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ANALYSIS OF THE EUTROPHICATION FACTORS IN THE SUTLA RIVER BASIN

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The Sutla River forms the border between Slovenia and Croatia. The area of Sutla river basin is 590.6 km^{2,} of which 78% is located in Slovenia, and the rest in Croatia. The nature retention function for flood control purposes and wetland ecosystems have developed on the edge and at the bottom of the nature retention/reservoir. The area of the entire reservoir as well as the entire riverbed of the Sutla River was declared NATURA 2000 site. For the planning of remediation measures according to the WFD and reducing the risk of eutrophication, the DPSIR approach with use of spatial data, quantification of nutrients by Soil Water Assessment Tool model (SWAT), the analysis of physico-chemical and biological indicators for good water status and measures within integrated water management are analysed.

KEY WORDS: DPSIR, eutrophication, SWAT, good surface water status, measures

ANALÝZA EUTROFIZAČNÝCH FAKTOROV V POVODI RIEKY SUTLA. Rieka Sutla tvorí hranicu medzi Slovinskom a Chorvátskom. Rozloha povodia rieky Sutla je 590,6 km^2, z toho sa 78 % nachádza v Slovinsku a zvyšok v Chorvátsku. Prirodzená retenčná funkcia na regulovanie povodní a systémy mokradí sa vyvinuli na kraji a na dne prirodzenej retencie/rezervoáru. Oblasť celej nádrže ako aj celé koryto rieky Sutla boli vyhlásené za lokalitu NATURA 2000. Pri plánovaní sanačných opatrení podľa Rámcovej smernice o vode (RSV) a znižovaní rizika eutrofizácie bol analizovaný spôsob DPSIR s využitím priestorových údajov, kvantifikácia živín použitím modelu na hodnotenie kvality pôdy (SWAT), analýza fyzikálno-chemických a biologických ukazovateľov dobrého stavu vody a opatrenia v rámci integrovaného vodného hospodárstva.

KĽÚČOVÉ SLOVÁ: DPSIR, eutrofizácia, SWAT, dobrý stav povrchových vôd, opatrenia

Introduction

For all river basins of the EU Member States water management must be organized in terms of the implementation of the European water policy and objectives of the Water Framework Directive (WFD). The Sutla River forms the border between the Republic of Slovenia and the Republic of Croatia. The area of the Sutla river basin is 590.6 km^2. The Sutlansko Lake (Vonarje Reservoir) and dam, with a volume of 12.4 million m^3, was built in a natural retention and filled in 1980 for the purpose of public water supply, irrigation and flood control. Shortly after filling, the water quality has extremely deteriorated in the reservoir, which reduced the possibility of water use. Increased eutrophication in the reservoir was found in 1987. Further, other extreme water quality problems have been detected not only in the lake water but also in the river water downstream. Due to a high risk for the population and environment caused by inadequate management of the reservoir and in the absence of better remediation measures, the reservoir was completely emptied in 1989. It now operates only as a dry retention basin for flood protection. Since wetland ecosystems have developed on the edge and at the bottom of the reservoir, the area of the entire reservoir as well as the entire riverbed of the Sutla River was declared a NATURA 2000 site (Ćosić-Flajsig et al., 2014). Related to the exceptional biodiversity of the Sutla River, it has become a tourist and recreational area in the past decade. Presently, there are a number of initiatives to reuse the reservoir, which indicates a necessary improvement of water quality for the purpose of achievement the good water status and redefinition of the Sutlansko Lake (Ćosić-Flajsig et al., 2015). Both

Slovenia and Croatia, being the new EU Member States, are now faced with the big challenge to achieve not only the good ecological and chemical status of the Sutla Lake and the river Sutla (as directed by WFD), but also to achieve good or excellent quality for bathing and protection from adverse effects of water (http://ec.europa.eu/environment). Furthermore, they also have to deal with tourist, recreational, fishing and irrigation needs at the same time. But firstly, they have to guarantee that emissions from urban areas and agricultural activities in the catchment are reduced and managed accordingly. Therefore, the challenge to achieve good ecological and chemical status of the river Sutla is today even higher than it has been in the past. Slovenia and Croatia are expected to apply for new development and cohesion funds to develop environmental and other infrastructure in the catchment. It is important to mention that Slovenia and Croatia had two different national institutional systems of water management and different economic developments in the past two decades, but also strong cultural ties between local communities on both river sides.

The implementation of the WFD is the starting point for the integrated water management. Small rural river basins, together with the lack of sanitation in agglomerations of less than 2000 PE and agricultural activities, present a challenge to water quality management for each state. These river basins are sources of organic pollution and nutrients, and the methodology to solve such problems is specific and dealt with at the national level, while the European water policy is conducted primarily in terms of achieving good status of all water bodies and environmental objectives for the river basin. In case of transboundary basins with high biological diversity and numerous NATURA 2000 areas, it is particularly necessary to apply an innovative approach to water quality management. This paper will analyse the conditions for water management using the DPSIR (D – driving forces, P – pressures, S – state, I – impact and R – responses) approach and taking into account the principle of sustainability. Successful management of rural river basins includes various measures, from very expensive to low-cost measures to protect water bodies. Using appropriate mathematical models can help in the assessment of environmental impact and implementation of optimized measures. Through a preliminary selection of appropriate models for rural river basins, the mathematical model SWAT (Soil and Water Assessment Tool) was found to be appropriate (Ćosić-Flajsig et al., 2014). It can be upgraded for specific needs, such as changing the trophic status of reservoir (ETC/ICM Technical Report, 2016). SWAT also fits in the framework of integrated modelling, and thus allows the use extensions for economic analysis and ecosystem services and human well-being (Ćosić-Flajsig and Karleuša, 2015). This paper is structured in seven parts. After the Introduction, the importance of eutrophication assessment is given in Section 2. Section 3 deals with the description of DPSIR approach and the indicator system. Section 4 deals with Material and methods of the research while Section 5 describes Results of the research. Finally, the paper ends with the Discussion in Section 6 and the Conclusion.

