Specific pesticide groundwater vulnerability and contamination risk maps of the Czech Republic

Kodeš, V.1; Kodešová, R.2; Brodský, L.3

1 Department of Water Quality, Czech Hydrometeorological Institute, Na Šabatce 17, 14306 Prague, CZ
2 Department of Soil Science and Soil Protection, Czech University of Life Sciences, Kamýcká 952, 162 57 Prague, CZ
3 Department of Remote Sensing, GISAT Ltd, Milady Horákové 57, 170 00 Prague, CZ

kodesova@af.czu.cz

Introduction

Groundwater contamination caused by pesticides used in agriculture is an environmental problem worldwide. Groundwater contamination depends on many factors and conditions. Groundwater vulnerability maps may be constructed using the DRASTIC methodology (Aller et al., 1987), which considers following factors: depth of groundwater table, net recharge, lithology of an aquifer, soil material, topography, lithology of a vadose zone and hydraulic conductivity of an aquifer. Two DRASTIC models have been developed to predict generic groundwater vulnerability and pesticide groundwater vulnerability. They differ in weights, which are used to multiply the DRASTIC rating for each input layer, and summed to determine the DRASTIC vulnerability index. Both models were widely applied, but none of presented studies considered specific behaviour of particular chemicals in soils, which may considerably affect groundwater vulnerability. The potential groundwater contamination by pesticides also depends on amount of particular pesticide applied at the soil surface. Application (dose and timing) depends on plant, for which protection are used.

Groundwater is an important source of drinking water in the Czech Republic. The goal of this study was to design the groundwater vulnerability and contamination risk maps for eleven selected pesticides to optimize groundwater quality monitoring system in the Czech Republic. To design these maps the Pesticide DRASTIC methodology was extended to take into account particular pesticide behavior (e.g. its adsorption in various soils and half-life) and estimation of spatial pesticides’ distribution within the Czech Republic.

Material and methods

The Pesticide DRASTIC methodology was first applied to calculated vulnerability index. The GIS layers of the 7 DRASTIC parameters were prepared using GIS tools and the intrinsic pesticide groundwater vulnerability map was calculated by map algebra functions.

Then two new indexes (mobility index and stability index) were proposed and used combining with the Pesticide DRASTIC vulnerability index to calculate the specific vulnerability index. Resulting indexes were applied to construct specific pesticide groundwater vulnerability maps. The index of mobility was derived from the Freundlich adsorption coefficient. Spatial distributions of coefficients for selected pesticides were created based on the developed pedotransfer rules for 11 pesticides (azoxystrobin, fipronil, chlormequat chloride, chlorotoluron, hexazinone, metolachlor, metribuzin, prometryn, terbutylazine, thiacloprid and trifluralin), soil map and soil properties database (Kodešová et al., 2011). The index of stability was derived from the pesticide half-life (the average value for each pesticide).

Next the potential distribution of particular pesticide within the Czech Republic during years 2007 and 2009 was estimated. The method was based on remote sensing data crop classification (e.g. delineation of the areas of particular crop within each county), annual statistics on usage of pesticides on certain crops at county level (e.g. total applied amount of particular pesticides on various crops/groups of crops within each county registered by State
Phytosanitary Administration of the Czech Republic during 2007-2009) and the link between the crops, plant protection products and active substance (e.g. information about type and usage of particular pesticides for each crop protection). The method provided an estimate of redistribution from county aggregated data into pesticide loads per 1 square km on arable land (e.g. with respect to crop distribution). Areas with predominant occurrence of specific crop were mapped using the medium spatial and high temporal resolution ESA Envisat MERIS FR images together with the single high spatial resolution IRS AWiFS image covering the whole area of interest.

By combination of specific vulnerability maps and spatial distribution of estimates of pesticides loads, the specific pesticide groundwater contamination risk index was calculated and the groundwater contamination risk maps were derived. The specific pesticide groundwater contamination risk index was calculated from the normalized values of the specific pesticide vulnerability index and pesticide load with respect to maximum cell values. The results of the extended groundwater quality monitoring in 2009 were used to validate obtained maps.

Results

Improved method produced groundwater vulnerability maps and groundwater contamination risk maps, which more specifically indicated areas with increased groundwater contamination threat. While classes of groundwater vulnerability in the single intrinsic groundwater vulnerability map mostly reflected depth of groundwater table and vadose zone permeability, classes in the specific pesticide groundwater vulnerability maps more explicitly delineated areas of increased specific pesticide groundwater vulnerability reflecting mainly depth of groundwater table and soil cover. Even greater diversification would be obtained if variable pesticide degradation rates (e.g. assumption of variable soil and climatic condition) would be assumed. Areas of the very high to medium risk of groundwater contamination in the groundwater contamination risk maps were even more strictly delineated in comparison with original intrinsic or specific pesticide groundwater vulnerability maps.

Observed groundwater contamination by specific pesticide mostly corresponds with regions of the very high and medium risk of groundwater contamination. However, since the position of monitoring well exactly does not often precisely correspond to position of delineated areas of high groundwater contamination risk, regression analysis could not be used to document model validity. This could be attributed to a lateral flow of the ground water (due to very complex and complicated hydrogeological conditions of the Czech Republic). The pesticide percolation towards the groundwater table may be also accelerated due to the preferential flow in soils with strongly developed structural elements (Kodešová et al., 2012) and/or flow through geological fractures etc. Pesticide percolation may be also influenced by the actual climatic conditions. Finally, detection of particular pesticide in groundwater also depends on the groundwater monitoring timing (e.g. combination of the time of pesticide application at the soil surface, pesticide percolation time towards to groundwater table and time of groundwater sampling).

References

