AQUARIUS project

Assessing water quality improvement options concerning nutrient and pharmaceutical contaminants in rural watersheds

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Czech-Norwegian Research Programme (CZ09), project n. 7F14341 (2014 – 2017)

norway grants

Supported by Norway Grants

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NIBIO NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH

This publication has been released within the project 7F14341 - Assessing water quality improvement options concerning nutrient and pharmaceutical contaminants in rural watersheds (AQUARIUS) co-funded by the Norway Grants.
Through the Norway Grants and EEA Grants Norway contribute to reducing social and economic disparities and to strengthening bilateral relations with the beneficiary countries in Europe. Norway cooperates closely with the EU through the Agreement on the European Economic Area (EEA).
For the period 2009-14, the EEA Grants and Norway Grants amount to €1.7 billion. Grants are available for NGOs, research and academic institutions, and the public and private sectors in the 12 newest EU member states, Greece, Portugal and Spain. There is broad cooperation with Norwegian entities, and activities may be implemented until 2016. Key areas of support are environmental protection and climate change, research and scholarships, civil society, health and children, gender equality, justice and cultural heritage.

The project **AQUARIUS** is focused on evaluation of significant point and non-point sources of water pollution and its origins including evaluating the current/typical and alternative waste water treatment methods, aiming at minimizing surface and groundwater pollution. Attention is turned to reveal the true concentration/load dynamics of main nutrients and pharmaceuticals and personal care products (PPCPs), for which the factors/parameters of the related processes are assessed. The project assesses cost effective land and agricultural management actions or measures and waste water treatment technologies, including the use of constructed wetlands, to enhance landscape´s retaining water potential and to reduce input of pollutants into waters. Both for water quantity and quality, methods of continuous monitoring are employed in submerged hydrological and hydrogeological units of various scales. Results from monitoring serve as a base for modelling approach within a catchment area. Short term events as well as long term water balance are modelled to distinguish and quantify runoff components and pollution being transported by them. Models simulate diverse scenarios of land use, agricultural management, wastewater technologies and involvement of various biotechnical measures to increase water retention time in a catchment and to enhance surface and groundwater quality. The project outcomes are necessary for completing conceptual and expert documents and guidelines for soil and water conservative management and proper wastewater treatment in a catchment scale, as well as for planning of land use within areas used as water supply sources.

The **AQUARIUS** work plan is divided between 4 technical WPs and 1 WP dedicated to management, dissemination and coordination.

WP1: Testing the efficiency in removal of nutrients and pharmaceuticals from waste water

Objective: Testing the effectiveness of diverse alternative wastewater treatment approaches/methods and formulating their applicability for small villages/dwellings. Aspects of: water quality and quantity, costs, management.

WP2: Monitoring of waste water types, surface- and groundwater pollution in the catchment sites

Objective: Reveal the true concentration/load dynamics and source of origin of the main nutrients and PPCPs. Assess the effectiveness of current treatment technologies for waste waters containing pharmaceuticals and the processes of natural attenuation of pharmaceuticals in the rock environment.

WP3: Modelling of hydrological and environmental data

Objective: Integration of findings from WP1 and WP2 to model water and nutrient balance of selected area (watershed, sub-catchment/wetland system itself or more units together).

WP4: Cost and social analyses

Objective: Assessment of all measures / changes in waste water treatments and catchment management from the view of cost / effectiveness to formulate options for (re)constructing the WWTP, wetlands and/or alterations on land use within a catchment (grassing of arable land, etc.).

WP5: Coordination, dissemination and management

WP6: Economical and social problems of drugs in water

This WP6 was added in the year 2016 to support the socio-economic results of the project.

Main objective of additional research activities is to increase the quality of ongoing sociological survey among Czech and Norwegian populations. This survey examines the reaction of people to information that the water for the drinking purposes contains potentially harmful substances. These issues are addressed by means of statistical evaluation of questionnaires distributed in network of Norwegian and Czech communities around the existing pilot sites. The questionnaire, which takes into account social, economic and genders factors, age and education issues, has already been designed and approved by the Czech and Norwegian partners. The weakness of the existing solutions is the limited informative value of this survey, which is based on a relatively small number of the answers, which, in addition, will come from only a few locations.

The aim of additional research activities is to eliminate this problem and to expand an inquiry to a much wider range of respondents. New study should gain a statistically more significant amount of data, which will include a more diverse set of processed data (including e.g. the urban population, the municipality of protected areas and vice versa very environmentally affected regions). This will significantly improve the planned output.

Pict. 1 Constructed wetland Chmelná in the Czech Republic designed to treat municipal sewage.

