A Model for the Mesta River Pollution Assessment Based on the Integral Indices

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A new conceptual model for integrated river pollution assessment is proposed. The pollution dynamics at the end of Bulgarian section of the Mesta River is investigated for estimation of the anthropogenic impact. A model for the dynamics of the integral index for the level of the stream water trophic pollution is proposed. The integral index is based on the oxygen balance, organic and nutrients loading, suspended and dissolved substances. This index was applied for assessment of the level of the trophic pollution of the Mesta River in point Hadjidimovo at the end of Bulgarian section. A modified method of time series analysis is applied.

Key words:
Assessment, integral index, model, pollution level

Introduction

The European Directive on Water (EU Framework directive 2000) prescribes the *good quality* as a goal for all water bodies within a given catchments instead. *Good status* could be defined as a good environmental status on the base of biological, physicochemical, and hydro-morphological characteristics. To achieve this *good status* each EU country should develop an optimal management strategy. Within the context of this directive, the countries from European Union conduct researches aimed at a more precise integral assessment based on *biological*, *physicochemical*, *ecotoxicological* and *hydro-morphological* characteristics of the river courses.[11]

The idea laid down in the proposed EU Directive is to set up monitoring and basic classification systems for assessing the water ecosystems' ecological status. The common component of most procedures is to have undisturbed ecosystems as a basis for measurements and assessments.

In a number of EU-countries the assessment of water pollution is based on integral indices. Indices like the Basic Prati Index (BPI), Prati Index (PI) Quality Index (QI), and Organic Pollution Index (IPO), are commonly know.[16,20]

A conception for integrated ecological assessment of the River ecosystems was elaborated by.[12,13,17,21]

An integral approach for ecological assessment of the state of River waters is used by.[14,15,18,19]

The main objectives of the present work are:

– Integral trophic pollution assessment of the Mesta River at the end of Bulgarian section;

– Development model for the dynamics of the integral index for the level of the stream water trophic pollution.

The catchment area of the Mesta River in Bulgarian section are show in Figure 1.

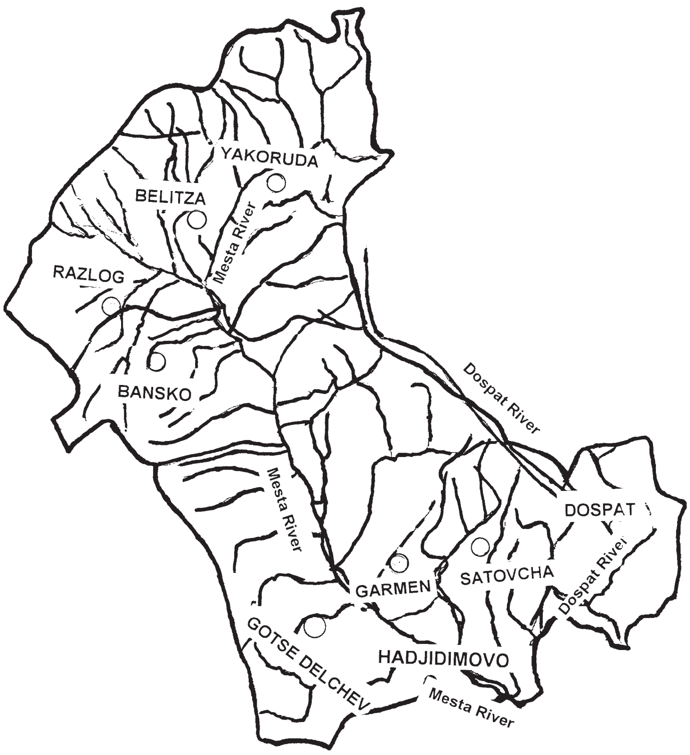

Fig. 1 – *The catchment area of the Mesta River in Bulgarian section*

Materials and methods

Modeling by a modified method of time series analysis

According to this method the temporary order is examined as a sum of the determined component trend y_T, which describes regularity in developing of a examined phenomena; the periodical component y_P and the accidental component e_t:[1]

$$y = y_T + y_P + \varepsilon_t \quad (1)$$

The determined component y_T is a polynomial up to third degree and the periodical component y_P is described by order of Fourier. The accidental component is ignored, i.e. $\varepsilon_t = 0$. Simulative investigations have shown that the model gives adequate results, without component ε_t, because of that it has not been taken into account.