Eutrophication assessment

European policy has consistently identified eutrophication as a priority issue for water protection, in particular through the Urban Wastewater Treatment Directive (UWWTD) and the Nitrates Directives (ND), as well as the more recent WFD adopted in 2000 and a number of international conventions on river basin management. The general objectives of European and national policies, such as good ecological status under the WFD need to be broken down to more specific objectives and quantitative targets to guide eutrophication abatement. In addition to the EU Directives, the 7th European Environmental Action Program (EAP) has amongst others the objective to ensure that by 2020 „the nutrient cycle (nitrogen and phosphorus) is managed in a more sustainable and resource-efficient way. This requires, in particular: taking further steps to reduce emissions of nitrogen and phosphorus, including those from urban and industrial wastewater and from fertilizer use, through better source control, and the recovery of waste phosphorus“ (ETC/ICM Technical Report, 2016). The exceeding of nutrient standards in water bodies must be translated into objectives for nutrient load reductions, because it is more ecologically sound than targets set with respect to some reference year. The input of nutrients in upstream areas causes the changing of the water status and load objectives for downstream area (ETC/ICM Technical Report, 2016). The environmental policies and legislation have the common objectives to reduce eutrophication and thereby securing healthy ecosystems, safe bathing or drinking waters, and the monitoring of the eutrophication as the widely used tool, for planning water management measures. The objectives represent a common understanding of the potential nutrient reduction measures that would be sufficient to provide recovery from eutrophication (ETC/ICM Technical Report, 2016). Requirements to assess eutrophication are included in the EU water policy through some directives, as it is described in document „European assessment of eutrophication abatement measures across land-based sources, inland, coastal and marine waters“, ETC/ICM Technical Report – 2/2016. Minimum monitoring WFD requirement relevant for eutrophication are: phytoplankton, aquatic flora, macroinvertebrates, fish, physiochemical quality elements (N and P), and hydromorphological elements. Nutrients can sometimes cause changes in the taxonomic composition of plants or algae, without causing the biomass to increase to a level where is secondary on flora, fauna or water quality in general. There is no unique approach and relevant policy that aim at controlling the pressures from human activities with an impact on the natural condition of the ecosystem, status of water body and nutrient enrichment which cause eutrophication (ETC/ICM Technical Report, 2016). Eutrophication of natural and artificial lakes is a problem that needs the preventive and continuous work in order to be solved. This paper presents an innovative approach for the eutrophication assessment which is based on:

- the application of DPSIR approach to the analysis of human activities in the catchment area and the input of nutrients in the water with the use of spatial data (GIS);
- the quantification of input pollution in water using a mathematical model SWAT;
- the analysis of the condition of the water ecosystem in relation to the climatological-hydrological conditions, abiotic and biotic factors.

DPSIR and indicator system

With problem oriented DPSIR approach, according to the WFD, all types of pressures (pollution, water use and hydromorphological pressures) can be analysed to assess the risk of not achieving a good ecological status of a water body (Ćosić-Flajsig et al., 2015). This paper aims to show the model of eutrophication process in order to implement measures that could avoid a possible new occurrence of eutrophication, which is one of the biggest challenges in water management. In the case of transboundary river basin, the challenge is even higher because of a range of factors related to diversity of water management, backgrounds, approaches, interests and development scenarios for the defined area. The DPSIR framework distinguishes driving forces (D), pressures (P), state (S), impact (I) and responses (R) - programmes and measures (ETC/ICM Technical Report, 2016). The eutrophication conceptual framework provides an effective mean for identifying the critical processes that can be adapted to processes specific to different water body categories. Using the indicator system, which explains causal relationship of the eutrophication process, special emphasis will be given on the analysis of biological indicators (elements of water quality) that are critical in the assessment of the state of aquatic ecosystems. Direct effects of nutrient enrichment are on indicators: phytobenthos, phytoplankton, macrophytes, increase turbidity and decreased light transparency. Indirect effects of nutrient enrichment are on indicators: change of habitats, algae toxins and organic matter that have impact on the macroinvertebrates and fish. Indicators are a widely used instrument for monitoring the eutrophication status and to document the distance to target and the progress of policy implementation over time. Eutrophication indicators for nutrient pressure, state and impact in rivers, lakes and transitional waters are: *Pressure indicators*: nutrient emissions, nutrient loads – for all water bodies*, State indicators*: phosphorus concentrations (Total – P, orthophosphate), nitrogen concentrations (Total N, NO_3) - for all water bodies*, Impact indicators*: Ecological status and Macrozoobenthos (community composition, biomass) – for all water bodies; Phytoplankton (chlorophyll a, biovolume) and Secchi depth – for water bodies of lakes; Macrophytes (lower growing depth) and (community composition)- for water bodies of lake; Phytobentos (benthic algae community composition) – for water bodies of rivers and lakes; Bottom water oxygen concentrations – for water bodies of stratified lakes only (ETC/ICM Technical Report, 2016). The impact indicators used in connection with eutrophication vary depending on the water category, but they are generally sensitive to nutrients, either directly (biological indicators) or indirectly (physico-chemical indicators affected by biological processes) (Ćosić-Flajsig and Karleuša, 2015). Nutrient emissions or load indicators are important performance indicators. Load indicators show how much nutrient loads have been reduced and whether the nutrient load reduction targets have been achieved. Nutrient emissions are assessed per sector and provide a direct link to the respective polluters. Data on sectoral nutrient emissions and the need for load reductions in each sector are gained by source apportionment. This is useful to identify the main contributors to the loads and where further measures would be most effective (ETC/ICM Technical Report, 2016).

