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ATV-DVWK MODELLING FOR ANALYSIS OF ZEIMENA AND NEVEZIS RIVERS WATER QUALITY

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Abstract. Modelling is one of the tools that contribute to analysing the fluctuation of rivers water quality. Knowledge on the quality of water bodies is very important for the implementation of the European Union Water Framework Directive's requirements.
There was employed ATV-DVWk model simulating the fluctuation of nitrates and ammonium ions in rivers Zeimena and Nevėzis. There were introduced more than 50 parameters characterizing the physical-geographical, climatic conditions, anthropogenic activities as well as morphometric conditions of the watercourses analyzing the stretches of the investigated rivers. Summarizing the modelling results obtained, it could be stated that ATV-DVWk model is suitable for Lithuanian conditions. Maximum divergence among the values of biogenic substances concentrations obtained using a modelling simulation method and direct measurements have not exceeded 38 %.

Keywords: mathematical modelling, water quality, nitrates, ammonium ions, runoff

1. Introduction

Biogenic and organic pollution of water bodies are among the most important problems determining rivers water quality in Lithuania. Rivers that carry nutritional materials to the Curonian Lagoon and the Baltic Sea increase their eutrophication. Baltic countries signed the HELCOM Convention in 1992, thus made an agreement to reduce runoff of nitrogen by 50% (till the level of year 1987) [1]. First of all, in order to implement the latter agreement, it is necessary to evaluate the current situation.

Nitrogen and phosphorus compounds are the main biogenic substances enabling the eutrophication process. The following main sources of water pollution with biogenic substances in rivers are: diffused (non-point source) agricultural pollution and point source pollution.

There are line various complex interdependent factors determining the water quality of rivers. Thus, for the effective management of the water resources it is necessary to assess all factors and processes that may influence the quality of water bodies. There are employed different mathematical models, which are characterized by their distinguished structures and described particularities of modelling processes analyzing water quality problems. Depending on the description of "impact–response" relations, mathematical models are divided into: full-scale comprehensive; based on the physical processes; and simplified (conceptual and empiric) models. Mathematical models based on physical processes are described employing differential equations deducted given the fundamental physical laws. Conceptual models are based on a simplified interpretation of the physical processes [2].

Mathematical models of surface waters are often used for the analysis of data, for verification of scientific hypothesis, understanding of environmental processes and their interaction, for evaluation of management scenarios [3].

Mathematical modelling is defined as description of processes occurring in the natural environment (for example, river). Model is a sort of a „digital" laboratory, which enables to investigate and analyse natural processes, examining various pollution scenarios; because it is impossible to make an experiment with natural systems, equally it is impossible to analyse and foresee various situations capable to emerge around whatever water body.

There have been developed different models around the world until now: leaching of nutrients, soil erosion, management of agricultural pollution, etc.

Various mathematical models have been applied in most of the European countries: in Belgium– SENTWA (System for the Evaluation of Nutrient Transport to Water), SIMCAT (Semantic Similarity Measurement for Role-Governed Geospatial Categories), in Norway – QUAL2E (River and Stream Water Quality Model), EPD-RIV1 (One Dimensional Riverine Hydrodynamic and Water Quality Model), WASP (Water Quality Analysis Simulation Program) and many others. There have been developed separate software program packages applicable to the physical-geographical conditions of Germany, Austria, Switzerland. NONERIS, N-Balanz, ATV-DVWK-Water Quality models are among the best well-known and generally applied [5, 6, 7]. Those models are used to simulate scenarios of biogenic substances fluctuations in their concentrations and quantities, given different non-point sources and point-sources pollution.