Pict. 2 Constructed wetland Gryteland in Norway designed for treatment of agricultural runoff.

WP1. Testing the efficiency in removal of nutrients and pharmaceuticals from wastewater

The aim of WP1 is to evaluate treatment efficiency of constructed wetlands in the watersheds of drinking water reservoirs Švihov in the Czech Republic and Lake Gjersjøen in Norway. In the Czech Republic, four constructed wetlands that have been in operation between 12 and 25 years were selected (Pict. 1). All constructed wetlands treat municipal sewage from small villages. In Norway, two constructed wetlands were selected (Pict. 2). The first system is designed to treat a mixture of municipal sewage and road runoff, the second system has been designed to treat agricultural runoff and drainage. Treatment efficiency is evaluated on the basis of chemical parameters such as organics, suspended solids, nitrogen and phosphorus. In addition, 47 pharmaceuticals including several metabolites were evaluated as well. The monitored pharmaceuticals belongs to NSAID drugs (non-steroidal anti-inflammatory drugs, antibiotics, antibacterial agents, pain relievers, anticoagulants, antidepressants, beta-blockers, diuretics, antiepileptics and fibrates). Both in Norway and the Czech Republic, the effect of discharged water on receiving streams is evaluated as well. In Norway tracking of the pollution sources (microbial source tracking – MST), in particular human (mostly from wastewater) and non-human (mostly form agriculture) has been performed. For this reason, microbial analyses of faecal water pollution (*E. coli*) and molecular tests applying a suite of sensitive host-specific quantitative real-time PCR were employed to determinate the source and origin of the contaminants.

The results indicate that constructed wetlands in the Czech Republic exhibit very high removal of organics and suspended solids while removal of ammonia and phosphorus is lower. However, this is expected as all constructed wetlands with horizontal subsurface flow are predominantly anoxic and therefore do not support nitrification. Due to low flow, the effect on water quality in receiving streams is negligible. Similar results were found in Norway despite different wastewater characteristics (much lower inflow concentrations). Pharmaceuticals were quite commonly recorded in inflow water samples in high concentrations with the highest concentrations being found for paracetamol, caffeine, furosemide and ibuprofen. Treatment efficiency for pharmaceuticals varies widely between 90% (paracetamol) and 10% (gabapentin). The microbial analyses revealed very wide fluctuation of human and non-human bacteria ratio during the year. Also, the ratio between total coliforms and *E. coli* varies during the year. *E. coli* were dominating in a mixture of sewage and road runoff while total coliforms dominated agricultural runoff.

WP2. Monitoring of drainage-, surface- and groundwater pollution in the catchment sites

The main aims of WP2 are to reveal the true concentration/load dynamics and sources of pollution in small water courses, and tile drainage under different soil, land use and agricultural management manners, in drinking water reservoir basins in Czechia and in Norway. Further goals are to assess the effectiveness of current treatment technologies for waste waters containing pharmaceuticals and the processes of natural attenuation of pharmaceuticals in the rock environment in order to increase the efficiency of wastewater treatment in the existing sewage treatment plants. To achieve this, two small agricultural, tile-drained catchments are monitored within drinking water reservoir basin Švihov and one site for groundwater monitoring close to Prague in Czechia. Gryteland stream in the Skuterud catchment is monitored in Norway (Pict. 3). During the project, the continuous monitoring of discharge, nutrient (N, P) concentrations in waters, including rainfall-runoff (R-R) events by the help of automatic samplers is performed in tile-drained catchments to quantify the share of R-R events on the total nutrient flux. Moreover, measurement of stable isotopes ^{18}O and ^{2}H in precipitation, drainage waters and groundwater is realized to assess the mean water residence time (MRT) in catchments.

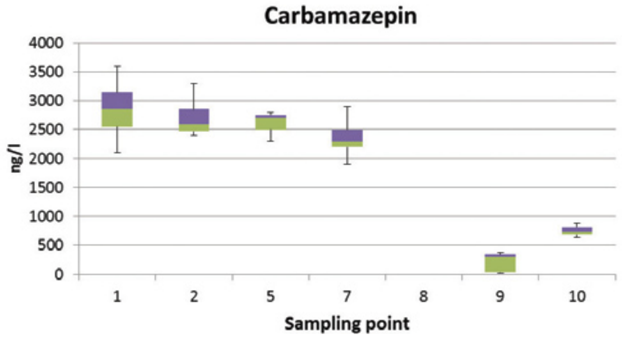
Pict. 3 Sampling spot of stream water at the Skuterud catchment in Norway.

