} + S + A \cdot R, \tag{1}$$

where $A(x,t)$ is supervised cross-sectional area, $c(x.t)$ is the concentration of the observed pollution, c_0 is the pollution concentration at headwater node of the river, c_L is given concentration at downstream node of the river, $v(x.t)$ is mean stream velocity, $D(x.t)$ is coefficient of longitudinal hydrodynamic dispersion, L is the distance between the downstream and headwater node, $S(x.t)$ are external pollution sources, $R(x.t)$ is the constituent of changes (growth, decay), x is the coordinate measured along the stream axis, t is time.

2.1 Initial and boundary conditions

Initial condition expresses the state of the pollution at the initial time ($t_0 = 0$) at the headwater of the river.

$c(x, 0) = c_0(x)$ at the time $t = t_0 = 0$. (2)

Boundary conditions

Two types of boundary conditions are applied:

1. known concentration at boundary nodes of the river network:

$c(0, t) = c_0(t)$ at input node ($x = 0$); (3)

$c(L, t) = c_L(t)$ at end node ($x = L$);

2. at the end node of the river system ($x = L$) the zero concentration gradient can be applied:

$$\frac{dc(L,t)}{dx} = 0 . \quad (4)$$

The following additional simplifications were assumed:

- the flow and pollution conditions are steady, the average discharge, pollution sources, concentrations, mass flow and other variables are assumed;
- the dispersion coefficient can be neglected at the steady state conditions (Riha *et al.*, 1997);
- the Streeter-Phelps first order kinetics decay formula $R = -k \cdot c$ is used, where k is rate constant (Brown and Barnwell, 1987).

Than the equation (1) can be reduced into

$$\frac{d(A \cdot v \cdot c)}{dx} - S + A \cdot k \cdot c = 0 \quad (5)$$

with boundary condition $c(0, t) = c_0(t)$ at the input node ($x = 0$); the concentration at the node $x = L$ is calculated by further described method.

2.2 The numerical method

The numerical solution was carried out using the simple numerical scheme based on the finite difference method. Assuming mass flow L_j, L_k in nodes j, k, are expressed as $L = A \cdot k \cdot c$ and the sum of pollution sources along the river reach is $L_S = S \cdot \Delta x$, the equation (5) can be written in the following form:

$$L_k - L_j - L_S + A \cdot k \cdot c \cdot \Delta x = 0 . \quad (6)$$

Water mass decay is expressed in (6) as

$$A \cdot k \cdot c \cdot \Delta x = k \cdot t \cdot L_j . \quad (7)$$

The final expression for mass flow in the river node (cross section) k is the following:

$$L_k = L_j + L_S - L_j \cdot k \cdot t = 0 . \quad (8)$$

3. Modeling Results

The Liedas river water quality results obtained at the laboratory are presented in Table 1.

Table l: River water quality parameters

Analyte name	Test Results	Measurement unit
pH	8.2	
Oxygen saturation	118	%
Permanganate oxidation	8.4	mg O_2 / l
BOD_7	2.9	mg O_2 / l
Nitrates	4.1	mg N / l
Phosphates	0.06	mg P / l
Total phosphorus	0.14	mg P / l

The key characteristics of hydrochemical parameters, describing the state of the river (concentration of nutrients) were simulated applicating the software QUAL2E. Total phosphorus (Fig.1) and nitrate nitrogen (Fig. 2) concentration change in the investigated river is very similar: concentration of the mentioned materials increases moving from the upper to the lower reaches of the river. This is because the contaminants move through cultivated fields that are currently less fertilized. Earlier there has been an intensive development of agriculture and the accumulation of unused nutrient content may have access into the Liedas river, increasing its contamination.