Before one applies this method, it is necessary to make a check for presence of trend, and to develop a methodology for statistical analysis which enables to check the adequacy of the model.

Check-up for presence of trend

This problem is approached as follows:

1. The experimental data and the time are standardized between 0–1 with the formula: $y_i = (x_i - x_{min)/(}x_{max} - x_{min})$, where x_i, x_{min} and x_{max} are as follows actual, minimal and maximal values;

2. The arithmetic average of the experimental data is calculated by the formula:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i;$$

3. The check for presence of the trend is calculated by the formula:[9]

$$4.\ T' = \frac{n}{(n-1)} \frac{\sum_{i=1}^{n-1}(y_{i+1} - y_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} > T[\alpha, Z(x)] = = 2.0 - \frac{2.0 - \alpha Z(x)}{\sqrt{n}} \quad (2)$$

5. The value of $Z(x)$ for definite x and α is initiated;

6. The check is made: IF $T' > T$, that we have presence of trend.

Model validation

Model validation was tested based on the following statistical criteria: R^2_E, F_E, WR*MSE*^{2} and S_L:[10]

$$R_E^2 = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(y_i^m - \bar{y}_m)}{\sqrt{\left[\sum_{i=1}^{n}(y_i - \bar{y})^2\right]\left[\sum_{i=1}^{N}(y_i^m - \bar{y}_m)^2\right]}}$$

$$F_E = S_e^2 / S_0^2 \quad (3)$$

$$\text{WRMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} V_i (y_i - y_i^m)^2}, \quad (4)$$

where:

$$\bar{y}_m = \frac{1}{n}\sum_{i=1}^{n} y_i^m, \quad S_e^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2,$$

$$S_0^2 = \frac{1}{n-k}\sum_{i=1}^{n}(y_i - y_i^m)^2.$$

The relative error is determined as:[10]

$$S_L = \sqrt{\frac{1}{(n-v)}\sum_{i=1}^{n}(1 - y_i^m / y_i)^2} \quad (5)$$

The lower the values of the indexes (4) and (5), the higher is the validity of the model for the investigated indexes.

The main trend is defined

$$y_M^T(t) = A_0 + A_1 t \quad (6)$$

The determined component is defined

In contrast of the classical approach in most papers, it is suggested to use a polynomial of the fifth degree for the determined component:

$$y_T = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \quad (7)$$

A Periodical component

In contrast to the classical method for analyzing temporary series, where the Fourier series are used, the present research proposes the uses of the periodical functions *sin* or *cos*, where their determination is carried out on the basis of statistical criteria. The *sin*, *sin*^{2}, *cos* and *cos*^{2} functions have been tested. The best results were shown by the function (comparison R^2_E and F_E):[7]

$$y_P = \sum_{k=1}^{m} b_k \sin^2\left(\frac{2\pi}{c_k} t + d_k\right) \quad (8)$$

Then the model (1) for analysis has the following form when $\varepsilon_t = 0$:

$$y = \sum_{j=0}^{5} a_j t^j + \sum_{k=1}^{m} b_k \sin^2\left(\frac{2\pi}{c_k} t + d_k\right) \quad (9)$$

A regression analysis

It is supposed, that the models describing adequately the dynamics of the integral index for the level of stream water pollution I_T, depending on stream water quantity, is:

$$I_t = p_0 + p_1 \log(Q) + p_2 \log(Q)^2 + p_3 \log(Q)^3 \quad (10)$$

Algorithm for identification of parameter in models

The coefficients in the models (6)-(10) are defined by the following algorithm:

1. Beginning
2. The main trend (6), determined component (7) and regression analysis (10) are determined by the software programs ORIGIN 6.0;
3. The models (9) are determined by the programs for SIMPLEX method for optimization. The optimization program for direct search of the minimum of the criteria. The minimization criteria used in the program is:[8]

$$\mathrm{SSWR} = \sum_{i=1}^{n} \frac{\Delta^2}{W_i^2} \rightarrow \min,$$

where:

$$\Delta_i = (y_i^m - y_i), \quad W_i = \max(y_i, y_i^m).$$

4. Make check for adequacy of the models. For this aim the correlation coefficient-R^2_E, the experimental value of Fisher's function-F_E, from (3), the statistical index *WRMSE* from (4), and the relative error S_L (5), are calculated;
5. Comparison with the theoretical correlation coefficient R^2_T and Fisher's function F_T is made. IF $R^2_E > R^2_T$ and $F_E < F_T$, then the model is adequate. Other criterions serve for information and show the diversion from the experimental data. The model predictions are more reliable if their values are near to 0.
6. End

The pollution dynamics of the Mesta River in Bulgaria is carried out on the base on the data obtained by the National System for Ecological Monitoring for the period 1986–2001.

We examined the water quality in point Hadjidimovo at end of Bulgarian section of the Mesta River; the following indices of the trophic water pollution are determined: γ_{O_2}, γ_{BOD}, γ_{COD}, $\gamma_{KM_3O_4}$-oxidation, $\gamma_{N\text{-}NH_4}$, $\gamma_{N\text{-}NO_3}$, γ_{PO_4}, suspended and dissolved substance. In the present work pollution level of the River is appointed after standard values.

By integral assessment of water pollution, the conception of ecological integrity from Water Framework Directive should be taken into account.

The main directions and requirements of the ecological integrity are shown on Figure 2.

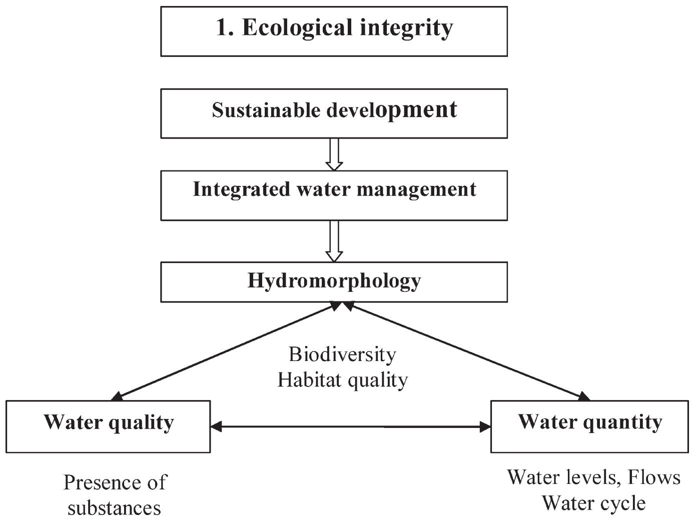

Fig. 2 – *Scheme of the Ecological integrity*

Results and discussion

A system of integral ecological indices has been worked out to assess the degree of pollution of running waters (I_p), sediments (I_s), and rivers (I_r)[3–6].

The system for integrated indices for the level of river pollution is based on ecological integrity of river flow. Ecological integrity can only be achieved if physical, chemical, and biological integrity simultaneously occur.

