AN INTEGRATED APPROACH FOR MANAGEMENT OF AGRICULTURAL NON-POINT POLLUTION SOURCES IN THE CZECH REPUBLIC

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ABSTRACT

We report a new, integrated approach to the identification and localization of potential critical areas of non-point agricultural water pollution in the Czech Republic. The methodology is presented in model catchments of IV. order, namely the Hrejkovický and Bilinský brooks in the water reservoir Orlík watershed. The risk rate of non-point source pollution is evaluated with the help of GIS tools, integrating the assessment of geomorphology, land use and soil conditions within a territory in conjunction with the agricultural tile drainage systems. Besides the areas prone to erosion and 'direct protection localities' along water courses, spots with increased potential of nutrient leaching into groundwater and drainage water are delineated, based on a synthetic map of shallow groundwater vulnerability. These spots are classified using analysis of the Valuated Soil Ecological Units (VSEU) code, while agricultural drainage systems are identified according to the documents of the former Agricultural Water Management Authority of the Czech Republic. Results from geographical analysis show differences between intrinsic parameters of model catchments, which influence the vulnerability potential towards diverse types of non point pollution. The potential pollution thread of surface and groundwater by leaching is relatively high in both catchments, in the Bilinský brook catchment due to prevailing arable land on first and second vulnerability classes within the tile drainage subcatchments and in the Hrejkovický brook catchment due to dense occurence of first and second vulnerable clasess in the catchment area, though comprised from a third by grassland. Water erosion potential jeopardy is bigger within the Bilinský brook catchment with 10% of arable land having the average soil loss 4–10 t ha^{-1} y^{-1}, contrary to 2% within the Hrejkovický brook catchment. Presented approach can help in prioritizing protective measures and management strategies in a catchment to curtail the negative impacts of non point agricultural pollution in water bodies and in the whole environment.

Key words: water vulnerability, infiltration areas, tile drainage, erosion, non-point pollution sources, GIS

1. Introduction

The quality of surface and groundwater is significantly influenced by pollution from point sources (settlements, waste-water treatment plants, fish ponds and industrial or agricultural works) and also by non-point pollution sources from prevailingly agricultural activities, causing elevated leaching of nutrients into waters and increased erosion (Macleod et al. 2007). The significance of non-point pollution sources will probably grow with continually decreasing pollution from the point sources (Haygarth and Jarvis 2002; Langhammer et al. 2009). Its contribution is important especially in the case of nitrogen and phosphorus, varying in the regions of the Czech Republic according to the land use, farming intensity and methods, morphological and hydrological characteristics of the territory, and the level of atmospheric deposition. While assessing the contribution of individual pollution types by evaluating the solute loads based on the data acquired by non-continuous monitoring approaches, however, the amounts of phosphorus fractions, originating from erosion or re-suspension of e.g. stream bed sediments, as well as for nitrogen compounds, which are not detectable by point monitoring of water with monthly (or fortnightly) periodicity, are probably strongly underestimated (Kronvang et al. 2005; Hejzlar et al. 2008, Fučík et al. 2010a).

The causality between land use in a catchment and quality of surface and ground water represents a principle documented by many authors (Haygarth and Jarvis 2002; Žížala et al. 2010) with larger or smaller impacts and differences, this principle is valid for various types and scales of catchments. The main factors influencing the nitrogen burden in waters , in conditions of the (not only) Czech Crystalline Complex, are the percentage of arable land within an area and the artificial drainage systems (Lexa et al. 2006; Fučík et al. 2008; Kvítek et al. 2009; Wade et al. 1998). Agricultural land drainage together with ploughing causes a general change in oxidation-reduction conditions in the soil profile; mineralization of organic nitrogen is accelerated and denitrification activity decreases. In contrast to permanent grasslands (further referred to as PGL), arable land lacks nitrogen-reducing vegetation, so that especially in winter and spring months nitrogen is leached into lower soil horizons, vadose zone, drainage and groundwater (Haberle et al. 2009; Kvítek and Doležal 2003).

Export of phosphorus compounds from non-point agricultural sources, occurring mainly through surface runoff, erosion processes and partly also via subsurface runoff, e.g. tile drainage (see e.g. Buczko et al. 2007; Deasy et al. 2008), is generally dependent on the slope gradients and their lengths in catchments, rainfall intensity, crop rotations, agronomical practices, soil types (namely soil

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texture, soil profile depth) and their actual conditions (wetness, bypass flow) and on the percentage of arable land in a catchment as well (Ekholm et al. 2000; Kronvang et al. 2003; Janeček 2007).

In recent years, research in the Czech Republic and abroad has focused on the effects of fluctuating ratio of various runoff components on pollutant loads from non-point sources (e.g. Hermann et al. 2008; Tomer et al. 2010; Zajíček et al. 2011). The validity of the hypothesis postulating the dominant effect of land use in the 'source areas' on surface and shallow groundwater quality in the conditions of Czech Crystalline Complex (Doležal and Kvítek 2004), has been verified experimentally. So far, this hypothesis has only been validated for nitrates (Fučík et al. 2010b) and thermal regime of different drainage runoff components (Zajíček et al. 2011); however, the hypothesis may be applied more extensively, namely to the pollutant-transporting medium – water; to its behaviour in the soil and hydro-geologic environment of the unsaturated zone of the Crystalline Complex. While testing this hypothesis it has been found that the drainage systems situated in the soils with crystalline bedrock and built in slopes only rarely receive water infiltrated directly from rainfall or ground water accumulated under the drainage system (Zajíček et al. 2011). In such cases the drainage system is often connected to a distant spring effluent or a shallow aquifer supplied from a source located outside the drainage system itself (Kvítek and Doležal 2003). The total runoff of the Bohemio-Moravian Highlands consists in ca 40% of shallow interflow and in ca 30% of baseflow (Doležal and Kvítek 2004).