Material and methods

Knowing the catchment hydrological and hydraulic characteristics, sources of pollution, pollutants' flow, various chemical parameters decomposition patterns and existing aquatic ecology is crucial for proposing remediation measures and setting economically sound environmental protection management measures. To face these challenges authors have developed conceptual water quality management model for the Sutla river catchment using the DPSIR approach and the SWAT model. It should initiate common approach for both countries to control water quality on catchment level and manage aquatic ecosystem to fulfilling environmental goals.

Study area

The river Sutla originates at the altitude of 717 meters below the Macelj hill and flows into the Sava River southeast of Brežice town. The terrain of the catchment area ranges from approx. 1000 meter above sea level to 100 meter above sea level (see Figure 1). It is 91 km long. After 3 km of headwater section, it becomes a national border between Slovenia (right side of the river) and Croatia (left side of the river). At the downstream section, before it flows into the Sava River, the national border is laying on the river Sutla and former course (before the regulation). Its catchment area is 590.6 km^2 large, of which 78% is located in Slovenia, and the rest in Croatia. The most significant two right tributaries are Mestinjščica and Bistrica ob Sotli (or shortly "Bistrica"). The only lake that existed shortly on the river Sutla was the Sutla Lake, the artificial lake behind the Vonarje dam. Area of the former reservoir, which was emptied in 1988 due to eutrophication, was 1.95 km^2, and is currently being used as retention in case of high water. Reservoir capacity is 12.4 million m^3, out of which 3.7 million m^3 is required for 100-year flood protection. The average annual precipitation in the Sutla river catchment is 1200 mm, and evapotranspiration is about 650 mm. The river Sutla has the Pannonian flow regime with two identical peaks, one in early spring and the other in late autumn. Low flows occur in summer and winter. Measuring stations that monitor the quantity and quality of water on river Sutla are presented on Figure 2 (Ćosić-Flajsig et al., 2014).

SWAT model

The SWAT model, daily time step semi-distributed process-based catchment model, was developed to help water resource managers in evaluating the impact of agricultural activities on waters and diffuse pollution in river catchments (Arnold et al., 2012; Tuppad et al., 2010). For the purpose of this study, SWAT 2012 model, Geographic Information System (GIS) ESRI ArcGIS 10.3 software and the ArcSWAT interface have been used. The SWAT model is extensively used in the world for modelling hydrology, water quality and climatic change (Gassman PW et al., 2007) and it is compared favourably with other runoff models and water quality models (Kronvang, B. et al., 2009). The model defines the river network, the main point of outflow from the catchment and the distribution of sub-catchments and hydrological response units (HRUs). Sub-catchments are spatially related to each other. HRUs are the smallest landscape components of SWAT with a unique combination of land use, soil, slope and land management, and those are not spatially related (Tuppad et al., 2010). The use of HRUs allows modelling of different evapotranspiration (ET), erosion, plant growth, surface flow, water balance, etc., for each sub-catchment or HRU, thus increasing the accuracy of the simulations (Moriasi DN et al., 2012). Erosion and sediment yield are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE). Runoff erosive energy is calculated by a hydrology model that supplies estimates of the runoff volume and peak runoff rate for the sub-catchment area. The model uses a soil erodibility factor. The cover and crop management factor is recalculated every day that runoff occurs and is a function of the above ground biomass, residue on the soil surface, and the minimum C factor for the plant (Neitsch SL et al, 2005). SWAT tracks the movement and transformation of several forms of nitrogen and phosphorus in the soil profile, shallow aquifer, reach, reservoir, pond and wetland.

Database and data analysis

Table 1 provides an overview of the SWAT model input data.

Model set up and evaluation

The River Sutla catchment was subdivided into 11 sub-catchments and 1970 HRUs.

