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Temporal variations analyses and predictive modeling of microbiological seawater quality

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ABSTRACT

Bathing water quality is a major public health issue, especially for tourism-oriented regions. Currently used methods within EU allow at least a 2.2 day period for obtaining the analytical results, making outdated the information forwarded to the public. Obtained results and beach assessment are influenced by the temporal and spatial characteristics of sample collection, and numerous environmental parameters, as well as by differences of official water standards. This paper examines the temporal variation of microbiological parameters during the day, as well as the influence of the sampling hour, on decision processes in the management of the beach. Apart from the fecal indicators stipulated by the EU Bathing Water Directive (*E. coli* and enterococci), additional fecal (*C. perfringens*) and non-fecal (*S. aureus* and *P. aeriginosa*) parameters were analyzed. Moreover, the effects of applying different evaluation criteria (national, EU and U.S. EPA) to beach ranking were studied, and the most common reasons for exceeding water-quality standards were investigated. In order to upgrade routine monitoring, a predictive statistical model was developed.

The highest concentrations of fecal indicators were recorded early in the morning (6 AM) due to the lack of solar radiation during the night period. When compared to enterococci, *E. coli* criteria appears to be more stringent for the detection of fecal pollution. In comparison to EU and U.S. EPA criteria, Croatian national evaluation criteria provide stricter public health standards. Solar radiation and precipitation were the predominant environmental parameters affecting beach water quality, and these parameters were included in the predictive model setup. Predictive models revealed great potential for the monitoring of recreational water bodies, and with further development can become a useful tool for the improvement of public health protection.

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1. Introduction

A coastal area, which in terms of ecology and human development represents a unique geographical setting, is strongly influenced by human activities such as urbanization, industrial development, farming, fisheries, discharge of wastewater and recreational activities.

Croatia, as a popular European tourist destination, was one of the first Mediterranean countries to begin examining the

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microbiological quality of bathing waters, back in 1989 (Ministry of Environmental protection Physical Planning and Construction, 2006). In the light of tourist surveys which indicate that the purity of seawater and the beauty of the coastline make up 90% of the reasons for attracting visitors to a particular beach, a more efficient and accurate control system of bathing water quality is one of the priorities of Croatian tourism.

The assessment of the potential health risk is based on data of bacteria indicator concentration, which indirectly indicates the possible presence of pathogenic microorganisms. Worldwide, different indicators and criteria are used for assessing the quality of coastal water. In the European Union, the revised EU Bathing Water Directive (Directive, 2006/7/EC) stipulates the determination of two fecal indicator bacteria: *Escherichia coli* (EC) and enterococci (ENT). The EU Directive defines minimum criteria which the Member States have to achieve, but allows the application of more stringent criteria. Although national Croatian legislation is based on the relevant Directive, which Croatia has implemented since 2009, the national measures in force are stricter, like in France, Greece, Italy and Spain (MAP, 2010). Seawater samples are evaluated using a 90^{th} and 95th percentile of microbiological values. In the United States, the national guidance of the U.S. EPA has proposed the use of enterococci as the single marine bacterial indicator. The concentration of enterococci must not exceed the Geometric Mean (GM < 35 CFU/100 mL) and Statistical Threshold Value (STV < 130 CFU/100 mL) per month (U.S. EPA, 2012).

Currently in Croatia, sampling and laboratory testing takes an average time of 2.2 days. Therefore, the information that is supposed to be forwarded to the public, after this period, is outdated. Furthermore, because Croatia has, after Greece, the most rugged coastline in the Mediterranean, it is difficult to include some remote islands in monitoring. The bathing season usually lasts for 5 months, from mid-May until the end of September. In that period, the frequency and number of sampling points are constrained by the available technical resources. Croatia is a country with a high number of beaches included in monitoring (cca 900 sampling sites; which is ~200 sites per million of inhabitants), much above the EU standard of 42 beaches per million of inhabitants. However, looking from the perspective of a long and indented coast, there is room for an increase in the number of test locations, following the examples of Italy, France and Spain (EEA, 2015). However, the frequency of sampling is only fortnightly (10 sampling actions per season) and is usually carried out during working days, commonly in the morning or early afternoon. Several studies emphasize that the concentrations of microbes in recreational waters show high temporal and space variation (Ekklesia et al., 2015; Enns et al., 2012; Hassou et al., 2014), and are subject to many factors: solar radiation, amount of rainfall, tidal stage, wind and speed direction, mixing, turbidity, predation, bather density, insufficient sewerage network capacity (Cho et al., 2010; He and He, 2008). Because of the predictable shortcomings of existing monitoring that were tackled previously, in certain situations, swimmers are exposed to an increased health risk.