By 1990, more than 1,078,000 ha have been drained in the Czech Republic (Kulhavý et al. 2007). Investigation of non-point pollution sources was therefore focused on the drainage systems that could significantly contribute to the nutrient load of surface waters. The presence of drainage systems modifies the natural pathways of water circulation and runoff – depending on soil characteristics and morphological conditions of a locality, weather course and parameters of the drainage system, the drainage usually shortens water cycle and retention time in the soil-rock environment (Doležal et al. 2000). Due to the characteristic shallow pattern of water circulation in the Crystalline Complex, the morphologically higher situated localities are hydrologically connected with the drainage system and have essential impact on the formation of runoff and the quality of drainage water. The soils located in upper parts of the landscape are typically shallow with little sloping, and so prone to accelerated infiltration (Kvítek and Doležal 2003). It is therefore reasonable to expect that the landuse within the most vulnerable enclaves due to infiltration – critical source areas of the catchments – will significantly influence the hydrology and hydrochemistry dynamics of tile drainage systems built on the territory of the Czech Crystalline Complex.

Although transformation processes of both major nutrients (nitrogen and phosphorus) occurring in agriculturally exploited land have been relatively well documented, it is difficult to predict and quantify the loss of nutrients from agricultural non-point pollution sources and precisely localize their origin. A number of studies have confirmed the validity of the method of identifying the 'critical source areas' in a catchment as an appropriate approach to the description of nutrient loss pathways. This principle has been recognized and used in various modifications worldwide (see e.g. Pionke et al. 2000; Heathwaite et al. 2005; Lyon et al. 2006; Srinivasan et al. 2005; Strobl et al. 2006).

There are several ways of perception and usage of the term „vulnerability" across the scientific field, very often being addressed exclusively to vadose zone, aquifers or groundwater (Gogu et al. 2000) or to a whole environment, as a result of all factors which may mutually affect the dynamics of surface and groundwater quality in an area. The definition of the latter interpretation describes the Intergovernmental Panel on Climate Change (IPCC 2001) as a function of exposure, sensitivity and adaptive capacity, where exposure means a system's degree of exposure to external impacts, sensitivity is the degree to which a system responds to external impacts and adaptive capacity is defined as "the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate" (IPCC 2001). In this study, vulnerability is considered as a fusion of exposure and sensitivity, being expressed in a qualitative (shallow groundwater vulnerability and direct protection) and quantitative (erosion) conception.

The main goal of this work is to document the methodology of defining the three types of critical source areas on the example of two closely situated, but different catchments of the Water Reservoir Orlík, with the purpose to reduce the nutrient leaching into surface and groundwaters.

2. Study area

The model catchments of the Hrejkovický and Bilinský brooks in the watershed area of Water Reservoir Orlík (Fig. 1) were selected as both best representing and distinctive the land cover species and built tile drainage systems. Both the catchments also contained monitoring objects (profiles).