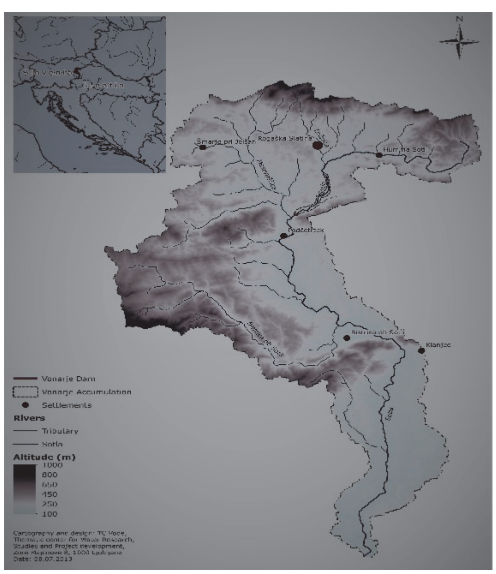

Fig. 1. The Sutla River Basin (Ćosić-Flajsig et al., 2014).
Obr. 1. Povodie rieky Sutla (Ćosić-Flajsig et al., 2014).

Fig. 2. Monitoring stations that monitor the quantity and quality of water on river Sutla – right (Ćosić-Flajsig et al., 2014).
Obr. 2. Monitorovacie stanice kontrolujúce množstvo a kvalitu vody v rieke Sutla (Ćosić-Flajsig et al., 2014).

Table 1. Model input data sources for the river Sutla sub-basin
Tabuľka 1. Zdroje vstupných údajov do modelovania pre čiastkové povodie rieky Sutla

Data Type	Characteristics	Source	Data description
Topography (DEM raster)	Slovenia: 25 m Austria: 1 m	Copernicus land services - European Environment Agency	Elevation
Soils	Slovenia: 1:25000 Croatia: 1:25000	Ministry of Agriculture, Forestry and Food of the Republic of Slovenia; Biotechnical Faculty (University of Ljubljana), Faculty of Agriculture (University of Zagreb)	Spatial soil variability, soil types and properties
Land Use	Slovenia, Croatia: 1m vector data (Graphical Units of Agricultural Land) Croatia: 100 m Corine Land Cover (CLC) 2012, Version 18.5.1	Slovenia: Ministry of Agriculture, Forestry and Food of the Republic of Slovenia Croatia: Paying Agency for Agriculture, Fisheries and Rural Development; Copernicus land services - European Environment Agency	Land use, Land cover classification and spatial representation
Land Management information	/	Chamber of Agriculture and Forestry of Slovenia - Agricultural advisory service; Field trip	Crop rotations (harvesting, planting, management), fertilizer application (rates and time)
Weather	Slovenia 9 and Croatia 3 stations	Environment Agency of the Republic of Slovenia (ARSO), Croatian Meteorological and hydrological service	Daily precipitation, Temperature (max., min.), relative humidity, wind, solar radiation from 2001 -2014
River discharge	1 monitoring point (CRO - Zelenjak)	Environment Agency of the Republic of Slovenia; Hrvatske vode – Croatian legal entity for water management	Daily flow data (m^3/s) from 2001 - 2014
Waste water treatment plants	Slovenia: 10 Croatia: 2	Environment Agency of the Republic of Slovenia; Hrvatske vode – Croatian legal entity for water management	Average daily discharge of orgP, sediment and orgN and other parameters
Water quality	1 monitoring point (CRO - Zelenjak)	monthly monitoring	TSS, NO_3^-, PO_4^{2-}, TP, TN (2001 - 2012)

The number of HRUs in each sub-catchment was set by a minimum threshold area of 0%:0%:0% for land use, soil and slope classes, respectively. High number of HRUs is correlated with step topography, dispersed agricultural areas and 39 soil types of the study area. River flow daily time step sensitivity analysis and calibration were performed for the sub-catchment 6 outlets for the period 2009-2014, with a three-year warm up period (2001-2003) and one validation periods (2004-2008). Sediment, nutrients (NO3-N, PO_4^{2-}) monthly time step and river flow daily time step sensitivity analyses and calibrations were performed for the water quality monitoring point at the sub-catchment 6 outlets for the period between 2004 and 2012. The first step in the calibration and validation process in SWAT is to determine the most sensitive parameters for a given basin. For the sensitivity analysis and calibretion, special software called SWAT-CUP is used, and within it the Sequential Uncertainty Fitting (SUFI-2) algorithm (Arnold et al., 2012; Abbaspour et al., 2007). The sensitivity analysis was performed using measured data for the river Sutla. The analysis was carried out for average daily flow and monthly sediment, nitrate and phosphorus. The default lower and upper bound parameter values for all parameters was used (Neitsch SL et al, 2005). Defined stream flow was identified to be sensitive to changes. It has the greatest impact on the model output when changed. The most sensitive parameters were used to perform model calibration. In this study, calibration of the model was performed for flow on daily basis and sediment, nitrate nitrogen and phosphorous on a monthly basis.

