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Comparison of different model approaches for a hygiene early warning system at the lower Ruhr River, Germany

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ABSTRACT

The lower Ruhr River is located in a densely populated and industrialized area in Northrhine-Westphalia (NRW) in western Germany. Due to upgrades of sanitary infrastructure, such as wastewater treatment plants (WWTPs) and combined sewer overflows (CSOs), and a decline of industrial production, water quality of Ruhr River has been constantly increasing over the past decades. One effect is a growing attractiveness of the Ruhr for bathing and water sports.

In order to enable future bathing in the lower Ruhr, this study investigates methods for predicting the permissibility of bathing, according to the microbial water quality regulations of the Bathing Water Ordinance of Northrhine-Westphalia (NRW-BWO). On basis of the European Commission Bathing Water Directive, the NRW-BWO defines methods for the assessment of bathing water quality on basis of bacterial threshold concentrations of *Escherichia coli* (*E. coli*) and intestinal enterococci (Int. Ent.). Furthermore, if the bathing water is subject to short-term pollution, the NRW-BWO requires the installation of an early warning system to prevent bathers' exposure.

Laboratory detections of both bacteria species from water samples are not suitable to be used in an early warning system. Online measurement devices for bacteria showed to be not sensitive and accurate enough to reliably indicate an exceedance of the threshold values. Thus, the application of a prediction model is appropriate. In total, four different modeling approaches were developed and compared to provide short-term predictions of bacterial concentrations: (i) statistical modeling based on linear correlations between hydro-chemical parameters, such as ammonia and turbidity, and bacteria, (ii) modeling based on artificial neural networks (ANNs), which consider non-linear correlations between hydro-chemical and climate parameters and bacteria concentrations, (iii) a balance model, which considers all in- and outflows, both in terms of water quality and quantity, along a stretch of the lower Ruhr River, and (iv) binary modeling based on precipitation rates, as rainfall is assumed to trigger high bacteria loads in the river. It could be shown that ANNs allow the most accurate prediction of bacterial concentrations in the lower Ruhr River. However, the model performance varies among different stretches along the Ruhr River. This indicates that local conditions, e.g. distance to next upstream WWTP or CSO, are essential and need to be further investigated. The binary model which considered rainfall effects also provided acceptable short-term predictions. For example, at all potential bathing spots, after two days following substantial precipitation amounts, bathing would have been allowed. The balance model showed the weakest results, which is mainly due to data gaps, as time series of bacterial loads from tributaries, WWTPs and CSOs had to be estimated. As a next step, high resolution bacterial measurements following CSO discharge events are planned in order to develop a concise picture of processes determining bacterial concentrations at the Ruhr River.

Abbreviations: ANN, artificial neural network; CFU, colony forming unit; CSO, combined sewer overflow; DOC, dissolved organic carbon; *E. coli*, *Escherichia coli*; EC, electric conductivity; Int.Ent., intestinal enterococci; NH_4^+, ammonia; NO_2^+, nitrite; NO_3^+, nitrate; NRW, Northrine-Westphalia; NRW-BWO, NRW bathing water ordinance; PO_4^3, ortho-phosphate; Q, river runoff; RV, Ruhrverband; RWW, Rheinisch-Westfälische Wasserwerksgesellschaft mbh; SAC, spectral adsorption coefficient; T, water temperature; TOC, total organic carbon; TU, turbidity; WWTP, wastewater treatment plant.

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1. Introduction

During the last decades, bathing in the natural environment has experienced a reconnaissance in Germany. Although many bathing spots are located at lakes and coastal beaches (EEA, 2014), there is also a growing demand for bathing in local rivers. This also applies for the lower Ruhr River in western Germany, which is located in a densely populated area with nearly 5 million inhabitants. During the second half of the last century, the area had been developed as a key German industrial region. As a result, due to pollution from industry and population, bathing in the lower Ruhr River has been prohibited since then. Today, after facing a strong decline in industrial production and advances in wastewater treatment technology and their widespread implementation, bacterial background concentrations in the lower Ruhr River are lower. This offers the opportunity to discuss the bathing potential at lower Ruhr River on a new level, which has resulted in a joint research project, funded by the German Federal Ministry of Education and Research (BMBF, 2015). Nevertheless, as riverine bacterial peaks, which are often induced by combined sewer overflows (CSOs), still can cause potential harmful conditions, bathing in the lower River Ruhr needs to be regulated. As bacterial in situ measurements are inaccurate in terms of concentration levels and laboratory detection methods only provide results after 24 h, a new method needs to be developed to assess real time bathing conditions. Therefore, this study focusses on comparing different model approaches on setting up a hygiene early warning system, which could be implemented at the lower Ruhr River.