The integral index for the level of trophic pollution is based on the indices γ_{SS}, γ_{BOD}, γ_{COD}, γ_{TOC}, $\gamma_{N_{tot}}$, $\gamma_{P_{tot}}$, γ_{NO_3}, γ_{NO_2}, γ_{PO_4}, γ_{O_2}. To assess the level of trophic pollution for a certain period of time, it is necessary to determine the ratios between the actually measured values of the individual variables and standard values for a particular water body, or

$$L_i = \frac{C_i}{C_{i,0}}, \quad L_{i,\max} = \frac{C_{i,\max}}{C_{i,0}}. \quad (11)$$

The integral index for the level of trophic pollution for a certain period of time should be determined as the arithmetic mean of all measured values of individual parameters, or

$$I_{\mathrm{t}} = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m}\frac{C_{i,j}}{C_{i,0}}. \tag{12}$$

The index indicating the level of pollution with hazardous substances is based on the indices for metals, organic compounds like aromatic hydrocarbons, phenols, phthalates, chlorine containing compounds, and detergents.

The integral index for the level of pollution with hazardous substances for a certain period of time shall be determined as an arithmetic mean of the ratios $S_i/S_{i,0}$ as follows:

$$I_{\mathrm{n}} = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m}\frac{S_{i,j}}{S_{i,0}}. \tag{13}$$

The integral parameter showing the degree of microbiological pollution is based on the parameters overall coli-titre, overall number of microorganisms, and possibly other parameters that are being monitored. The integral index for the assessment of the microbiological pollution for a certain period of time shall be determined as the arithmetic mean of the ratios $K_{\mathrm{i,j}}/K_{\mathrm{i,0}}$ as follows:

$$I_{\mathrm{b}} = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m}\frac{K_{i,j}}{K_{i,0}}. \tag{14}$$

The integral index for the degree of pollution of running waters I_{p} is determined as a geometric mean of the values of the index for the level of trophic pollution I_{t}, the index for the pollution with hazardous substances I_{n}, and finally the index indicating the level of microbiological pollution I_p, as follows:

$$I_{\mathrm{p}} = \sqrt[3]{I_{\mathrm{t}} I_{\mathrm{n}} I_{\mathrm{b}}} \tag{15}$$

The integral index for assessment of the pollution of rivers is based on the integral index of water pollution (I_{p}), the integral index of sediments pollution (I_{s}) and integral biological index (I_{m}) or $I_{\mathrm{r}}=f(I_{\mathrm{p}}, I_{\mathrm{s}}, I_{\mathrm{m}})$.

The used method is appropriate for integral assessment of the pollution of transboundary rivers, because it gives a possibility to assess the contribution of each country in the basin.

The integral index for the level of water trophic pollution is used for assessment of Mesta River in point at Hadjidimovo. This index was applied for the anthropogenic impact assessment on catchment area of the Mesta River in Bulgarian section. The obtained results are discussed in this paper.

In this paper the dynamics of the integral indices I_{n} and I_{b} are not discussed. The dynamic of these integral indexes will be an object in following development of the collective.

A model for the dynamics of the integral trophic pollution index for the Mesta River in point Hadjidimovo is developed (equation 6, 7 and 9). Figure 3 shows the results of models in the Hadjidimovo point for period 1986–2001.

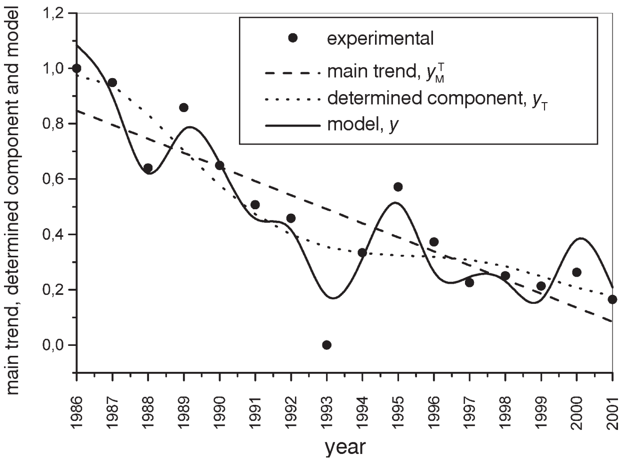

Fig. 3 – *Dynamics of the integrated index for the level of trophic pollution of the Mesta River in the point at Hadjidimovo*

A model for the dynamics of the average annual values of the integral trophic pollution index, depending on average annual values of river water quality, is developed (equation 10). Figure 4 shows the results of models in the Hadjidimovo point.