Results

Calibration and Validation

Objective functions show that the simulated total flow is within the acceptable range (Table 2). To achieve acceptable calibration and validation results, a list of model parameters was changed from default to final values. Table 2 lists the calibration and validation values for the model performance for flow. Negative percent bias (PBIAS) values indicate a small overestimation of the simulated values. Nash-Sutcliffe efficiency (E_{NS}) on daily time steps are in the acceptable range (Moriasi et al., 2007), however, the E_{NS} coefficient is very sensitive to values that stand out from the average (Krause P. et al., 2005). The SWAT model simulated the streamflow trends good and very good, as simulated streamflow values do not exceed the measured streamflow data by more than 15% (Moriasi et al., 2007). Comparing simulations run under different time steps shows that this element is important for understanding model performance (Krause P. et al., 2005). After the base model calibration was completed, the parameters remained fixed for further use in scenario modelling. The results of the validation in this study are in line with the calibration results. Objective functions for monthly time step sediment, nitrate-nitrogen and phosphorus calibration (Table 2, Figure 3) show that the model is acceptable for predicting all of them. The Nash-Sutcliff coefficient (E_{NS}) is in the range of very good results for sediment, nitrate-nitrogen and satisfactory for phosphorrus and PBIAS in the range of satisfactory model performance for sediment and very good for nitrate nitrogen and phosphorus (Moriasi DN et al., 2012).

Base scenario results

Through analysis of the base scenario, the critical source areas (CSAs), i.e. where the source and transport areas that are connected to water bodies, have been determined. HRUs where the annual average sediment yield exceeded 0.5 t/ha and average nitrate nitrogen loading from groundwater exceeds 5 kg/ha are considered to be CSAs (Figure 3). These areas have in terms of erosion unstable geology and soil types susceptible to soil erosion, and for that reason are strongly subject to the action of weather forces. The spatial variability of sediment yield is influenced by many factors, particularly land use, management practice, slope and soil characteristics. The impact of land management on erosion and nitrogen leaching and its graphical representations greatly depend on the accuracy of the spatial and attribute data used in the modelling process. The average annual sediment and nitrogen yields at the HRU level were divided into six classes (Figure 3). The source of sediment in this river basin is spatially heterogeneous and on average 0.76 t/ha/year. This study shows that in certain HRUs, sediment yield can reach up to 31.61 t/ha/year (Table 2, Figure 3). This value can be exceeded during periods of heavy rainfall. The highest amount of sediment is transported from vineyards (3.5 t/ha/year), followed by arable fields (186 t/ha/year) (Figure 4).

The areas with arable fields and especially the one on shallower soils and on lowland sandy soils are exposed to nitrogen and phosphorus leaching which ends in the main river channel. Their sources in groundwater in this river basin are spatially concentrated on agricultural land and are on average 1.97 kg N/ha/year and 0.59 kg P/ha/yr. This study shows that in certain HRUs, nitrate nitrogen and soluble phosphorus yield can reach up to 54.53 kg/ha/year and 12.99 kg/ha/year, respectively (Figure 4). This value can be exceeded during periods of heavy rainfall. The highest amount of nitrate nitrogen is on average transported from orchards (4.5 kg/ha/year), amount of soluble phosphorus in mineral forms is on average transported into the main channel from arable fields (1.7 kg/ha/year), followed by orchards (0.8 kg/ha/year) and vineyards (0.7 kg/ha/year). Modelling results for the study period between 2004 and 2014 also showed that on average it can be expected at the main catchment outlet at confluence with the river Sava almost **14.000 tons/year of sediment, 1741 tons/year of total nitrogen and 125 tons/year of total phosphorus.** Results show that main point sources (waste water treatment plants) in normal conditions contribute very small quantities of N (10.75 tons/year) (0.62%) and P (4.29 tons/year) tons of (3.43%) on average daily basis.

Table 2. Statistical values for the calibration of for river flow (m^3/s) (2004 – 2014) and sediment concentration (mg/l), nitrate nitrogen concentration (mg/l) and load (kg/day) and mineral phosphorus load in the river Sutla (2004 – 2012)

Tabuľka 2. Štatistické hodnoty pre kalibráciu toku rieky (m^3/s) (2004 – 2014), koncentrácia sedimentov (mg/l), koncentrácia dusíka (mg/l) a zaťaženie (kg/day) a zaťaženie minerálnym fosforom v rieke Sutla (2004 – 2012)

	Objective function	
	E_{NS}	PBIAS
River flow (daily)		
Calibration (2009 – 2014)	0.59	-10.58
Validation (2004 – 2008)	0.54	0.59
Sediment (monthly)		
Load Calibration (2004 – 2012)	0.72	34.35
Nitrate nitrogen (monthly)		
Concentration Calibration (2004 – 2012)	0.82	-1.96
Load Calibration (2004 – 2012)	0.65	31.30
Mineral phosphorus (monthly)		
Load Calibration (2004 – 2012)	0.41	2.32