So far, few other studies have addressed similar problems, however, mostly for bathing spots at lakes, e.g. Lake Michigan, U.S.A. (Nevers and Whitman, 2005) and oceans, e.g. in England (Kashefipour et al., 2002). Nevers and Whitman (2005) applied a statistical model based on correlations between bacteria and other water quality parameters to predict bathing water quality. A similar approach was applied by Frick et al. (2005) for Lake Erie, U.S.A. Viegas et al. (2012) developed a hygienie early warning system for a beach at the Portuguese coast based on a deterministic modeling approach, taking into account tides, currents, and wind. Another method to predict bathing water quality was proposed by Lin et al. (2008) and Kashefipour et al. (2005): artificial neural networks (ANNs), which received input data from a hydrodynamic and water quality model. Vinten et al. (2004) tested three different model approaches for bathing water quality at a river in Scotland: (i) a soil transport model, (ii) a regression model, and (iii) a distributed catchment model. The regression model yielded the best results, whereas the main pollution source was identified as agriculture. Stidson et al. (2012) considered antecedent rainfall conditions to predict bathing water quality for ten sites in Scotland. Based on these proposed methods for a hygiene early warning system, four different set-ups were tested at the lower Ruhr River: (i) statistical modeling based on linear correlations between hydro-chemical parameters, (ii) modeling based on artificial neural networks (ANNs), (iii) a distributed balance model, which considers all in- and outflows, both in terms of water quality and quantity, and (iv) binary modeling based on precipitation rates.

The applicability and reliability of each method were evaluated by using bacterial concentration thresholds provided by the national Bathing Water Ordinance of Northrhine-Westphalia (NRW-BWO, NRW, 2007), which refers to the European Bathing Water Directive (EC, 2006). It provides a classification of bathing water quality according to the concentrations of *Escherichia coli* (*E. coli*) and intestinal enterococci (Int. Ent.) based on statistical evaluations of a defined number of concentration measurements during the bathing seasons of the last 4 years. Furthermore, threshold values of 1800 CFU/100 ml for *E. coli* and 700 CFU/100 ml for Int. Ent. were defined. In case of exceeding these thresholds, bathing will be prohibited. NRW-BWO also states that surface water may be subject to short term pollution events, which are defined as microbiological contaminations by *E. coli* or Int. Ent. that have distinct identifiable causes and are normally not expected to affect bathing water quality for more than approximately 72 h. The public must be informed whenever such pollution is predicted or present and must be advised that bathing is temporarily prohibited.

2. Material and methods

2.1. Study area and data availability

The investigation focused on the lower Ruhr River, as shown in Fig. 1. This section stretches from Lake Kemnade in the east and the confluence with Rhine River in the west and is located in of the most densely populated regions of Germany, covering the cities of Hattingen, Essen, and Mülheim an der Ruhr. Beside urban zones, also agricultural areas are situated in the catchment area. In the middle of this section, Lake Baldeney is located, an artificial lake which is

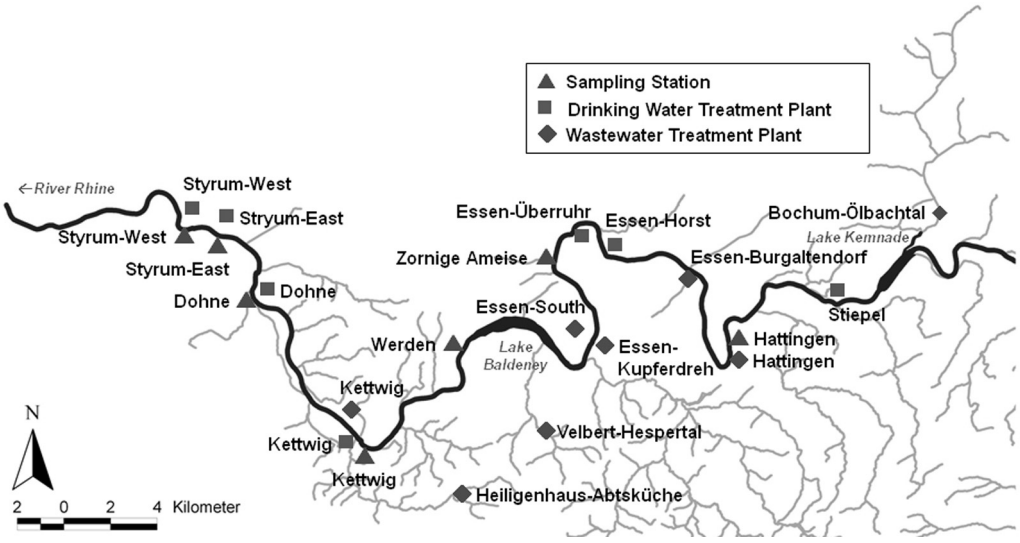

Fig. 1. Project region: catchment of the lower River Ruhr, which is located in western Germany.