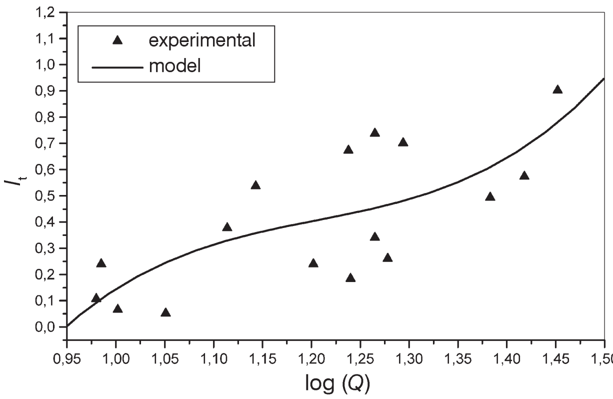

Fig. 4 – *Dynamics of the annual average values of the integrated index for the level of trophic pollution depending on the annual average values of the River water quantity*

The values of the integral index for the level of trophic pollution I_{t} are between *0.541* and *1.203*. For the studied period, most of the researches take values of the integral trophic pollution index lower than 1, which shows that the standard values of the water quality are not exceeded. A trend of decrease in the river water pollution is observed. Only five values exceed 1 and they are between *1.057* and *1.203*. By investigating the integral trophic pollution index (equation 12) it is noted that the pollution in Hadjidimovo point, in the greater part of the research, is less than the standard value of $I_t = 1$.

Equation (10) describes the relation between the average annual values of the integral pollution index I_t and the average annual values of water quantity Q in point Hadjidimovo. It provides a possibility for an integral assessment of the level of trophic pollution depending on the river water quantity for a definite period of time.

The check for the adequacy and the coefficient of the models are shown in Table 1. Theoretical correlation coefficient and Fisher function are $R^2_T(14) = 0.497$ and $F_T(15,15) = 2.56$ for $\alpha = 0.05$.

The models (6), (7) and (9) their adequacy (Table 1) were proved by the values of the experimental coefficients of correlation $R^2_E = 0.825 > R^2_T$, $R^2_E = 0.8877 > R^2_T$ and $R^2_E = 0.96617 > R^2_T$. The experimental Fisher function $F_E = 1.4693 < F_T$, $F_E = 1.2689 < F_T$ and $F_E = 1.1247 < F_T$.

The model (10) adequacy (Table 1) was proved by the values of the theoretical coefficients of correlation $R^2_T(8) = 0.632 < R^2_E = 0.7375$, the theoretical Fisher function $F_T(9,9) = 3.23 > F_E = 1.8386$, and the relative error.

The elaborated method for integral assessment of trophic pollution and for quantitative estimation of the relation between the integral trophic pollution index and the river water quantity has a wide application on carrying out variable monitoring programs and integrated water management. Therefore, the new methods and models are needed for the management of water quality.

Conclusions

1. The organic and the biogenic pollution of the Mesta River in the Bulgarian section does not result in any negative trends to aggravating the river water quality. The water trophic pollution is according to the Bulgarian standards.

2. The model of integral index for the level of trophic water pollution is an instrument of the river water quality management.

3. The integral assessment allows a complex view on the physico-chemical, biological, and hydro-morphological parameters for the state of the river.

4. The proposed model provides a possibility to determine the trend in the dynamics of the integral trophic pollution index for certain period of time. This trend gives an opportunity for assessment of the strategy efficiency for water management.

