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Coastal bathing water quality and climate change – A new information and simulation system for new challenges

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ABSTRACT

Human pathogenic micro-organisms in coastal waters receive increasing attention. Climate change with its multiple effects on micro-organisms is one major reason. Changing survival rates, sources and new invasive species are a challenge for bathing water quality management. We present a new online bathing water information system. It includes an alerting system, software to supports communication between authorities, local municipalities and the public as well as simulation tools, based on a 3D-flow and particle tracking model. In scenario simulations with focus on enterococci and *Escherichia coli* bacteria we show the potential impact of climate change on bathing water quality and the potential relevance as a decision support system in the large, shallow Szczecin lagoon. Szczecin lagoon in the Baltic at the German/Polish border is a pollution hot-spot and frequent bathing prohibitions hamper tourism development.

Because of climate change, the risk of river floods is supposed to increase in future. Higher discharge causes an increased transport velocity in the river flow. At the same time, run-off from city surfaces and agricultural land along the river can cause increased *E. coli* concentrations in all surface waters. As a consequence *E. coli* and especially Enterococci are transported far into the lagoon and high concentrations can cause bathing water quality problems even on distant beaches. Especially heavy lasting rain in the river basin together with local rain events are a serious threat for bathing water quality in the lagoon and will very likely require a closing of beaches for swimming. Similar to other coastal waters, a wide range of other potentially human pathogenic micro-organisms might create a threat for the lagoon in future.

1. Introduction

The effects of climate change on waterborne and vector-borne diseases are intensively studied and have high relevance for public health (e.g. Epstein, 2002; Patz et al., 2005; Lafferty, 2009). Examples are ongoing discussions of climate change effects on the infection risk of dengue fever (Hales et al. 2002), malaria (Paaijmans et al., 2009) and cholera (Lipp et al., 2002). Increasing temperatures due to climate change can have multiple effects on vectors and diseases (Gubler et al., 2001; Hunter, 2003), will alter the survival conditions for several human-pathogenic microorganisms, and allows the invasion of new vectors and diseases. Especially human pathogenic microorganisms in coastal waters and their relation to climate change receive increasing attention (Roijackers and Lürling, 2007). Improved monitoring and analytical methods draw attention to unknown and invasive organisms and raised awareness of existing risks. Examples along the southern Baltic coast are recently observed high concentrations of native vibrions (*Vibrio vulnificus*), which caused lethal infections in the coastal Baltic Sea and are today considered as a major threat for summer seaside resorts in Germany (Böer et al., 2010). Another example of a new challenge is *Escherichia coli* O157:H7, an *E. coli* strain that can produce toxins and can cause gastroenteritis, urinary tract infections and neonatal meningitis (e.g. Mudgett et al., 1998; Paunio et al., 1999). Many other, potentially more problematic microorganisms, might create problems in our coastal waters (Roijackers and Lürling, 2007). Even if bathing water meets the microbiological standards of the European Bathing Water Directive (2006/7/EC), many potential pathogenic organisms could be present (WHO, 2009). Furthermore, many of these microorganisms

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will benefit from climate change and might cause increasing problems in future. Against this background, new simulation, management and decision support tools for bathing water quality are required.

We present a new on-line bathing water quality information system. The system has been developed within the project GENESIS as a general European approach to support regional authorities. It combines a model and simulation tool with an alerting and improved communication system. The model tool consists of a three-dimensional flow model (GETM) together with a Lagrangian particle tracking routine (GITM). Here, we exemplary apply our model tool and prove its suitability as well as its potential and practical relevance. Spatially, we focus on the Szczecin lagoon at the German/Polish border (southern Baltic coast). The Lagoon is affected by the Odra river and sewage water of Szczecin city and is a pollution hot-spot region. Insufficient bathing water quality causes beach closures and hampers tourism development. In several scenario-simulations we give an overview how climate change might affect the survival of various human-pathogenic organisms in this region and assess how the spatial contamination risk in the lagoon will alter in future and show the benefit of the bathing water quality information system. In these scenarios we focus on the indicators of the European Bathing Water Directive (2006/7/EC), namely enterococci and *E. coli* bacteria.