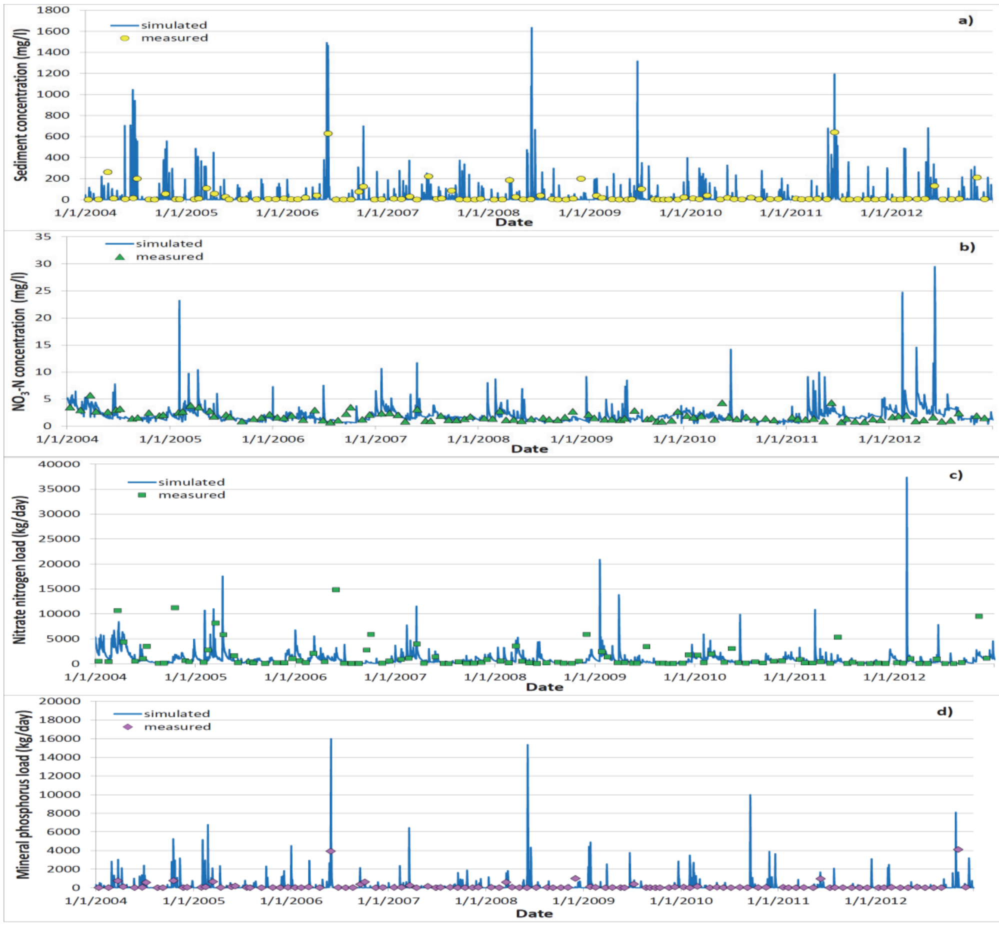

Fig. 3. A comparison of the simulated and the calculated sediment, nitrate-nitrogen and phosphorus in the river Sutla for station Zelenjak at sub-basin 6 outlets between 2004 and 2010.
Obr. 3. Porovnanie simulovaného a vypočítaného sedimentu, dusíka a fosforu v rieke Sutla pre stanicu Zelenjak na 6 výtokoch čiastkového povodia v rokoch 2004 až 2010.

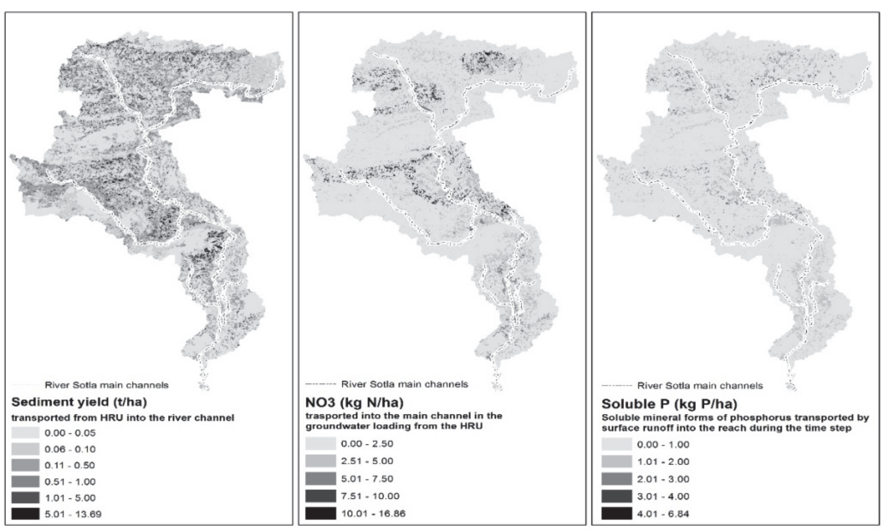

Fig. 4. Average annual sediment yield (t/ha/yr) and nitrate-nitrogen yield (kg N/ha/yr) transported into the main channel from the HRU.
Obr. 4. Priemerný ročný výnos sedimentov (t/ha/yr) a výnos dusíka (kg N/ha/yr) transportovaného do hlavného kanála z HRU.

Results of indices analysis for biological water quality elements, algae as eutrophication indicators