The results show considerable differences among the Czech monitored tile-drained catchments and seasons in the years 2013–2016. MRT for baseflow is 0.5–3 years, whereas for quick flow components (interflow, overland flow), it is in minutes or hours. For small tile-drained catchments, the mean specific load was for N 3.5–55 kg ha^{-1} $year^{-1}$ and for P 0.025–0.45 kg ha^{-1} $year^{-1}$. The share of R-R events on N loads was 5–30% (on average 24%) of the total year load, whereas for P (dissolved and total), the share of discharge events was 10–80% (on average 43%) on the total year load. The most precise method for solute load estimation was apparently the one including the R-R events. The methods for load assessment based on point monitoring of discharge and water quality under- or over-estimated the solute loads of N by 10–20%, of P by 30–80%. Runoff and water residence time in catchments were revealed as the main driving forces influencing N and P dynamics in surface and drainage waters.

The acquired findings are useful for improvement of nutrient load assessment in tile-drained catchments of various scales, as already employed in Norway JOVA monitoring programme. Further, the gained knowledge can help to design various mitigation measures on agricultural land or tile drainage systems, together with an estimation of „lag time" for efficiency of these measures, applicable e.g. in Nitrate Directive, Water Framework Directive or River Basin Management Plans.

Special case study: Monitoring of pharmaceuticals in the vicinity of psychiatric hospital Horní Beřkovice

The environs of the psychiatric hospital at Horní Beřkovice in Central Bohemia represent a unique pilot site, where infiltration of treated wastewater into the aquifer has been taking place for decades. Ongoing complex monitoring compares the quality parameters of local wastewater and wastewater in four other catchments with no concentrated pharmaceuticals contamination sources. While the monitoring in a common sewage system showed 10 pharmaceuticals, at Horní Beřkovice their number increased threefold. Regularly monitoring of the water quality allowed to determine the efficacy of removal of pharmaceuticals from wastewater at the local sewage treatment plant. The monitoring also registered the fate of substances that move from the treatment plant into the recharge ponds and then gradually infiltrate into ground waters.



Pict. 4 Box plots of carbamazepine concentrations in Horní Beřkovice pilot site.

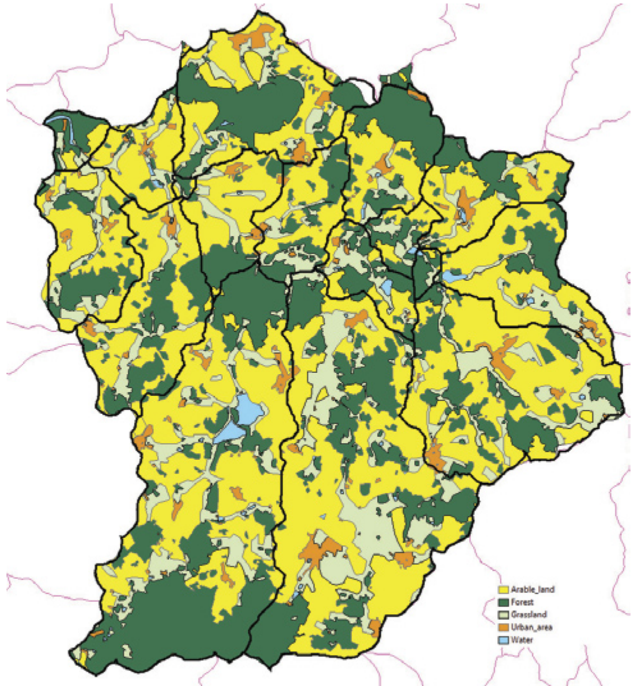
The results showed a significant decrease of all monitored micropollutants, which remained bound in sediments and in the unsaturated zone. Their passage into groundwater was very limited, and after a few hundreds of meters in the saturated zone they virtually disappear. The only locally problematic substance is Carbamazepine, for which the existing treatment technologies are inefficient. The substance passes through the unsaturated zone and systematically appears in samples of groundwater at a distance of about 1 km from the site of infiltration.