5. The developed method can be used for integral pollution assessment in specific points of the river flow. The method provides a possibility to use the results from National Monitoring Network in a typical measuring station.

6. Relation between the average annual value of the integral trophic pollution index and the average annual value of water quantity in point Hadjidimovo is obtained.

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Table 1 – *Statistical information and values of the coefficients in models*

Models and coefficients	R^2	F_E	S_L	WRMSE
main trend (eq.6), y_M^T				
$A_0 = 0.847354$, $A_1 = -0.76302925$	0.8250	1.4693	0.4710	0.5472
determined component (eq.7), y_T				
$a_0 = 0.974620$, $a_1 = 0.26422000$, $a_2 = -14.47903$, $a_3 = 39.27293$, $a_4 = -39.91726$, $a_5 = 14.06123$	0.8877	1.2689	0.3597	0.4457
periodical component (eq.8), y_P				
$b_1 = -0.2238015$, $c_1 = 0.6551324$, $d_1 = 0.443651$, $b_2 = 0.2013130$, $c_2 = 0.3697104$, $d_2 = 1.043941$	0.3232	6.9205	14.2984	1.8409
model (eq.9), y	0.9661	1.1247	0.3140	0.2512
regression model (eq.10), I_t				
$p_0 = -22.89894$, $p_1 = 56.51802$, $p_2 = -46.26435$, $p_3 = 12.79$.	0.7375	1.8386	0.5470	0.6539

Nomenclature

γ_{BOD} – biochemical oxygen demand, mg dm^{-3}
C_i – actually measured value
$C_{i,0}$ – standard values for individual parameters
$C_{i,j}$ – the value of the parameter in j^{th} analysis
$C_{i,max}$ – maximum value of an individual index for a certain period
$C_{i,s}$ – value of the parameter C_i in j-th analysis
γ_{COD} – chemical oxygen demand, mg dm^{-3}
I_b – index of the degree of microbial pollution
in – number of indices
I_p – index of the degree of pollution of running waters
I_r – index of the degree of pollution of rivers
I_s – index of the degree of pollution of sediments
I_t – integral index for trophic water pollution
k – degree of freedom of model
K_i – value of the parameter K_i in the j^{th} analysis, mg dm^{-3}
$K_{i,0}$ – standard values for individual parameters, mg dm^{-3}
$K_{i,j,}$ – value of the parameter K_i in the j^{th} analysis, mg dm^{-3}
m – number of indices
n – number of determination for indicated parameters
N – number of studies carried out for the indicated parameters
γ_{NO_2} – nitrites – nitrogen mass concentration, mg dm^{-3}
γ_{NO_3} – nitrate – nitrogen mass concentration, mg dm^{-3}
$\gamma_{N_{tot}}$ – nitrogen total mass concentration, mg dm^{-3}
γ_{O_2} – oxygen mass concentration, mg dm^{-3}
γ_{PO_4} – phosphate mass concentration, mg dm^{-3}
$\gamma_{P_{tot}}$ – phosphate total mass concentration, mg dm^{-3}
Q – average annual stream water quantity, m^3 s^{-1}
$S_{i,0}$ – standard values for every individual parameter, mg dm^{-3}
$S_{i,j}$ – value of the parameters S_i in j^{th} analysis, mg dm^{-3}
S_L – relative error, –
γ_{SS} – suspended solid., mg dm^{-3}
t – dimensionless time, –
γ_{TOC} – total organic carbon, mg dm^{-3}
V – factor of diversion, respective of the dispersion of the experimental, –
W_i – the mass of the variable, –
WRMSE – the statistical index accepted by the European Union, –
x – experimental data points, mg dm^{-3}
y – dimensionless experimental data points, –
$\bar{y}$ – arithmetic average of the experimental data
$\bar{y}_m$ – arithmetic average of the model data
$Z(x)$ – value of the Gauss's distribution, –
α – level of confidence
ε_t – accidental component
ν – degree of freedom

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