2. Study site and methods

2.1. Szczecin coastal region

The Odra (German: Oder) coastal region, with the large Szczecin lagoon, is located at the German and Polish border in the southern Baltic. The lagoon covers an area of 687 km^2 and has an average depth of 3.8 m. Tourism is the major source of income in the coastal region. According to the Central Statistics Office in Poland the municipalities counted the following numbers of tourist overnight stays in 2006: Goleniów (3 018), Stepnica (207), Dziwnów (87 371), Kamień Pomorski (4 914), Międzyzdroje (110 165), Wolin (8 524), Nowe Warpno (7 637), Police (7 784), Świnoujście (111 614) and Szczecin (352 415). Major beaches in the Polish part of the lagoon are Stepnica, Trzebież, Czarnocin, Lake Nowowarpieńskie and Wolin. The municipalities differ considerably in terms of population and income. The municipalities with the highest income are the tourism resorts located on the Baltic Sea coast. Municipalities around the lagoon have an income below the national average mainly from farming, light industry and commerce. However, tourism is still growing and of increasing importance. Especially the fast development of marinas in the lagoon with about 2 400 mooring spaces is one indicator (10 marinas on the Polish side with altogether about 600 mooring spaces as well as 14 marinas in the German part of the lagoon) (Steingrube et al., 2004). The regional plan by the Marshal of Zachodniopomorskie Voivodship suggests the creation of a West Pomeranian Sailing Route covering the lagoon and the Baltic. It includes new sport boat harbours and the modernization of existing ones. For a further development of tourism around the lagoon a good water quality is imperative.

During recent years, the Oder/Odra estuary faced many problems with microorganisms. A *Salmonella* pollution event in the seaside resort Miedzyzdroje caused a beach closing for more than 4 weeks during high-season in August 2008. High concentrations of *V. vulnificus* were frequently found in Karlshagen, Island of Usedom and in Lubmin, Greifswald Bodden. In 2009, the maximum was above 1 million germs per litre in Lubmin. In 2003, 2010 bathers died after a vibrion infection and in 2006, three people fell ill but and were saved only by fast application of antibiotics (LAGUS pers. com). However, most common are problems due to high concentrations of coliform, *E. coli* and *Enterococci* bacteria. In the past, coliform bacteria often caused a closing of beaches according to EU Bathing Water Quality Directive (76/160/EEC), e.g. in Stepnica (from 08.08.2006 for 25 days; from 19.07.2006 for 15 days), in Trzebież (from 01.08.2006 for 42 days; from 20.07.2007 for 42 days; from 24.07.2008 for an unknown period) and in Czarnocin (from 27.07.2006 for 50 days; from 10.07.2007 for 35 days and from 01.08. 2008 for an unknown number of days). Data on bathing water quality in Poland are publicly provided by the Chief Sanitary Inspectorate. Data on local bathing water quality are also available on the websites of public health services.

Insufficiently treated sewage water is the most important reason for microbial problems and caused serious water quality problems in the lagoon during the last decades. Today the situation is improving because 288 million Euros have recently been invested in sewage treatment plants around the city of Szczecin, which is the major centre and located at the Odra river, north of the lagoon. However, the other municipalities sharing the Polish coastal region play a role, as well. The total population (Central Statistics Office data for 2006) and the percentage of it connected to a sewer system differs between the municipalities: Goleniów (33 289, 76%), Stepnica (4,770, 66%), Dziwnów (4,127, 95%), Kamień Pomorski (14 664, 59%), Międzyzdroje (6,449, 90%), Wolin (12 475, 43%), Nowe Warpno (1,605, 61%), Police (41 099, 80%), Świnoujście (40 688, 93%) and Szczecin (401 437, 89%). In 2006, 65% of the sewage was treated biologically/chemically while 27% of Szczecin's effluents were still treated mechanically and 8% of the water even went untreated (Council of Ministers Republic of Poland, 2008).

In 2010 the amendment of the Polish Water Law was published. It defines objectives, instruments, procedures, institutional actors of the water administration, implemented the new EU Bathing Water Quality Directive (2006/7/EC) and modified some responsibilities. Today, bathing sites are managed on a local level by administrators or the communities and the Sanitary Inspection takes care of bathing water monitoring and the compliance of water quality with Directive (2006/7/EC). In the following we focus on *E. coli* and *Enterococci* bacteria because they are the new indicators in this Directive and in 2011 replace coliform bacteria in the monitoring programme. One of the crucial element in the new EU Bathing Water Directive are bathing water profiles. Their aim is to provide the public and authorities with information about physical, geographical and hydrological characteristics of a bathing places as well as possible pollution sources impacting bathing water quality.

2.2. The model system

In this study we apply the General Estuarine Transport Model (GETM, Burchard and Bolding (2002); Burchard (2009). This 3D-flow model allows reliable and spatially high resolved flow and transport simulations in shallow systems with a complex bathymetry and coastline. It was successfully applied and validated in recent studies (see e.g. Burchard et al., 2005; Lettmann et al., 2009; Hofmeister et al., 2011; Gräwe and Burchard, 2011). The model allows coastal areas to be flooded and to fall dry at low water levels. Wave dynamics is not taken into account. Basis for the flow calculation is a curvilinear grid that reflects the coastline and the bathymetry of the estuary. The horizontal spatial grid resolution varies between 15 m in the southern Odra mouth (our focus region) and 200 m in the Pomeranian Bight. The vertical water column is always subdivided into 10 layers with a similar thickness (sigma levels). The whole area covered by the model-grid (domain) contains 800 *1300*10 (x,y,z) grid points (see Fig. 1).

To compute 2D variables like (e.g. sea surface elevation), a time step of 0.4 s is used. To compute the 3D variables (temperature, salt