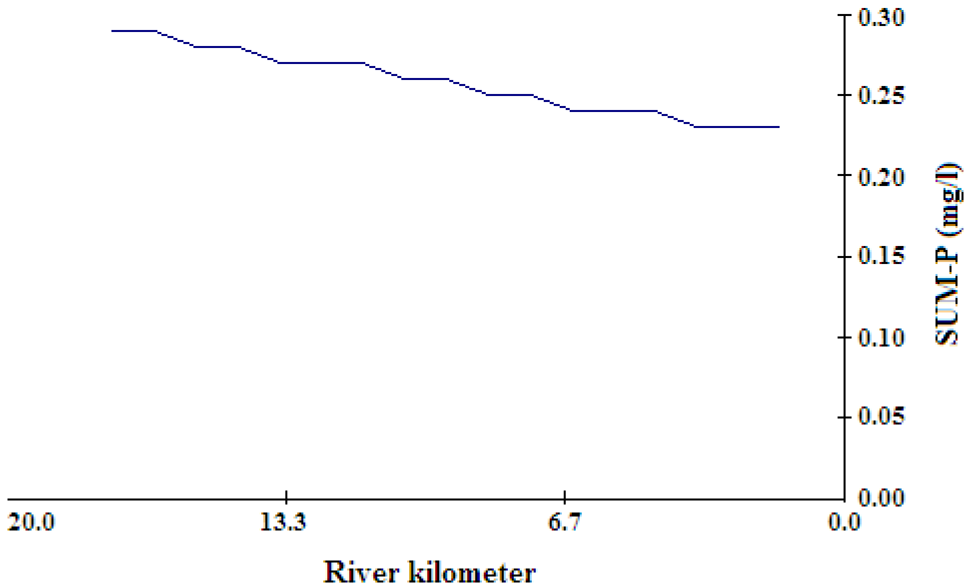

Figure 1: Change of total phosphorus concentration in the river

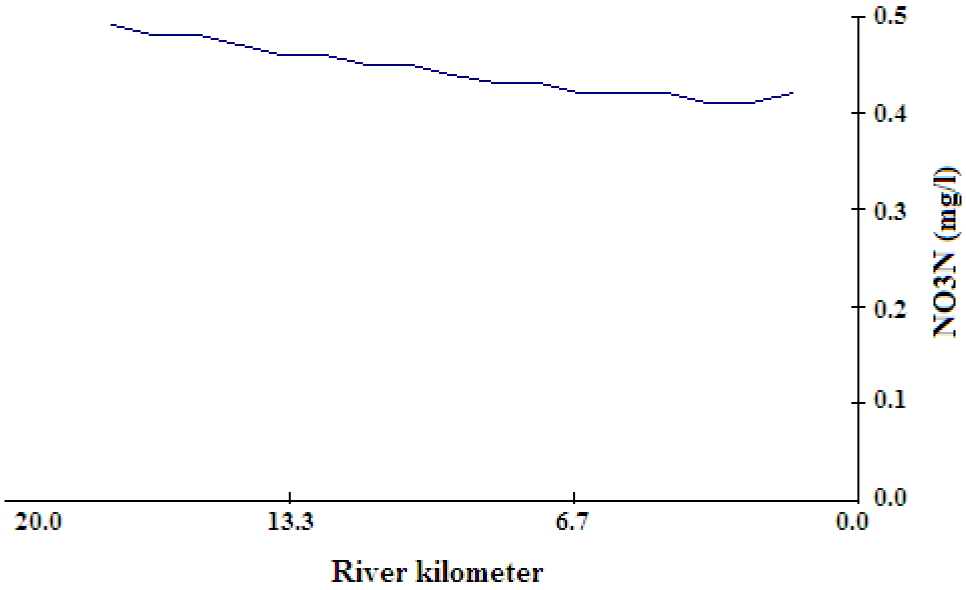

Figure 2: Change of nitrate concentrations in the river

4. Conclusions and Recommendations

1. The East European River (Liedas, Lithuania) according to the obtained results can be assigned to water quality class II (clean water), but some of the parameters are close to the water quality class III (slightly polluted water).
2. It was found that direct fertilization effect on river pollution is expressed as there are many cultivated fields at the river baseline.
3. According to the results it is recommended to limit the use of fertilizers and to determine their rates at cultivated fields are located within the basin.
4. It was found that the the recent changes in agriculture can be the major reason for the increase of the river pollution. A number of nutrients has accumulated before the land reform in abundantly fertilized lands. In this way the excess of not consumed nutrients could fall into the river and increase its pollution.
5. Nitrogen and phosphorous inflow to the water can be reduced by the transformation of agricultural land: enhancing the natural area of agricultural land in the river basin, replacing the existing natural land territorial formation and transformation of agricultural land so that their economic use intensity will decrease toward the beds.
6. The plants which could cover the surface of the earth for a longer time must be grown in order to reduce nitrogen pollution from agricultural fields. Winter crops and grass the best suit for this.

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