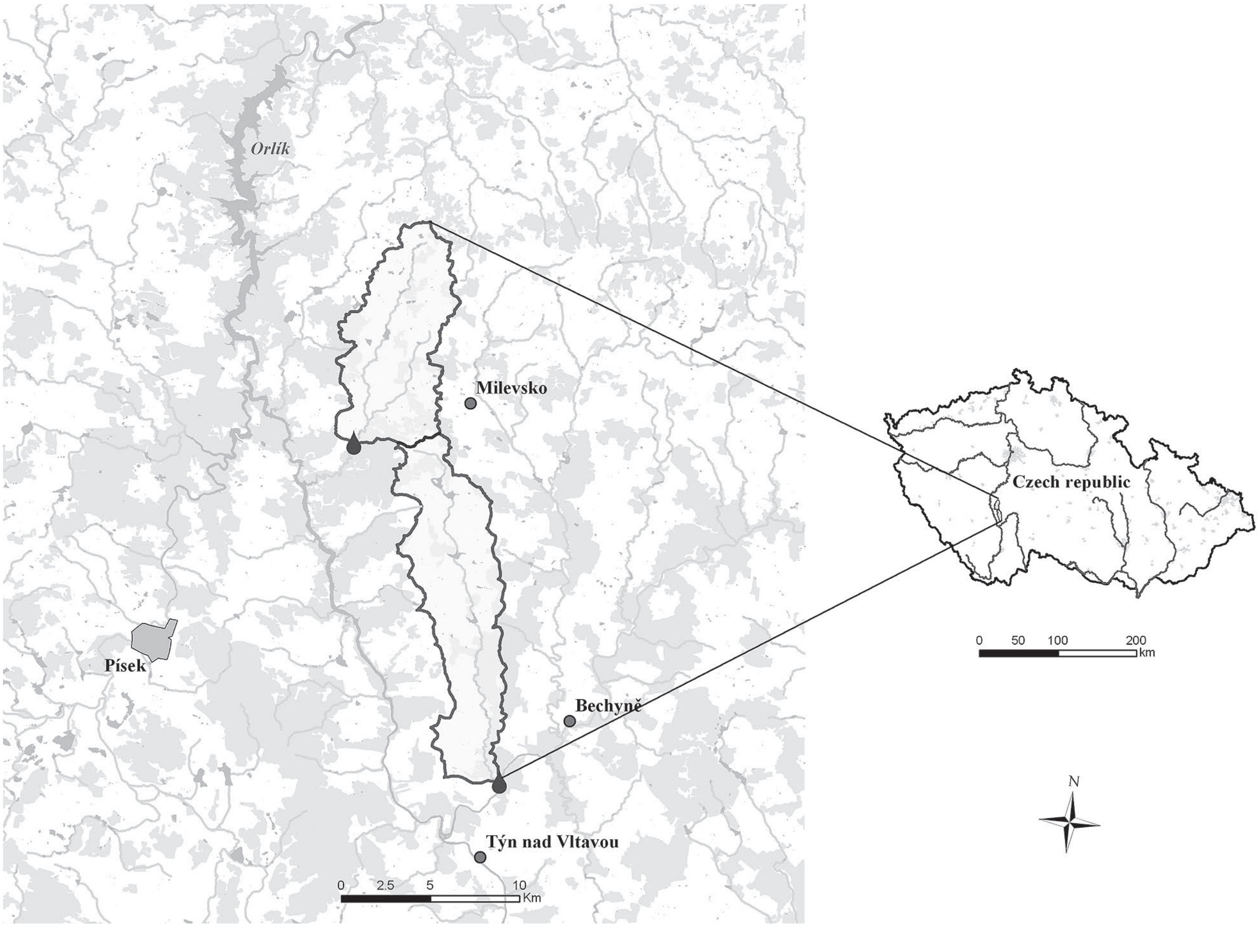

Fig. 1 Study area

Hrejkovický Brook

Profile number 211 008
Catchment area – 58.21 km²
Slope: average – 3.63°
maximum – 28.43°
Altitude: minimum – 420.30 m a.s.l.
maximum – 608.32 m a.s.l.

The dominant evaluated soil types were mesobasic and eubasic modal Cambisols on coarse weathered rocks (30.33%), weakly gleyic Regosols and Cambisols (24.16%), and brown Gleysols (16.85%).

Hydrogeological region – Crystalline complex in the catchment of the central Vltava River

By its geomorphologic distribution, the southern part of the catchment belongs to the Milevsko Hills and its northern part to the Kovářov Uplands. The Milevsko Hills display broken topography, sitting mostly on granitoids of the Central Bohemian Pluton, with articulated erosion-denudation relief broken by structural ridges and monadnocks. The Kovářov Uplands are flat uplands sitting on granitoids of the Central Bohemian Pluton with articulated erosion-denudation relief.

The brook is a right-hand affluent of the Vltava River.

Of demographic importance in this catchment is the Hrejkovice municipality with 465 inhabitants.

Bilinský Brook

Profile number 211 064 (211 063)
Catchment area – 71.46 km² (211 064)
Slope: average – 2.97°
maximum – 40.15°
Altitude: minimum – 379.41 m a.s.l.
maximum – 570 m a.s.l.

The dominant soil types were arenic, weakly gleyic Regosols and Cambisols (23.33%), modal eubasic to mesobasic Cambisols, medium-textured (14.58%), and modal Luvic Pseudogleys and gleyic Cambisols (12.91%).

Hydrogeological region – Crystalline complex in the catchment of the central Vltava River

By its geomorphologic distribution, the catchment belongs to the Bechyně Hills, represented by an erosion-denudation relief disturbed by faults in the N-S direction, with structural monadnocks displaying remnants of tabulated surfaces and deeply cut valleys.

The brook is a right-hand affluent of the Lužnice River.

Sources of geographical data used in this work:
- Valuated Soil Ecological Units (VSEU) – graphical and numerical database of soil data in original mapping scale 1 : 5000; these data were originally intended for soil pricing

– Land Parcel Identification System (LPIS)
– CORINE Land Cover
– Digital Elevation Model (DEM 10 ×10 m)
– Digital Base of Water Management Data (DIBAVOD)
– Principal Base of Geographic Data 1 : 10,000 (ZABAGED)
– Synthetic map of ground water vulnerability (Novák et al. 2010)

As an additional source we used information of the drainage systems placement from the mapping documentation of the former Agricultural Water Management Authority of the Czech Republic scaled 1: 10,000 on the Basic Map of the Czech Republic.

3. Methods

Critical source areas of non-point agricultural pollution are generally represented by agricultural land enclaves with high potential risk associated with fast export of nutrients and pollutants or soil particles (Pionke et al. 1996). In our work, the critical source areas were classified using three criteria. First, they represent source areas of increased potential leaching of pollutants into drainage and groundwaters, determined according to the vulnerability of ground water with shallow circulation (Janglová et al. 2003; Novák et al. 2010); second, they represent areas prone to erosion defined by the USLE method (Wischmaier-Smith 1978) in combination with DEM analysis; and third, they are defined as direct protection localities of water courses, represented by districts closely associated with the embankment zones of water courses. The classification of critical source areas of non-point agricultural pollution was done in the ARC GIS environment.

