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Climate change impact on the leaching of a heavy metal contamination in a small lowland catchment

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Abstract The objective of this study was to assess the potential effects of climate change on the transport of pre-existing spatially-extensive trace metal contamination to a small lowland catchment in the south of the Netherlands. The area surrounding the Keersop has been contaminated with heavy metals by the atmospheric emissions of four zinc ore smelters. This heavy metal contamination, e.g. with Cd and Zn, has accumulated in the topsoil and leaches towards surface water system, especially during high groundwater levels and high discharge rates. Simulated projections of future climate predict increased precipitation in winter, less precipitation in summer, and higher air temperatures throughout the year. These climate change scenarios projected lower groundwater levels and lower discharge rates. As a result of lower groundwater levels, transport of Cd and Zn towards surface water is also projected to decrease in the future climate. These results indicate a positive effect of climate change on a limited aspect of surface water quality.

Key words climate change; surface water quality; heavy metal contamination; future climate scenarios

INTRODUCTION

The impact of climate change on water resources is one of the most important questions facing hydrologists today. While many studies have shown the impact of climate change on water availability or peak discharge (e.g. Van Roosmalen *et al*., 2007), only a few have focused on the effects on water quality (e.g. Darracq *et al*., 2005; Destouni & Darracq, 2009; Van Vliet & Zwolsman, 2008). The objective of this study was to assess the potential effects of climate change on the leaching of a pre-existing spatially extensive trace metal contamination to the surface water system of the Keersop, a small lowland catchment in the Kempen area on the border of the Netherlands and Belgium (Fig. 1). The area surrounding the Keersop has been contaminated with heavy metals by the atmospheric emissions of four zinc ore smelters. This heavy metal contamination, with Cd and Zn for example, has accumulated in the topsoil and leaches towards the surface water system, especially during periods with high groundwater levels and high discharge rates (Rozemeijer & Broers, 2007).

METHODS

Model

A quasi-2D unsaturated-saturated zone model (SWAP v3.2, Kroes *et al*., 2008) of the Keersop catchment (43 km^2) was forced with climate change scenarios to simulate the

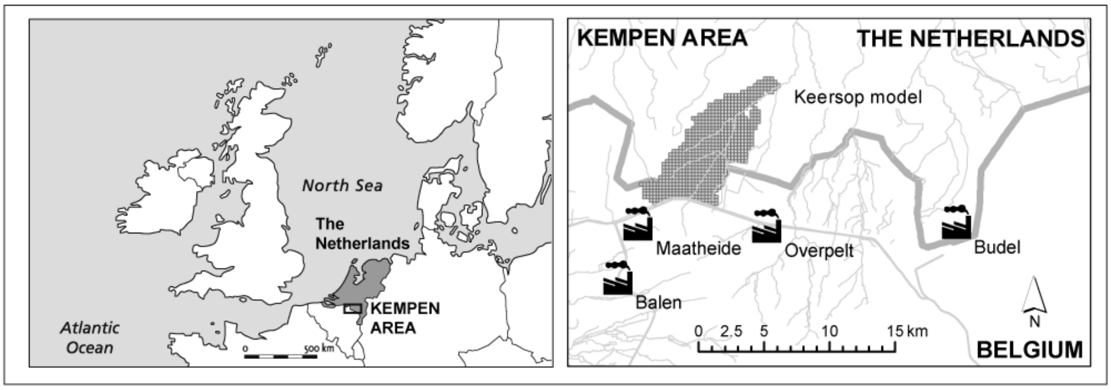

Fig. 1 Location of the Kempen area (left) and the Keersop model area and zinc ore smelters (right).

effect of climate change on the hydrology and leaching of Cd and Zn. The SWAP model is 1D, but lateral water and solute flow through the groundwater system is modelled using a pseudo 2D approach (Groenendijk & Van den Eertwegh, 2004). The study area was modelled using an ensemble of 686 1D models, each of which represented a 250 × 250 m area within the catchment (Kroes *et al*., 2010). Using this approach the contaminant load to surface water of a catchment size study area can be simulated transiently with a single model within reasonable simulation times.

Climate Scenarios

The SWAP model was driven by 100-year-long daily time-series of precipitation and potential evapotranspiration, representative for the periods 1961–1990 ("baseline climate") and 2071–2100 ("future climate"). The time-series were generated by the stochastic rainfall model Rainsim V3 (Burton *et al*., 2008) and the Climatic Research Unit (CRU) weather generator (Watts *et al*., 2004; Kilsby *et al*., 2007). Precipitation and evaporation recorded at the Eindhoven meteorological station served as input, in combination with projections of change derived from the results of eight regional climate model (RCM) experiments from the European Union Fifth Framework Programme (FP5) PRUDENCE project (Christensen *et al*., 2007). These RCMs were driven by two different General Circulation Models (GCMs) under the SRES A2 emissions scenario. The resulting time-series of future climate were characterized by lower annual precipitation (–1 to –12%) but decreased summer precipitation and increased winter precipitation, higher annual air temperatures (between 2°C and 5°C) and as a result higher potential evapotranspiration (Van Vliet *et al*., 2010).

