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An empirical model to quantify fecal bacterial loadings to coastal areas: Application in a Mediterranean context

Marlène Rio [a,*], Christian Salles [a], Claire Rodier [a], Franck Cantet [b], Pierre Marchand [a], Thomas Mosser [a,1], Flavie Cernesson [c], Patrick Monfort [a], Marie-George Tournoud [a]

[a] HydroSciences Montpellier (HSM), UMR 5569 CNRS, IRD, Université de Montpellier, 34093 Montpellier cedex 05, France
[b] Infectious Disease Research Institute of Montpellier (IRIM), UMR 9004 CNRS, Université de Montpellier, 34293 Montpellier cedex 5, France
[c] Territoires, environnement, télédétection et information spatiale (TETIS), UMR IRSTEA, CIRAD, AgroParisTech, 34093 Montpellier cedex 5, France

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ABSTRACT

In coastal catchments, rainfall events primarily drive bacterial inputs to the sea by causing land runoff, surface leaching and sewer overflow. Under semi-arid climate, extensive dry periods are interspersed with extreme precipitation. This paper aims to assess the impact of intense summer rainstorms events on Fecal Indicator Bacteria loadings to Mediterranean seawaters. Firstly, explanatory relationships were derived between an Antecedent Precipitation Index and the loads of thermo-tolerant coliforms and intestinal enterococci measured at three catchment outlets in the Gulf of Aigues-Mortes (southern France). Secondly, fecal bacterial loadings were simulated during summer season from 2006–2016, with a confidence interval arising from measurements uncertainties. On average, more than two rainstorms per summer season elevate bacterial loads at least by one order of magnitude, potentially leading to the degradation of bathing and fishing water quality observed in regulatory monitoring data. The results highlight the crucial importance of considering hydrological conditions in coastal water quality management.

1. Introduction

Coastal water quality is a key driver of seaside tourism economy. Elevated fecal contamination may threaten human health, impair the aquatic environment and lead to prohibition of bathing and shellfish harvesting (Coulliette and Noble, 2008; Dwight et al., 2004). In coastal catchments, the rapid urbanization and the expansion of agricultural land generate increasing levels of pollutants. Consequently, regulatory bodies are required to actively manage coastal water quality to promote economic development along with the protection of public health and marine environments.

Fecal Indicator Bacteria (FIB), such as thermo-tolerant coliforms and intestinal enterococci are used across the world to detect fecal pollution and set water quality standards. Fecal contamination may come from humans and animals frequenting beaches (Elmir et al., 2007; Wright et al., 2009) and from continental inputs, such as surface leaching, land runoff and sewer discharges (Ahn et al., 2005; Jeong et al., 2005; Reoyo-Prats et al., 2016). Although coastal waters may be contaminated during dry periods (Stein and Ackerman, 2007), numerous studies highlighted the effects of hydroclimatic conditions on

* Corresponding author.
E-mail address: marlene.rio@umontpellier.fr (M. Rio).
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bacterial contamination in seawaters (Boehm et al., 2002; Fiandrino et al., 2003; Parker et al., 2010).

During rainfall events, runoff is generated by different processes. It occurs directly on impervious surfaces and on permeable soils when rainfall intensity exceeds the infiltration rate or when the soil is saturated (Hillel, 2003). Therefore, bacterial contaminants deposited by domestic animals, birds and rodents are conveyed into the watercourses (Causse et al., 2015; Ram et al., 2007). Extreme events also lead to important contamination in urban watercourses due to sewer overflow (Marsalek and Rochfort, 2004). In agricultural areas, microbial pollution is mainly generated by livestock and wild animals (Sigua et al., 2010). Further, Muirhead et al. (2004) showed that sediment resuspension in natural streams and drainage networks highly contributes to bacterial contamination of coastal waterways.

Under semi-arid climates, intense and local storms occur after long dry periods and lead to flash floods (Perrin and Tournoud, 2009; Terranova and Gariano, 2014). In such areas, the major annual rain events are responsible for more than 97% of annual fecal bacterial load in coastal rivers (Chu et al., 2011; Reeves et al., 2004). Precipitations with high intensities and depth are especially characteristic of tropical climates, in particular during the wet season. Consequently, bacterial contamination of coastal waters is highly driven by hydrological conditions in tropical areas (Cho et al., 2010; Rochelle-Newall et al., 2016).