The initial analysis of LULC (Land Use Land Cover) development was done using the CORINE Land Cover data layer, recording the representation of land cover species in the model catchments in 1990, 2000, and 2006. The classification system assigns individual categories to the land type groups (211 – non-irrigated arable land, 231 – meadows and pastures, 243 – agricultural areas with natural vegetation, 312 – coniferous forests). The impact of LULC on the quality of surface water is reflected mainly in the proportion of arable land and PGL in the total area of agricultural land. Due to the 1 : 200,000 scale of the background source, the classification of some land types into categories in this background suffers a certain extent of bias and ambiguity (Hanzlová et al. 2007).

A more detailed LULC background is provided by the LPIS 2010 system (colour appendix Figs IV–V) operated by the Czech Ministry of Agriculture. This is a system of graphic records of farming sections based on cadastral records, with links to complex information including data on the land type (culture). This material keeps records of only registered land users receiving various fundings within the State agricultural policy, so that the system leaves uncovered areas. It is the faithful representation of the current situation of agricultural land fund containing information on the allocation of agricultural State funding. The only disadvantage of its use is the difficulty of obtaining retrospective data. Data are distributed in the *.shp format.

3.1 Definition of shallow groundwater vulnerability

The layer of shallow groundwater vulnerability was generated using an analysis of VSEU codes. The graphical and numerical VSEU database is unique by the precision of its processed data scale – 1 : 5000 (Mašát et al. 2001). To assess the infiltration process we used the last four code digits – main land unit, slope, exposure, skeleton content and soil depth, which were classified into categories 1–5 (category 1 = highest infiltration capacity, 5 = lowest infiltration capacity). The individual code elements were then assigned weights expressing the significance of particular criteria for the infiltration process. Multiplication of category values by weight of the criterion and their mutual addition gave five categories of vulnerability in relation to the potential infiltration of precipitation water into the soil and rock environment (Figs 2–3), where categories 1 and 5 express the maximum and the minimum infiltration rates, respectively (Janglová et al. 2003). The method is protected by Utility Model No. 20352 registered with the Office of Industrial Property of the Czech Republic.

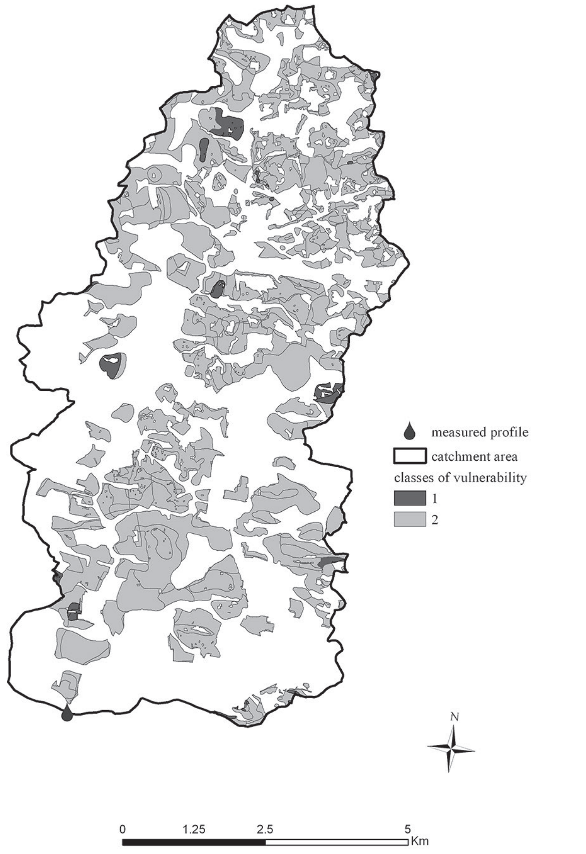

Fig. 2 Categorization of shallow groundwater vulnerability (Hrejkovický brook)

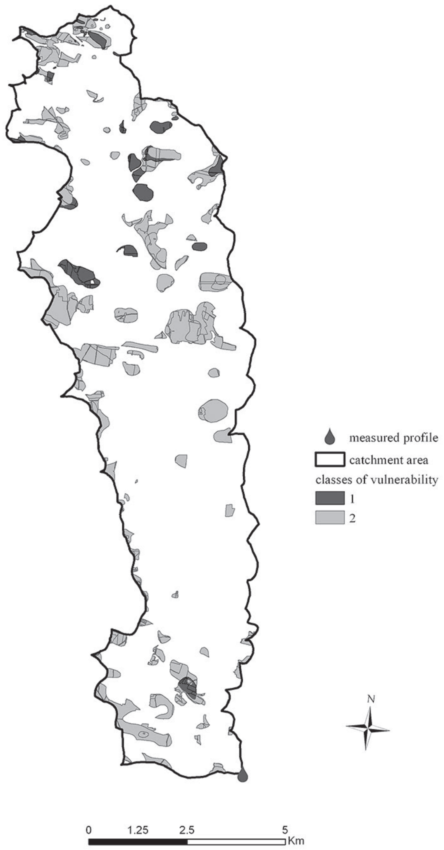

Fig. 3 Categorization of shallow groundwater vulnerability (Bilinský brook)

To obtain information about hydrological connectivity between the enclaves with different vulnerability levels of shallow groundwater and the agricultural drainage systems we used the GIS layer of the former Agricultural Water Management Authority of the Czech Republic with locations of the built drainage systems scaled 1 : 10,000, to which we generated subcatchments taking into account the local soil conditions and morphology using DEM. In the ARC GIS environment we then intersected the vulnerability categories 1 and 2 with these subcatchments and subsequently delineated the areas most vulnerable to leaching of risk compounds into shallow groundwater (Figs 4–5).