RESULTS

Hydrology

Monthly mean discharge of the Keersop (Fig. 2) shows typical seasonal patterns, with high discharge rates in the winter months and low discharge rates in the summer months. Higher air temperatures throughout the year in future climate projections resulted in a reduced net precipitation, less groundwater recharge (–30 to –50%), and lower groundwater tables. Monthly discharge rates in the Keersop in the future climate are generally projected to decrease, by as much as 63% in December (HAD_H scenario, Fig. 2 right). The decrease in discharge in autumn and winter is mostly caused by groundwater level decline during summer, rather than lower precipitation rates in winter. The annual discharge of the Keersop stream decreases for all selected RCM experiments by 21–37%.

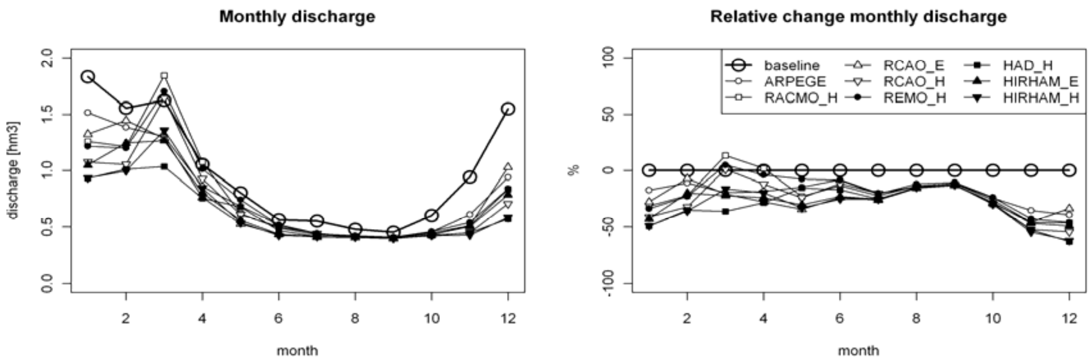

Fig. 2 Monthly discharge (left) and relative change of monthly discharge (right) of the Keersop stream, for the baseline scenario and eight future climate scenarios.

Contaminant transport

Because Cd and Zn have accumulated in the top soil (Kroes *et al*., 2010), the concentrations in the Keersop stream under present day climate react to groundwater level fluctuations and show the same patterns as monthly discharge, i.e. high concentrations in December–May, and lower concentrations in June–November (Fig. 3).

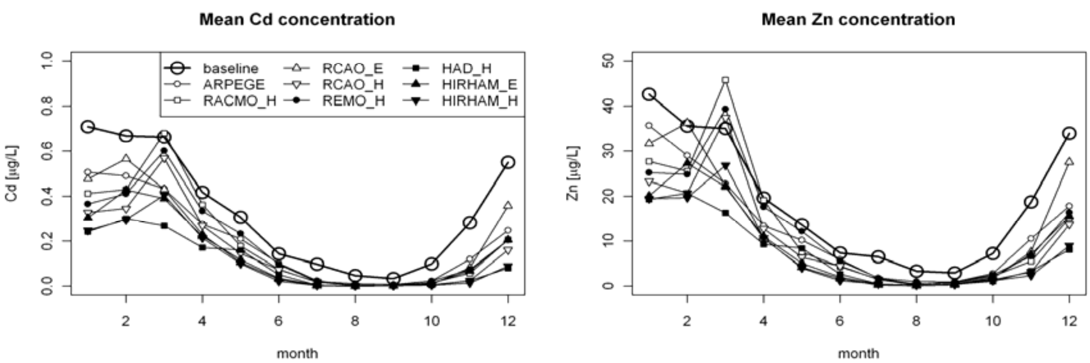

Fig. 3 Monthly averaged modelled Cd (left) and Zn (right) concentrations in the Keersop stream, for the baseline scenario and eight future climate scenarios.

As a result of lower groundwater levels under future climate scenarios, the transport of Cd and Zn towards surface water is projected to decrease. The decrease is strongest in autumn and early winter, when groundwater levels are still low due to increased evapotranspiration during summer. However, peak discharge events in February and March are projected to cause increased monthly Cd and Zn loads for some future climate scenarios (RACMO_H, RCAO_H and REMO_H).

DISCUSSION AND CONCLUSIONS

Discharge rates are projected to decrease in the Keersop catchment as a result of higher evapotranspiration under future climate. Mean Cd and Zn concentrations and loads will decrease for most of the year as a result of lower groundwater tables induced by climate change. For a few climate change scenarios, increasing concentrations and loads are projected in March. Our results generally indicate a positive effect of climate change on Cd and Zn concentrations in the Keersop stream, which only represent a limited aspect of surface water quality. To provide useful advice to water managers on the effect of future climate on water quality, all aspects of water quality should be considered.

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