To avoid deficiencies in observation, routine monitoring can be supplemented with predictive models. Modeling, coupled with the results of the most recent monitoring and a large set of historical data, can deliver both the timely identification of potential health risks and proper management procedures for water quality assurance (Cho et al., 2010). The revised BWD (2006/7/EC) states that EU countries should introduce improved monitoring and management systems in order to upgrade the protection of public health against fecal pollution in bathing waters. Predictive modeling is much more in use in the USA (U.S. EPA, 2010a) while in the EU it is in the early stages of implementation (Bedri et al., 2016). *GoSUMD 3.0* software (copyright@ Aimdyn, Inc., Santa Barbara, USA) was chosen for prediction modeling in our research, as it has been verified in significant studies that are similar to our research from the algorithm point of view. These applications include energy efficiency in buildings (Eisenhower et al., 2012), a performance study of adaptive control in aircraft models (Loire et al., 2013), global sensitivity analysis for a socio-cultural agent-based model (Fonoberova et al., 2013), a study of resonant breathing in human physiology (Fonoberova et al., 2014), etc. No matter how different they are, these pieces of research all use design of experiments (DOE), model learning, sensitivity analysis, and robust global optimization. *GoSUMD 3.0* software incorporates several significant algorithms for these tasks.

The main goal of this paper is to explore the temporal variation of multiple microbial indicator bacteria and how recreational water management measures may be influenced by the day period of sampling. The most important environmental factors influencing the concentration of specific microbiological parameters were identified. Likewise, how the choice of different parameters and standards affects the ranking of a particular beach was also analyzed. Additionally, an estimation of the correlation of required indicators with the supplemental fecal indicator (*C. perfringens*) and non-fecal bacterial parameters (*S. aureus* and *P. aeruginosa*) was carried out. As an upgrade to the existing monitoring program, a predictive model was developed. The model allows the forecast of water quality for each location based on meteorological and historical water quality data. In this way, preventative action and the protection of swimmers can take place during risk condition periods.

2. Materials and methods

2.1. Location

The city of Rijeka, with the largest and most important port in Croatia, is an industrial urban center in the north-eastern Croatian Adriatic, in Primorje-Gorski Kotar County, where bathing quality assessment is carried out at 237 points. With more than 150,000 inhabitants, it is the third largest Croatian city, and is located on the northern coast of Rijeka Bay, as a part of the much wider Kvarner area. With an average annual rainfall of 1530 mm (Benac et al., 2003) and surroundings characterized by much higher rainfall (even up to 4000 mm), it is one of the wettest areas in Croatia. Due to the specific hydrogeological features of karst terrain, characterized by numerous crevices and caverns through which precipitation quickly infiltrates the underground water system, the process of self-purification is reduced and limited. The Adriatic is the northernmost part of the Mediterranean Sea (~4.6% of the Mediterranean total surface area) and it collects a third of the fresh water flowing into the Mediterranean. Abundant coastal and submarine freshwater springs are common features along the Eastern Adriatic shore, which boosts the effect of rain on overall seawater quality along the coast.

The present study comprised five adjacent beaches in Rijeka's urban area: 3. MAJ (3M; the length of the beach is 50 m), Kantrida East (KE; 130 m), Kantrida West (KW; 140 m), Ploce East (PE; 160 m), Ploce West (PW; 170 m), Fig. 1. Although positioned in a relatively small stretch, 1700 m of coastal line, historical data places them in different water quality classes. Unlike the PW and PE sites, 3M and KE showed evidence of recurrent pollution events over the longer periods, while KW was only occasionally moderately polluted.

Because the results of testing are worse after heavy rainfall, and the studied area is characterized by a higher number of coastal springs, plausible contamination sources can be attributed to non-point sources from a wider influential catchment area and the

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