In Europe, the exceeding of the quality thresholds in terms of fecal bacterial contamination is responsible for non-compliance with the European bathing water quality directive (European Environment Agency, 2016). To support coastal water quality management, previous research examined the relationship between environmental conditions and fecal bacterial levels in coastal waters. Strong correlations have been revealed between rainfall amounts and FIB concentrations in many regions, notably in the Flyde coast, UK (Crowther et al., 2001), in California, USA, (Ackerman and Weisberg, 2003) and in Korea (Cha et al., 2010). Although multiple linear regressions were used to link meteorological parameters to bacterial concentrations in urban storm-water runoff (Ekklesia et al., 2015; Farnham and Lall, 2015; Hathaway et al., 2010), little work has been conducted to model bacterial loadings at catchment outlets. However, continental inputs are driven by hydrological conditions and represent the major source of fecal contamination in coastal zones.

In the context of seawater contamination during extreme rainfall events, this paper aims at giving insights into summer storm effects on coastal water quality, by quantifying bacterial loadings from some Mediterranean catchments in Southern France. It intends to provide a simple tool based on rainfall data to characterize potential microbial contaminations of coastal bathing and fishing waters. A better understanding of water quality is essential to support coastal water managers in protecting human health and reducing the socio-economic impacts of such contaminations. The methodology can be conducted in other regions where fecal bacterial contaminations of bathing waters occur after rainfall events, such as touristic destinations in semi-arid and tropical climates.

2. Materials and methods

2.1. Site description

The Gulf of Aigues-Mortes, presented in Fig. 1, is a very attractive site for summer seaside tourism in southern France. The 20 km long coastline is shared by 31 beaches, 6 marinas and many nautical sport clubs. The catchment of the gulf encompasses more than 2300 km^2 with a mixed land use: 48% of the catchment is agricultural and 13.5% is artificial. The remaining 38.5% are forest, semi-natural areas and wetlands. The population is above 900,000 inhabitants, mainly distributed between the urban areas of Montpellier and Nîmes. According to the national institute of statistics and economic studies (INSEE), the population within the study area averagely increases by 1% per year. In coastal cities, the population increases by up to 40% during summer season. With an average annual rainfall of 672 mm, the climate is semi-arid with the majority of rainfall observed in autumn. A high inter-annual variability of rainfall is characteristic of the Mediterranean climate, along with the occurrence of extreme rainstorms. Consequently, the hydrological regime is extremely variable and leads to the contamination of coastal waters during flood events.

Three subcatchments are part of the Gulf of Aigues-Mortes catchment. Firstly, the Vistre–Vidourle (VV) catchment, with a population density of 240 inhabitants/km^2, covers a surface area of 1389 km^2 and contains the urban area of Nîmes. The Vistre and the Vidourle rivers join a mesh-type hydraulic system with two outlets, the Grau-du-Roi canal and the Ponant canal. Secondly, the 405 km^2 area of the Or catchment has a population density of 740 inhabitants/km^2 and contains a shallow lagoon of 31.7 km^2. The lagoon interacts with the sea through the Carnon canal. Finally, the Lez-Mosson (LM) catchment covers 709 km^2 on the west part of the gulf and contains the densely urbanized area of Montpellier. The population density is 691 inhabitants/km^2. Hydraulic exchanges take place between the Lez River and eight coastal lagoons upstream of the two outlets, the Prevost canal and the Lez River estuary. At the south end of Montpellier, a new wastewater treatment plant, MAERA, is operational since 2006 and collect the wastewaters of 16 municipalities, among which the coastal city of Palavas-les-Flots. The effluents are discharged through a sea outfall 10 km off the coast (Fig. 1). The level of sewage treatment of MAERA is 388,783 population equivalent, representing 64% of the wastewaters in the LM catchment. The remaining 36% of the effluents are discharged into continental waters. In the Or and VV catchments, respectively 142,853 and 409,233 population equivalents are treated, of which are the wastewaters from coastal cities, and the effluents are discharged into rivers and estuaries.

2.2. Sampling and bacterial analyses

Nineteen sampling campaigns were conducted in coastal river outlets and lagoon channels across the Gulf of Aigues-Mortes from June 2008 to January 2015. Hydrological conditions from low flow to high flow and floods