Lithuanian scientists have already adapted models for analyzation of different natural processes. A. Povilaitis, J. Ruseckas, R. Tumas [8, 9, 10, 11] employed CREAMS (A Field Model for Chemicals, Runoff and Erosion from Agricultural Management Systems), EPIC (The European Prospective Investigation into Cancer and Nutrition), WEPP (Water Erosion Prediction Project), SWRRBWQ (Simulator for Water Resources in Rural Basins Water Quality) models, that were designed for estimation of diffused non-point source agricultural pollution, thus enabling to forecast consistent patterns of aggregate (total) outflow, soil errosion and biogenic substances (N and P) outwash and leaching in various agricultural catchments. A. Šileika, H. Pauliukevičius used AGNPS (Agricultural Non-Point Source) model, which has become well-known all over the world. The latter model forecasts the soil errosion and nutrients outwash from the agricultural catchments during the realistic or hypothetical floodings [12, 13].

Due to the low accuracy rate other models are not suitable for Lithuanian conditions. Multiple observations should be carried out and numerous data must be gathered for verification and adaptation of those models to local conditions. Some particular data is lacking quite often, thus averaged mean parameters of the investigated river basin are employed for modelling. That also reduces accuracy and application possibilities of a model employed.

The purpose of current research is to evaluate possibilities employing the mathematical model ATV-DVWK to analyze the water quality.

2. Research subject and methodology

Selection of the most suitable model depends on the research subject and available data. Having compared quite diversified models, the most optimal for current research is considered such a model, using which the optimal balance of biases, originating due to the modelling preconditions (fundamental biases) and data biases (operational biases) are maintained. The latter indicated balance depends on the amount of data, because the higher amount of particular data is available, the more accurate detailed information of the model is chosen.

Firstly developed in Germany ATV-DVWk software program package was employed for modelling. There were selected 2 rivers for investigations: Nevėžis and Žeimena (Fig. 1). There are more than 2 water quality measurement posts located on those rivers.

Fig. 2 Water basins of investigated rivers

Nevėžis river basin is situated in the midlands of Lithuania. Heavy impermeable fractions of water soils predominate there. Lakes occupy just 0, 09 %, whereas forests – approximately 17 % total area of a river basin. The largest part of a river basin (45 %) is composed of agricultural property lands. Nevėžis river basin is anthropogenic. Substantial amounts of organic and especially non-organic biogenic substances have been registered in the water of river Nevėžis below the biggest cities. There are 35 enterprises situated in Nevėžis river basin, each of those submit data to the Ministry of Environment on the quality and quantity of waste water effluents.

Modelling has been employed for investigation of Nevėžis river basin stretch, situated 150 to 52 km from river mouth, i.e. beginning of a stretch above of city Panevėžys, and ending – below city Kėdainiai. There are quite a lot of tributaries in that stretch, but only the biggest of them were selected for modelling: Juosta, Kiršinas, Upytė, Linkava, Liaudė, Kruostas, Dotnuvėlė, Obelis. Žeimena is a river stretching in Eastern part of Lithuania. Forested areas compose 31% of the total river basin area. The predominating soils are characterized by their light mechanical composition (approximately 76% of the river basin area).

Total 22 enterprises registered in Žeimena river basin submit data to the Ministry of Environment on waste water effluents. Modelling has been employed for investigation of Žeimena river basin stretch, situated 78,6 – 13,7 km from river mouth, i.e. beginning at Kaltanėnai stretching till Pabradė. There are 5 tributaries of river Žeimena situated in that stretch, namely: Dubinga, Mera-Kūna, Saria, Lakaja, Kiauna. Physical–geographical conditions of the investigated river basins are presented in Table 1.

Table 1. Physical–geographical conditions of river basins

Characteristics of river basin		Žeimena		Nevėžis	
		Kaltanėnai	Pabradė	Panevėžys	Kėdainiai
Area of river basin, km^2	Total	2792,7		6140,5	
	Till water sampling sites	752	2580	1090 (1130)*	3230
Laky areas, %		8,9	7,0	0,4	0,2
Waterlogged areas, %		10	10	6	4
Forested areas, %		29	37	24	18
Sandy areas, %		44	76	20	6
Annual precipitation, mm		750	700	650	700

* Differences in areas due to 2 measurement stations – above and below the city

The calculations of nitrogen compounds and fluctuations of runoffs at the longitudal cross-section during the spring, summer and autumn-winter seasons were executed employing ATV-DVWk model.