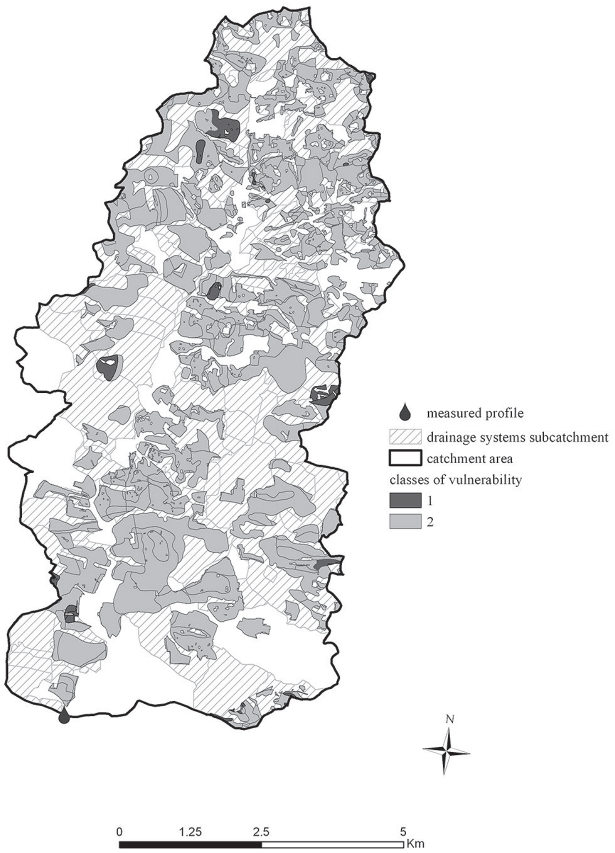

Fig. 4 Drainage systems subcatchment (Hrejkovický brook)

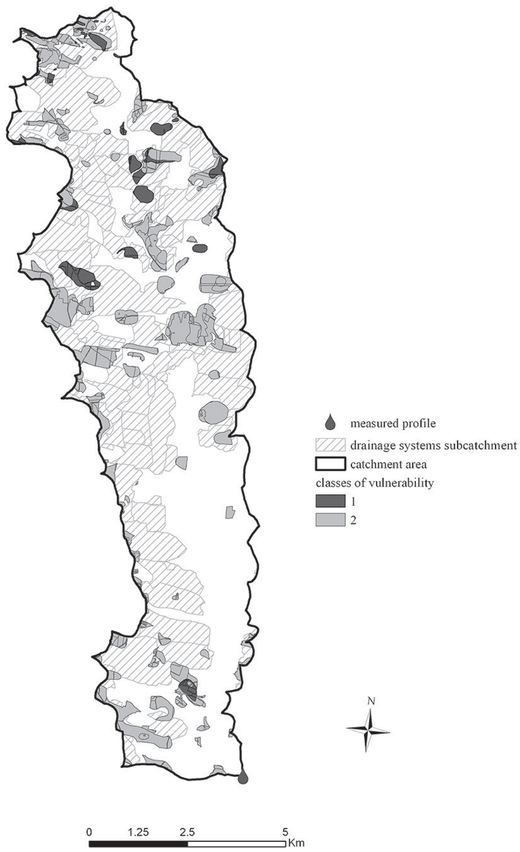

Fig. 5 Drainage systems subcatchment (Bilinský brook)

3.2 Definition of vulnerability to erosion

Selection of the risky localities due to erosion was done based on the long-term average soil loss using the Universal Soil Loss Equation, USLE (Wischmeier et al. 1978).

A = R · K · L · S · C · P
G = Computed soil loss per unit area ($t\ ha^{-1}\ year^{-1}$)
R = Rainfall factor
K = Soil erodibility factor
L = Slope length factor
S = Slope gradient factor
C = Cropping management factor
P = Erosion control management factor

The map of long-term average soil loss is presented as a raster layer with 10 m pixel resolution, containing the computed values of long-term soil loss per unit area (Novotný et al. 2010).

The erosive effect of a rain is determined by qualitative characteristics of the rainfall (kinetic energy, intensity, or their combination). For computing we used the recommended average value for the Czech Republic $R = 20\ MJ\ ha^{-1}\ cm\ h^{-1}$ (Janeček et al. 2007).

The soil erodibility factor represents the vulnerability of soil to erosion, i.e. the ability of soil to resist the erosive factors (precipitation, surface runoff). For computing we used the VSEU data scaled 1 : 5000, which were assigned updated values of K factor (Vopravil 2006).