Analysing the SWAT model results and the available water quality data based on the surveillance monitoring, which is carried out by Croatian Waters, as well as the results of the investigative monitoring, an analysis of the indexes for the biological elements of water quality and the presence of algae as an indicator of eutrophication was made. The Trophic Diatom Index (TDI) is a parameter that points to the load of the water body on the nutrients and the water temperature, i.e. its level of trophies based on the presence of diatom species (algae) (Rott et al., 1999). The saprobic index (saprobity) (SI) is a multimeter index that indicates the amount of nutrients in the watercourse. SI (Pantle & Buck, 1955; Zelinka & Marvan 1961) was calculated according to the revised saprobic values for each diatom species (algae) according to the Croatian HRIS (Croatian Saprobic Index) indicator system (Primc-Habdija et al., 2003). The non-Diatom index (NDI) gives information on the presence and percentage of all groups of algae (except diatoms) in a single sample. Namely, the presence of Cyanobacteria and Chlorophyta may significantly imply an increase in the level of trophy / saprobity. Because of this biological quality assessment only on Diatom index can be questionable, especially at degraded sites. For the classification of the biological state it is important to define Ecological Quality Ratio (EQR). Namely, the values of each index used differ significantly and it was necessary to transform these values into comparable form, i.e. the actual values of the index are transformed into values between 0 and 1 (1 is highest quality and 0 is the worst).The EQR values for the TDI and SI index for the Sutla-Prišlin sampling station for 2012 (Figure 2), when regular monitoring was conducted by Croatian Waters, were 0.38, which indicated poor water status, while values for SI_{PB} and SI_{HRIS} were 0.74, indicating the good water status. EQR values for the TDI and SI index for the Sutla-Zelenjak sampling station for 2012 (Figure 2), when regular monitoring was conducted, were 0.69, which indicates good water status, as values for SI_{PB} and SI_{HRIS}, which amounted to 0.77 and also indicated on the good water status. The EQR values for the TDI and SI index for the Sutla-Harmica sampling station for 2012 (Figure 2), when regular monitoring was conducted were 0.68, which indicates good water status and values for SIPB and SIHRIS were 0.75 and also indicated on the good water status. EQR values for NDI for all three sampling stations were 0.3 and indicated poor water status.

Measures

The planning and implementation of measures for reducing the risk of eutrophication has to be based on respecting the interests of all users of the river basin, and if is it possible, the ecosystem service and human well-being. The program of measures to reduce nutrient pollution pressures is the central element of an integrated water resources management plan that ideally fulfils the requirements of different water related policies like WFD, UWWTD, ND and national legislation (ETC/ICM Technical Report, 2016). Nutrients are a key factor in eutrophication and should be included in monitoring programmes for the assessment of eutrophication. Basically, two different monitoring concepts can be applied: monitoring of biological quality element(s) including supporting quality elements and monitoring of nutrients (and possibly other physico-chemical quality elements) as a screening tool. Generally, monitoring of nutrients will be at a higher frequency than for biological quality elements. (ETC/ICM Technical Report, 2016). In the case of Sutla River monitoring of biological quality elements is not sufficiently developed according to the requirements of the WFD. The analysis of total nitrogen and total phosphorus is the basis for budget calculations and overall assessments have been done by using the model SWAT. By using additional extensions for the model, this budget can be improved. For a detailed analysis of eutrophication processes all fractions of nutrients (dissolved and particulate, organic and inorganic forms of nitrogen and phosphorus) should be monitored to allow a better understanding of the status and the factors explaining the status. Such a detailed analysis can be part of an investigative monitoring programme, as it can be in case of Sutla river basin (ETC/ICM Technical Report, 2016). The programme of measures may be established when the most significant pressures have been identified and nutrient reduction objectives have been set. While the WFD, ND and MSFD give more space for the selection of specific and site adapted measures, the UWWTD defines clear technical and managerial measures to be taken. Mandatory measures, according to UWWTD, have been implemented for agglomerations bigger than 2 000 PE, but waste water in other settlements is collected in individual permeable septic tanks if not emitted directly into small creeks and rivers. Out of a total of 54 839 residents living in the Sutla river basin, only 11 070 inhabitants are connected to the sewage system and WWTP. The EU-WFD planning process distinguishes three categories of measures: basic measures, supplementary measures and additional measures. The program of measures has to be cost-effective and consulted with stakeholders to become operational and includes better cross-sectoral integration of water policies burden sharing between sectors, innovative approaches, and alternative concepts such as payment for ecosystem services.

Discussion

The challenge to secure good ecological and chemical status of the river Sutla is today even higher that it has been in the past. For this purpose, it is necessary to know the catchment hydrological and hydraulic characteristics, sources of pollution, pollutants' flow, various chemical parameters decomposition patterns and existing aquatic ecology. Only then pollutant's impacts on aquatic ecosystems and other quality parameters under different development scenarios can be analysed. Knowing these processes is crucial for proposing remediation measures and setting economically sound environmental protection management measures. To face these challenges authors have developed conceptual water quality management model for the catchment. Related to the quantification and spatial presentation of input pollution in water using a mathematical model SWAT, modelling results for the study period between 2004 and 2014 showed that on average it can be expected, at the main catchment outlet at confluence with the river Sutla, the increase in the level of trophy, which is particularly visible from the non-Diatomindex, likely due to the presence of the representatives of the algae groups Cyanobacteria and Chlorophyta. The Sutla-Prišlin sampling station shows worst water quality due to nutrients load, and this is probably the result of the impact of two larger settlements (Hum na Sutli in Croatia and Rogaška Slatina in Slovenia) with the corresponding industry located upstream from the sampling station. The influence of these settlements is even stronger because only 20% of the catchment population is connected to the public drainage system related to the requirements of the UWWTD and the fact that mostly inhabitants live in the small settlements. The main source of nitrogen pollution is run-off from agricultural land and forest. Based on the analyses of the spatial presentation of the N and especially the sediments in the Sutla catchment area, with a large forest and agriculture area, whereas most phosphorus pollution comes from agriculture and WWTP's contributed 3.43% of the total P only, the connection between the input N, the sediment and water quality was established. The data from water quality location Prišlin confirms this assumption. The similar situation occurs with the introduction of a sediment in the area of the Bistrica stream to the Sutla River. At the location mentioned there is no measurement station, Zelenjak is upstream, and Harmica runs downstream and does not significantly register the pollutant input. Recommended measures for reducing nutrient intake from agricultural areas are: agro – environmental policies: protection zone – buffer zone for river Sutla, financial support for organic and ecological food production; management plans for lower diffuse pollution loads; efficient organic and artificial fertilizer use; control of manure and slurry storage and re-use (Ćosić-Flajsig et al., 2014).