There were selected more than 50 parameters to characterize the following conditions: physical-geographical (forestered area, forests types in both of river sides, wetlands, geology), climatic (air temperature, nebulosity overcast, wind strength), anthorpogenic activities (concentrations of biogenic materials in the wastewater, runoff of effluents) and morphometric conditions of river watercourse (width of river watercourse, overgrowth with water plants, etc).

3. Results and Discussion

From environmental point of view it is important as far as possible to ensure vitality of water ecosystems natural status, diminishing influence of anthropogenic elements for the usable water, thus compensating harmful factors of the growing consumption. Based on the objectives of water protection, a process of water quality modelling becomes a supplementary measure to evaluate the demand for actions or impact of applicable measures and actions taken on a site.

Original review of the annual medium data was performed employing analythical methods, because the modelling program is designed for the short-term investigations.

The results collected during investigations revealed, that river Nevėžis is approximately 10 times more polluted with biogenic substances than river Žeimena. That shows obvious influence of intensive agricultural farming.

Nitrates concentrations recordered in river Nevėžis above the cities Panevėžys and Kėdainiai were ranging from 0,62 to 8,7 mg/l, and in river Žeimena (above Švenčionėliai and Pabradė) ranging from 0,0329 to 0,032 mg/l.

Similarly, nitrates concentrations in river Nevėžis below the cities Panevėžys and Kėdainiai have fluctuated from 0, 75 to 11, 0 mg/l, and in river Žeimena – approximately 0,033 mg/l.

Concentrations of phosphates in the water of investigated rivers above the cities were detected approximately 1,2 – 4 times less comparing those concentrations below the cities.

Having analyzed the factual data of several seasons, when the runoffs of the rivers were increasing (Nevėžis river runoff was nearly 40,0 m^3/s, and Žeimena river – 20,0 m^3/s), the fluctuations in concentrations of biogenic substances in both of the investigated rivers during spring seasons were observed. Concentrations of ammonium ions in Nevėžis river near city Panevėžys were detected 2,5 times higher comparing to summer season and 1,5 times lower comparing to winter season. Concentrations of nitrates in the water of Nevėžis river were 6,7 times higher in spring, and phosphates nearly 2 times higher than in summer.

Having employed DVWK-Water Quality model to estimate fluctuation of water quality in longitudinal cross-sections of rivers investigated during different seasons, it was determined that simulated values of nitrates concentration in the origin of investigated stretch amounted to 2,1 mg/l and 8,6 mg/l – at the end of the same stretch during spring time, but due to the tributaries inflow the maximum value of nitrates concentration (11,1 mg/l) was measured below Panevėžys, and the minimum value (0,98 mg/l) – above Kėdainiai.

Modellation of ammonium ions concentrations have fluctuated in the range of 0,007 to 0,23 mg/l.

Factual and simulated data of nitrates and ammonium ions concentrations during spring and autumn seasons are presented in Figures 3 and 4.

Having simulated biogenic substances of river Žeimena, nitrates concentrations were determined to 0,2 mg/l (at Kaltanėnai) and 0,40 mg/l (below Pabradė) in the origin of the investigated stretch during spring time. Dubinga tributary inflow reaches

the maximum 0,46 mg/l, while near Saria tributary the minimum 0,082 mg/l values.

Constant decrease of nitrates concentration has been observed between Kaltanėnai and Saria, while sudden increase of these concentrations stretching river Saria – below Pabradė, where saltatory alterations could be influenced by the tributaries of river Žeimena: Mera and Dubinga.

There have been recorded decrease of ammonium ions ranging from 0,029 mg/l till 0,109 mg/l during spring time.