To determine the LS factor we used GIS tools, establishing the LS factor separately for each square of the raster digital terrain model (DTM). The uninterrupted slope length was substituted with the runoff source area in square meters (micro-catchment) established separately for each land point (DTM square) (Desmet et al. 1996). The input data for computing were digital terrain model at the resolution corresponding to the scale and the layer of land use. These data serve to determine the slope and the area of a subcatchment substituting the length of runoff pathways. The S factor value is established for each point separately based on its local slope according to McCool approach (1987, 1989).

The cropping management factor (C) was defined based on the climate regions (Kadlec, Toman 2002).

The value of P was set 1, expressing the absence of any erosion-protective measures. Identification of land vulnerable to erosion was done by overlaying the map of long-term average soil loss with the LPIS database and selection of the areas with above-limit erosion (over $4\ t\ ha^{-1}\ year^{-1}$) in general conditions. In this way the land is assessed in relation to the long-term average soil loss – according to its area, slope gradient, morphology (convergence of surface runoff), local precipitation effect, soil characteristics, and protective cover effect (colour appendix Figs VI–VII). For selected soil sections we identified the relevant landowner plots.

When applying the methodology for selecting vulnerable areas relevant to protection of drinking water sources these limits are stricter, and the values of $0.5–2\ t\ ha^{-1}\ year^{-1}$ were considered as safe soil loss depending on the catchment characteristics (Janeček et al. 2007).

3.3 Definition of vulnerability from the aspect of direct protection

The areas for 'water course direct protection' are defined using generated soil representatives typical for alluvial localities, predominantly the Fluvisol soil group. Genetically, this soil group just corresponds to the area of recent floodplains, i.e. long-term and repeatedly waterlogged areas (Němeček et al. 2001). Sections of this vulnerability group are defined in more detail using the DEM data. The resulting information layer provides sufficient data to establish inundations, as 'direct protection localities of water courses' from the aspect of the water protection integrated system. In the flood plains, if not represented by natural floodplain forest, the proposed measures in the form of grassing or forestation must be strictly observed (including appropriate management) because of potential intensive leaching of risk compounds associated with fluctuations of groundwater level or presence of surface runoff (Kvítek et al. 2009). Flood plains are defined by the law as important landscape elements (Act No. 114/1992 of the Collection of Czech Laws).

3.4 Integrated approach to the definition of critical source areas

Combination of the three types of critical source areas defined in sections 3.1., 3.2., and 3.3. enables identification and global delineation of all potential source localities of non-point agricultural pollution. Their subsequent association with the LULC layer provides a current survey of the use of areas with potential non-point agricultural pollution in the territory of interest. The priority in this system poses an application of targeted grassing.

4. Results

Using the ArcGIS 10 software we evaluated the land use based on the CORINE layers and LPIS 2010 system. The investigated catchments were categorized according to CORINE classification in all stages of data processing (1990, 2000, 2006). Analysis of representation of the individual CORINE classes in the agricultural land fund (further referred to as ALF) in the particular years of data processing shows that both investigated catchments undergo gradual reduction of arable land proportion at the expense of PGL, and that in the Hrejkovický brook catchment the growth of PGL is more pronounced compared to the Bilinský brook, which shows a slower increase (Table 1).

Tab. 1 Development of arable land vs. PGL ratio in the catchments – CORINE

Hrejkovický brook [%]					Bilinský brook [%]							
CORINE	Profile No.	arable	PGL		Profile No.	arable	PGL		Profile No.	arable	PGL	
		211	231	243		211	231	243		211	231	243
1990	211 008	57.02	1.22	16.60	211 063	69.34	0.85	2.09	211 064	68.64	0.99	3.27
2000	211 008	53.85	4.39	16.60	211 063	69.34	0.85	2.09	211 064	68.52	1.10	3.27
2006	211 008	50.09	10.59	13.67	211 063	65.59	2.21	3.64	211 064	65.33	1.90	4.80

4.1 Assessment of shallow groundwater vulnerability

The proportions of arable land and PGL were analysed within the shallow groundwater vulnerability classes 1, 2 according to the LPIS and CORINE classifications, see Tables 2 and 3. LPIS data showed the proportions of arable land and PGL to be 49.5% and 33%, respectively. CORINE classification showed the following ratios in the Hrejkovický brook catchment: in 1990, the proportion of arable land was 73.97% vs. 21.36% PGL, in 2000 the ratio changed to 69.75% vs. 25.58% at the expense of PGL, and in 2006 the ratio was 65.27% vs. 30.35%, which around 9% decrease of ploughed land ratio compared to the initial situation. A similar analysis was performed for the Bilinský brook catchment, with the proportion of arable land 80.13% vs. 6.44% of PGL according to LPIS. More detailed analysis based on the CORINE classification did not bring such marked differences in these land proportions in the investigated years as in the Hrejkovický brook catchment, but the changes of landuse in vulnerability classes 1, 2 – from arable land to PGL – was also noticeable.

In the second phase of data processing, using the methodology for definition of shallow groundwater vulnerability, we performed an intersection of the areas with vulnerability classes 1, 2 with drainage system subcatchments to define the surfaces most vulnerable to leaching of risk compounds into surface and groundwater.