WP3. Modelling of hydrological and environmental data

Assessment of potential reduction in nitrogen loads by biotechnical measures

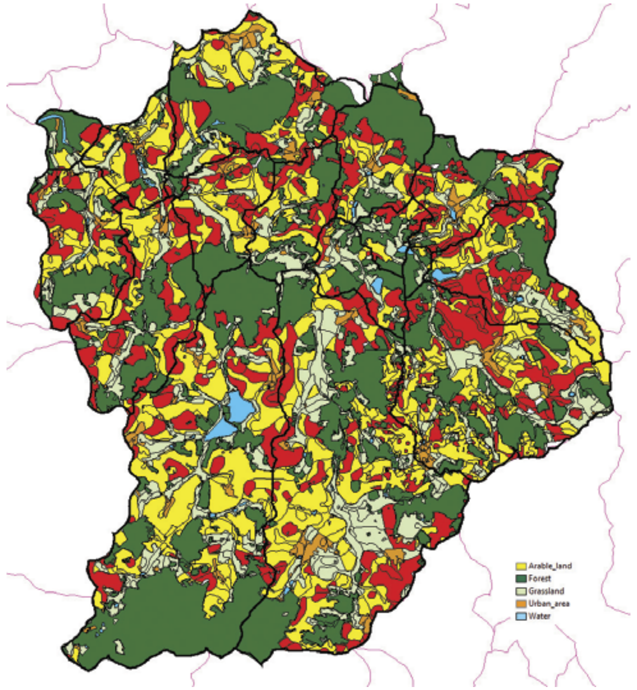
The Jankovský stream is a tributary to Zelivka river which contributes to the Svihov drinking water reservoir. The catchment has an area of 130 km² with elevation ranging between 445 – 765 m a.s.l. The catchment is a typical agriculturally exploited catchment (nearly 50% of area consists of arable land, about 30% is forested), see Pict. 5. It contains 37 settlements (with or without waste water treatment plants) and there is considerable number of fish ponds (1% of catchment area). Since the water quality is of a special concern due to the direct connection to the Svihov drinking water reservoir, we assessed the potential reduction of nitrogen loads in the catchment outlet by changing the land use (for reduction of diffusive sources) and construction of wetlends (for reduction of domestic polution).

Current sources of polution due to fertilization (amount and timing), livestock and domestic point sources were estimated from typical agricultural practices, data from Ministry of Agriculture and number of inhabitants and



Pict. 5 Current land use in Jankovský stream catchment.

tourists throughout the year. Two land use change scenarios were considered: limit scenario S0 which transforms all arable land to grass land and a more realistic S1 scenario transforming only arable land situated on coarse-textured, shallow and leaching-prone soils to grasslands leading to a 25% reducion in the proportion of arable land (Pict. 6). In addition we consider construction of wetland under each settlement. The effectiveness in reduction of nitrogen loads of a constructed wetland (45%) was estimated from long-term measurements. We used a Soil and Water Integrated Model (SWIM) for assessment of the effect of these measures. It was concluded that the limit land use scenario S0 leads to reduction of nitrogen loads in the catchment outlet by ca 30% while the effects of constructed wetlands on total catchment nitrogen load is



Pict. 6 Scenario considering transformation of arable land to grass lands in Jankovský stream catchment. The transformed land use is given in red.

relatively smaller (ca 6%). However, the local effects of constructed wetlands are considereble. Additional reduction could be gained when contructed wetlands for treatment of diffusive sources were employed.

WP4. and WP6. Economical and social problems of drugs in water

The issue of pharmaceuticals existence in surface water, groundwater and drinking water subsequently brings significant social impact, which is reflected in two spheres. Disclosure of information about the existence of potentially dangerous substances in drinking water can adversely affect the behavior of certain population groups. The question is, what will be the willingness of people to accept higher financial costs associated with the application of new technologies, wastewater treatment and water resources management.

AQUARIUS project have been aware of this problem and should therefore be dealt with in a separate WP „Ethical and social problems of drugs in water". It seeks to answer the following questions: Is it appropriate to disclose information about these new kinds of pollution in the water when until now we have only little information about the level of the real danger? Are the stakeholders interested to know information about the water quality? How much they would like to pay for really clean water? Equally important is the socio-economic issue. What will be the reaction of consumers on increased prices of drinking water?

These issues are addressed by means of statistical evaluation of questionnaires distributed in network of 90 Norwegian and 450 Czech communities. The questionnaire, which takes into account social, economic factors, age and education issues has already been approved by the Czech and Norwegian partners. The weakness of existing solutions are limited informative value of this survey, which is based on a relatively small number of answers, which, in addition, will come from only a few locations.

The aim of additional research activities is to eliminate this problem and to expand an inquiry in Czech Republic and Norway. Study gain a statistically significant amount of data, which include a diverse set of processed data (including e.g. the urban population, the municipality of protected areas and vice versa very environmentally affected regions).

The economic part of the project represents the estimated cost to implementation of filters on activated carbon in waste water treatment plants throughout the Czech Republic. This amount is CZK 1 billion annually.