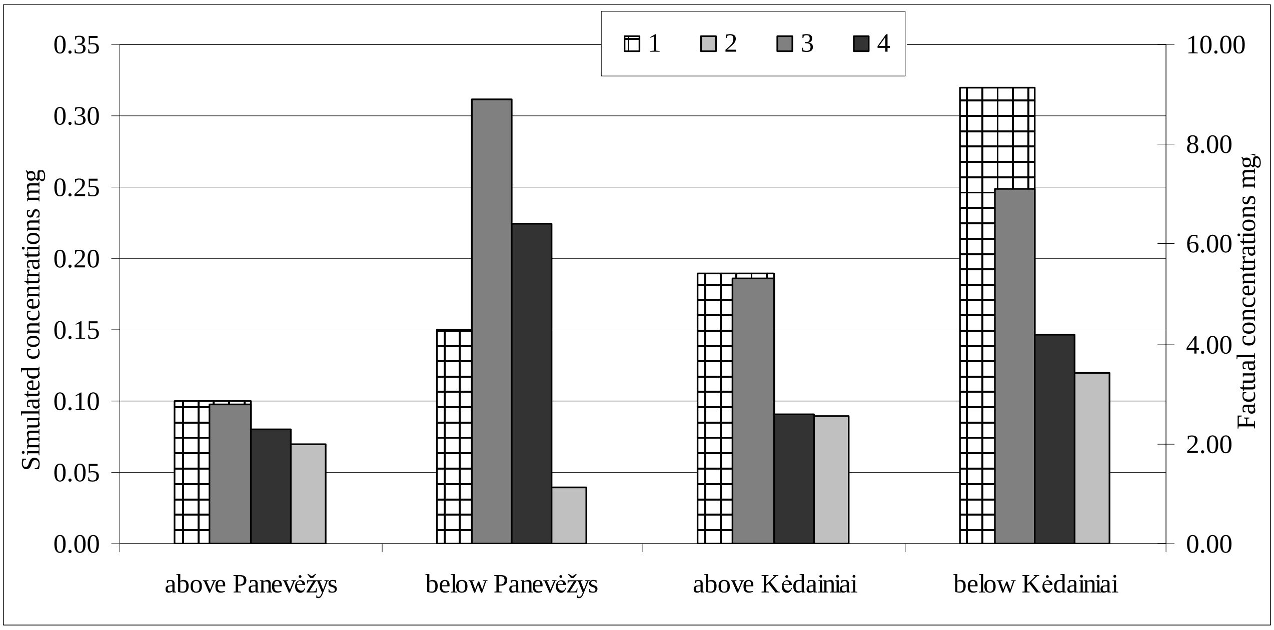

Fig. 3 Divergences among the factual and simulated data of nitrogen compounds in Nevėžis river during spring season
1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions
3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates

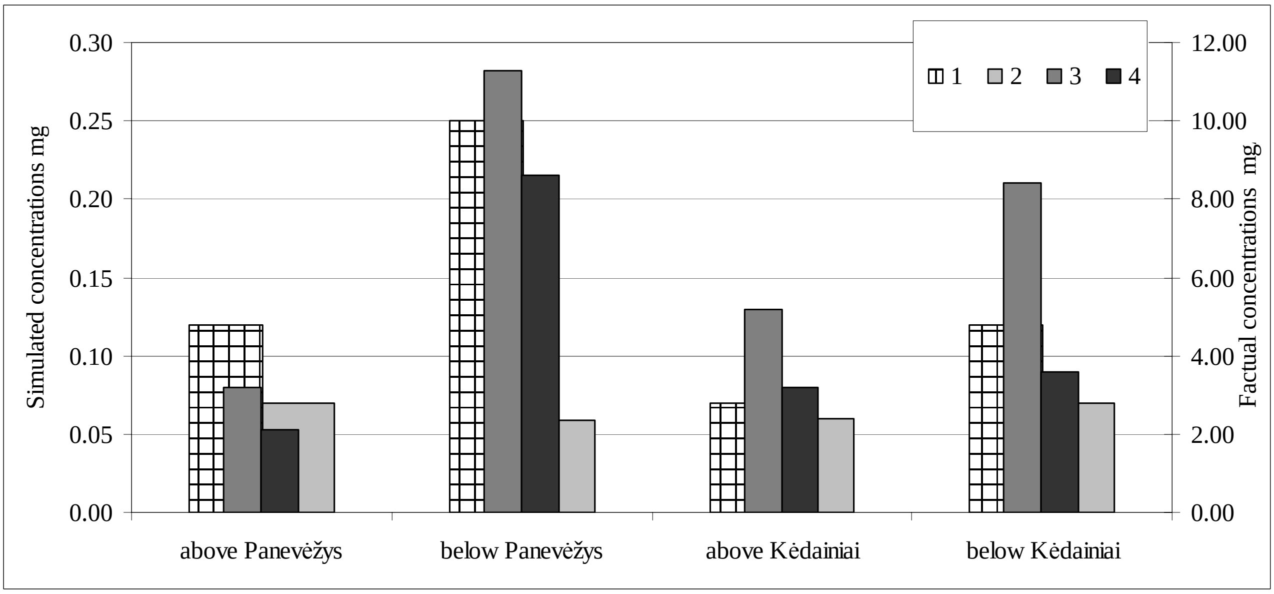

Fig. 4 Divergences among the factual and simulated data of nitrogen compounds in Nevėžis river during autumn season
1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions
3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates

There have been observed quite similar tendencies in alterations during spring and summer seasons with constant decrease of nitrates concentrations between Kaltanėnai and river Saria and sudden increase of concentrations stretching river Saria below Pabradė.

There have been recorded nitrates concentrations ranging from 0,147 mg/l till 0,423 mg/l during autumn time. It has been observed a tendency of nitrates concentration decrease towards river Saria, while further ahead concentrations of investigated materials have gradually increased. Ammonium ions fluctuate in the range from 0,0231 mg/l to 0,120 mg/l.

There have been determined divergence in simulated and factual values of river Žeimena runoffs ranging to 9,8 %. Runoff has been fluctuating from 2,9–8,2 (near Kaltanėnai) till 9,6–31,0 m^3/s (below Pabradė) in the cross-section during the investigative period. The following tributaries influence runoff of river Žeimena, namely rivers: Kiauna (its runoff 1,2–17,5 m^3/s), Lakaja (1,7–15,1 m^3/s), Saria (0,3–4,6 m^3/s), Mera (0,8–11,9 m^3/s) and Dubinga (1,7–13,9 m^3/s). Modelling has been employed for the shorter periods (i.e. separate months), because there was considerable divergence among the concentrations of biogenic materials factual and simulated values (till 78 % in river Nevėžis and till 74 % in river Žeimena).

Comparable analysis of the factual and simulated data during spring months are presented in Figures 5 and 6. The results obtained evidenced divergence among the simulated and factual nitrates concentrations 7,6 – 21 % in March and ranging from 17 – 23 % in April. Simulated concentrations of ammonium ions varianced with factual data up to 18 %.

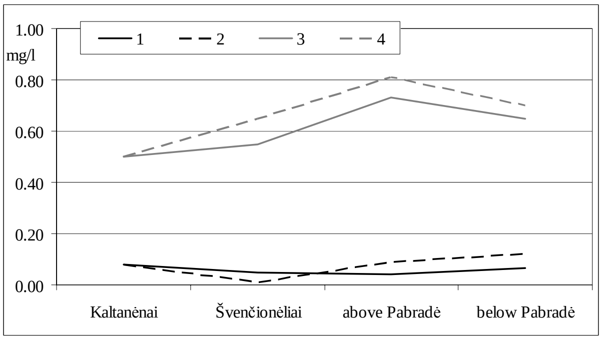

Fig. 5 Comparison of the simulated and factual nitrates and ammonium ions concentrations in March
(1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions, 3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates)

Analysis of summer seasonal months evidenced very close approximate values among the simulated and factual nitrates and ammonium ions concentrations. Divergence of nitrates concentrations amounted to 4,5–12 % and ammonium ions amounted to 8–17 % during May, July and August.