The analysis of vulnerability classes 1, 2 in drainage system subcatchments of the Hrejkovický brook shows that the vulnerability classes 1, 2 are present in the surface area of 18.89 km^2, representing 56.92% of ALF. In contrast, the drainage system subcatchments of the Bilinský brook show the presence of these vulnerability classes only in the surface area of 8.16 km^2, the percentage of vulnerability 1, 2 in ALF being 22.31% (Table 5).

We also analysed the proportion of arable land and PGL in vulnerability classes 1, 2 according to LPIS classification (Table 5). In drainage system subcatchments of the Hrejkovický brook we found the proportion of arable land and PGL to be 57.84% vs. 28.56%. A similar analysis was performed for the drainage system subcatchments of the Bilinský brook, showing that the proportion of arable land vs. PGL according to LPIS is 83.68% vs. 6.63%.

Tab. 2 Proportions of arable land and PGL within groundwater vulnerability classes 1, 2 (LPIS 2010)

LPIS				
Stream name	Profile No.	% vulnerability in ALF	Ratio arable x PGL [%]	
			arable	PGL
Hrejkovický brook	211 008	57.44	49.50	33.07
Bilinský brook	219 063	21.97	79.76	6.52
Bilinský brook	219 064	22.01	80.13	6.44

Tab. 3 Development of arable land and PGL ratios in groundwater vulnerability classes 1, 2 (CORINE)

Hrejkovický brook 211 - 008			Bilinský brook 219 - 063		Bilinský brook 219 - 064	
CORINE processing	Ratio arable x PGL [%]		Ratio arable x PGL [%]		Ratio arable x PGL [%]	
	arable	PGL	arable	PGL	arable	PGL
1990	73.97	21.36	94.97	0.59	94.16	0.78
2000	69.75	25.58	94.97	0.59	93.96	0.98
2006	65.27	30.35	91.34	3.86	90.95	3.66

Tab. 4 Area of drainage system subcatchments and the area of ALF in drainage system subcatchments

Stream name	Profile No.	Subcatchment area [ha]	ALF in subcatchment [ha]	% ALF in subcatchment
Hrejkovický brook	211 008	4139.67	3319.40	80.19
Bilinský brook	219 063	3629.20	3152.27	86.86
Bilinský brook	219 064	4153.08	3661.03	88.15

Tab. 5 Proportion of groundwater vulnerability classes 1, 2 on arable land and PGL (LPIS 2010) within drainage system subcatchments

LPIS				
Stream name	Profile No.	% vulnerability in ALF	Ratio arable x PGL [%]	
			arable	PGL
Hrejkovický brook	211 008	56.92	57.84	28.56
Bilinský brook	219 063	22.91	83.46	6.89
Bilinský brook	219 064	22.31	83.68	6.63

4.2 Assessment of land vulnerability to water erosion

The assessment of land vulnerability to water erosion based on computing the acceptable soil loss by water erosion brought different results for the investigated catchments (Table 6). While in the Hrejkovický brook catchment the situation corresponded with the results of slope gradient determination, and land plots with G value exceeding 4 t ha^{-1} $year^{-1}$ included only 2% of arable land, in the Bilinský brook catchment these land plots comprised 10% of arable land due to the higher length of uninterrupted slopes.

4.3 Assessment of vulnerability related to direct protection

The results of direct protection analysis corresponded with the hydro-morphology of the investigated catchments. While in lateral profiles the Hrejkovický brook catchment shows features typical for flat catchments, and thus higher representation of floodplain soils, the Bilinský brook catchment is characterized by lower mean width of the catchment, reflected in lower proportion of floodplain soils in the catchment. The proportion of the floodplain soil group in the Hrejkovický brook catchment is 3.15% vs. 1.43% in the Bilinský brook catchment.

5. Discussion and Conclusions

The potential source areas of agricultural non-point pollution were defined by combining all the three described principles of delineating critical source areas, while subsequent association with the LULC layer led to determination of the current extent and distribution of the source areas of non-point agricultural pollution in the territory of interest.

Concerning the distribution of land use types, both catchments showed a high proportion of agricultural land, Hrejkovický brook with 72.76% and Bilinský brook with 74.25% (CORINE 2006). Detailed analysis based on LPIS revealed the current ratio of PGL vs. arable land to be 33.07% vs. 49.50% in the Hrejkovický brook catchment and PGL vs. arable land to be 6.44% vs. 80.13% in the Bilinský brook catchment (the remaining percentage excluding LPIS), while in the long-term perspective we can notice a reduction of arable land compared to PGL growth in both investigated catchments.

Assessment of shallow groundwater vulnerability brought very diverse results for the particular catchments, which is mainly due to the second criterion for vulnerable area definition, i.e. an interaction with drainage systems.