Conclusion

An innovative methodology for eutrophication assessment using the DPSIR approach with GIS spatial analysis and the SWAT model is presented in the paper. The application of this methodology has proven to be appropriate on Sutla river basin case study because it enables the analysis of the eutrophication process in the basin as well as the selection of the optimal set of mitigation measures for prevention of the eutrophication process. Further and widespread application of this approach will enable wider acquisition of the basic knowledge for the Sutla river basin, which includes the natural processes, the generating pollution and decreasing risk of eutrophication. All input data that are used were provided by the official monitoring system, but it is necessary to continue the collection of new data and further development of the SWAT model for which it has been proven that it can improve the quality of the analyses, especially by using different extensions. In the future, it is necessary to carry out more detailed research of biological elements of water quality, especially periphyton and macrophytic vegetation, which are directly related to eutrophication. Research should take place for at least three consecutive years in the warmer part of the year during lower water levels in order to obtain a complete picture of the state of Sutla Lake.

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ANALÝZA EUTROFIZAČNÝCH FAKTOROV V POVODI RIEKY SUTLA

Objem nádrže Vonarje je 12,4 miliónov m^3. Nachádza sa na rieke Sutla, ktorá je prirodzenou hranicou medzi Slovinskou a Chorvátskou republikou. Priehrada a nádrž boli postavené a naplnené v roku 1980 na účely verejného zásobovania vodou, zavlažovania a protipovodňovej ochrany. V rokoch 1987 a 1988 bola v nádrži zistená zvýšená eutrofizácia a v roku 1989 bola nádrž úplne vyprázdnená. Eutrofizácia je "obohatenie vody živinami, najmä zlúčeninami dusíka a/alebo fosforu, čo spôsobuje zrýchlený rast rias a vyšších foriem rastlín, ktoré spôsobujú nežiaduce narušenie rovnováhy organizmov prítomných vo vode a ovplyvňujú kvalitu vody". Pochopenie "antropogénnej" eutrofizácie zodpovedá tomu, ako RSV klasifikuje ekologický stav povrchovej vody vo vzťahu k referenčným podmienkam špecifickým pre daný typ. Vodné útvary, ktoré nedosiahnu dobrý ekologický stav v dôsledku účinkov obohatenia živinami spôsobené ľudskou činnosťou, sa môžu považovať za nepriaznivo ovplyvnené eutrofizáciou. Cieľom tohto článku je ukázať model procesu eutrofizácie s cieľom zaviesť opatrenia, ktoré by mohli zabrániť možnému novému výskytu eutrofizácie, čo je jedna z najväčších problémov vo vodnom hospodárstve. V prípade cezhraničného povodia je problém ešte väčší, pretože existuje celý rad faktorov súvisiacich s rôznorodosťou vodného hospodárstva, prostredia, prístupov, záujmov a scenárov vývoja pre vymedzenú oblasť. Pre všetky povodia členských štátov EÚ musí byť vodné hospodárstvo organizované z hľadiska implementácie európskej vodohospodárskej politiky a cieľov RSV. V prípade cezhraničných povodí, ako je povodie rieky Sutla, je to obzvlášť dôležité. Problém eutrofizácie prírodných a umelých jazier je problém, ktorý si vyžaduje preventívnu a neustálu prácu na riešení problémov. Tento dokument predstavuje inovatívny prístup k hodnoteniu eutrofizácie, ktorý je založený na nasledujúcej analýze modelov:

- prístup DPSIR na analýzu ľudských činností v oblasti povodia a vstupu živín do vody s využitím priestorových údajov (GIS),
- kvantifikácia vstupného znečistenia vo vode pomocou matematického modelu SWAT,
- analýza stavu vodného ekosystému vo vzťahu k klimatologicko-hydrologickým podmienkam, abiotickým a biotickým faktorom.

Pomocou indikátorového systému, ktorý vysvetľuje príčinnú súvislosť procesu eutrofizácie, sa kladie osobitný dôraz na analýzu biologických ukazovateľov (prvkov kvality vody), ktoré sú rozhodujúce pri posudzovaní stavu vodných ekosystémov. Plánovanie a vykonávanie opatrení na zníženie rizika eutrofizácie musí byť založené na rešpektovaní záujmov všetkých užívateľov povodia a ak je to možné, na ekosystémových službách a ľudskom blahobyte. Zelená infraštruktúra, okrem potrebnej šedej infraštruktúry, prispieva k využívaniu ekosystémových služieb, ktoré zahŕňajú služby, ktoré poskytuje príroda zadarmo, a človek využíva na trvalo udržateľné integrované riadenie povodia.

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