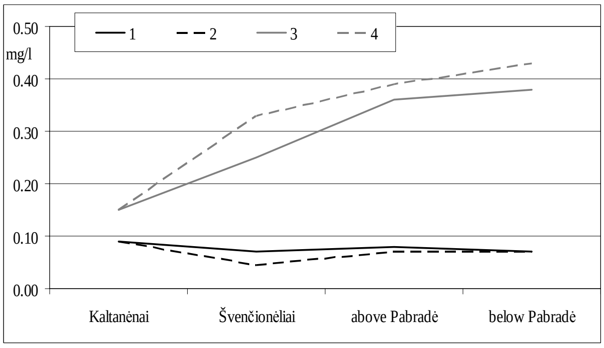

Fig. 6 Comparison of the simulated and factual nitrates and ammonium ions concentrations in April (1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions, 3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates)

The least diverged figures of the simulated and factual nitrates and ammonium ions concentrations amounting to 4 – 8% and 2,7 – 15% repectively were registered in June. The latter results are presented in Figure 7.

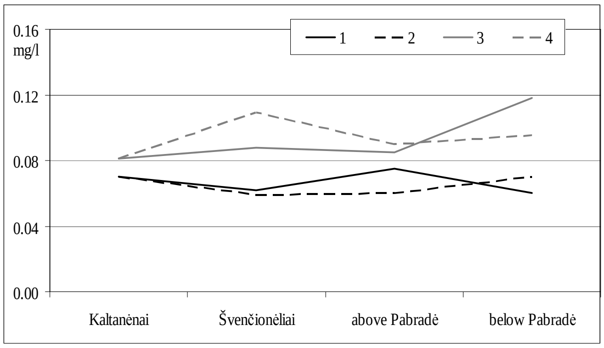

Fig. 7 Comparison of simulated and factual nitrates and ammonium ions concentrations in June
(1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions, 3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates)

The simulated concentrations of biogenic materials during autumn-winter months (October, November, December, January, February), alike spring season, have considerably divereged comparing to the factual values of direct measurements. Disparity reached even up till 41 %.

Comparative analysis of the simulated and factual data for December is presented in Figure 8. Results obtained show the divergence of nitrates concentrations in a range of 6,7 – 24,6 %, and ammonium ions concentrations in a range of 7,8 – 12,4 %.

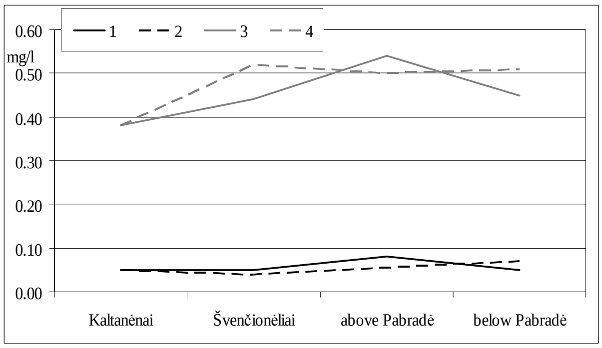

Fig. 8 Comparison of the simulated and factual nitrates and ammonium ions concentrations in December
(1 – Simulated concentrations of ammonium ions, 2 – Factual concentrations of ammonium ions, 3 – Simulated concentrations of nitrates, 4 – Factual concentrations of nitrates)

4. Conclusions

Having employed ATV-DVWk model for simulation of annual biogenic materials varied concentrations, considerable divergence of simulated concentrations from the factual values (10 – 78 %) was determined. The latter fact indicates that simulation is not suitable for the long-range modelling.

Having exercised simulations for the short-term periods (up to one month duration) it was determined that values of biogenic materials concentrations correlated with the factual values of direct measurements (discrepancies less than 30 %). That can be explained by the minor fluctuation of the runoff and a period of plants vegetation, when nitrogen compounds are being accumulated in biota.

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