Tab. 6 Percentage of classes of acceptable soil loss by erosion in individual types of land use

Acceptable soil loss – G – percentage [%]									
Hrejkovický brook 211-08				Bilinský brook 211-063			Bilinský brook 211-064		
G [t ha^{-1} $year^{-1}$]	Arable land	PGL	Soil sections total	Arable land	PGL	Soil sections total	Arable land	PGL	Soil sections total
Less than 1	59	98	73	50	99	59	45	97	54
1–2	27	1	17	26	1	21	24	1	20
2–4	12	1	9	18	0	15	20	1	16
4–10	2	0	1	6	0	5	10	1	9
Over 10	0	0	0	0	0	0	1	0	1

Much higher occurrence of tile drainage is found in the Hrejkovický brook catchment with 56.92% of ALF within drainage subcatchments being situated in first and second vulnerability clasess, but only by about 58% covered by arable land. In comparison, the Bilinský brook catchment had the ratio of ALF within drainage subcatchments on first and second vulnerability clasess 22.31 and 22.91%, respectively, used nearly by 84% as arable land.

Analysis of the potential soil loss due to erosion in Hrejkovický and Bilinský brook catchments corresponded to the slope characteristics and land use. The Bilinský brook catchment thus showed relatively high vulnerability to erosive effects namely in the lower part of the catchment, where as much as 10% of arable land was found in the interval 4–10 t ha^{-1} $year^{-1}$. Contrary to that, the Hrejkovický brook catchment may be characterized as significantly less threatened by erosion, in accord with its geographic characteristics.

The vulnerability associated with direct protection of water courses is defined according to the soil types in the immediate environment of the water courses. Its extent directly correlated with the morphology of alluvial location of these catchments. The direct protection should be implemented in 3.15% of the area of Hrejkovický brook catchment compared to 1.43% in the Bilinský brook catchment.

The described methodology serves for detailed definition and delineation of individual types of critical source areas of non-point agricultural pollution in the particular catchment zones. It is an appropriate tool for proposing measures to reduce the proportion of non-point sources of surface and shallow groundwater pollution with nutrients and risk compounds. A great advantage is that protective measures can be proposed for the particular landowner plot. There is a range of various methods which deal with the assessment of potential of non point pollution sources in agricultural catchments of different scales. However, predominance of these approaches usually do not encompass all the possible runoff pathways and potential contaminants in a landscape; they either focus separately on leaching (nitrate) or on overland flow and erosion processes (suspended solids and phosphorus). The most widespread approach for evaluation of groundwater vulnerability is the DRASTIC model (Aller et al. 1987; Murray and Rogers 1999), even though a number of other techniques have been developed and used in this field (Civita 2010).

Compared to other approaches, the originality of presented method is provided by the precision of the used data, scaled 1 : 5000 for pedology data and the layer of production sections representing landowner plots integrated into higher units with uniform culture. The generally used scales for pedology data are in the range of 1 : 50–200,000.

This work was aimed to document the differences in results obtained by the used methodology for definition of the critical source areas at two closely situated catchments with different natural conditions and land management. Our future efforts will be oriented towards collection of hydrological and water quality data for verifying the accuracy and applicability of the described approach using hydrology and nutrient balance, or optionally mathematical modelling in the field of hydrology and hydrochemistry in the territories of interest.

The presented methodology for defining the critical source areas of non-point agricultural pollution has been employed during designing of projects dealing with water protection, particularly in protection zones of water supply reservoirs, and by its complex approach is applicable to the large practice of natural resource preservation. The approach is further elaborated and modified in ongoing research projects.

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RÉSUMÉ

Integrovaný přístup k řešení problematiky plošného zemědělského znečištění v ČR

Příspěvek popisuje nový, integrovaný přístup v metodách identifikace a lokalizace potenciálních kritických zdrojových oblastí plošného znečištění povrchových vod dusíkem a fosforem, který je představen na modelových povodích IV. řádu Hrejkovického a Bilinského potoka v povodí vodní nádrže Orlík. Ohroženost vod plošným znečištěním je posuzována geografickou analýzou, která hodnotí geomorfologii, způsob využití a půdní podmínky území, ve vazbě na stavby zemědělského odvodnění. Vedle ploch podléhajících erozi a lokalit tzv. přímé ochrany podél vodních toků, jsou vymezovány oblasti zvýšeného potenciálního vyplavování živin do podzemních a drenážních vod, stanovené na základě syntetické mapy zranitelnosti mělkých podzemních vod. Tyto oblasti jsou klasifikovány na základě analýzy kódu bonitovaných půdně ekologických jednotek (BPEJ) a zemědělské odvodnění podle podkladů bývalé Zemědělské vodohospodářské správy (ZVHS).

Z výsledků geografické analýzy vyplývá rozdíl mezi dvěma sousedními povodími a jejich potenciálem k působení plošného zemědělského znečištění. Z výsledků analýzy LULC je patrný zhruba stejný podíl zemědělské půdy pro obě povodí ovšem struktura základních dvou druhů pozemků (orná půda x trvalé travní porosty) je odlišná. Vyšší podíl zatravnění je v povodí Hrejkovického potoka oproti Bilinskému, kde je zastoupení TTP relativně nízké. Z hlediska zranitelnosti vyplavování rizikových látek do povrchových a podzemních vod jsou náchylná obě povodí; povodí Bilinského potoka z důvodu převahy orné půdy na plochách se zranitelností 1. a 2. kategorie v mikropovodích drenážních systémů, povodí Hrejkovického potoka pro velmi častý výskyt ploch s 1. a 2. kategorií zranitelnosti (58% ZPF). Z hlediska potenciálního rizika výskytu eroze na zemědělské půdě je ohroženější Bilinský potok, zejména v dolní části povodí.