Autocorrelation and cross-correlation analyses of total bacteria: Case study of Banja karst spring in Valjevo, Serbia

Автокорелационен и крос-корелационен анализ на общото съдържание на бактерии: примерно изследване на карстов извор Баня, Вальево, Сърбия

Vesna Ristić Vakanjac[1], Radisav Golubović[2], Dušan Polomčić[1], Marina Čokorilo Ilić[1], Jana Štrbački[1], Dragoljub Bajić[1], Jelena Ratković[1]
Весна Ристич Ваканяц[1], Радисав Голубович[2], Душан Поломчич[1], Марина Чокорило Илич[1], Яна Щрубачки[1], Драголюб Байич[1], Йелена Саткович[1]

[1] University of Belgrade, Faculty of Mining and Geology, Đušina 7, Belgrade, Serbia; E-mail: vesna.ristic@rgf.bg.ac.rs
[2] Petnica Research Station, Valjevo, Serbia

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When speaking of the regime of either surface water or groundwater, what is usually meant is the regime of quantitative parameters (stage, discharge, aquifer yield, groundwater level, and the like). In addition to monitoring of the quantitative parameters, which are indeed among the main quantities that characterize a karst aquifer, it is also necessary, if possible, to establish monitoring of some of the qualitative parameters – primarily turbidity and the total number and species of bacteria in such waters. Quantitative and qualitative parameters are generally monitored only at capped karst springs. However, if spring water is not captured, very little us usually known about its regime even though such a water source often represents an alternative solution for municipal, industrial and agricultural water supply and similar uses.

Even if some of the parameters are observed, in most cases monitoring is usually sporadic, on an as-needed basis – annually, seasonally/quarterly, monthly or weekly. Assessments of the resulting time series can be misleading, especially when outliers are analyzed (Ristić Vakanjac et al., 2015). The places of emergence of karst groundwater (often inaccessible), the distance from urban centers and the financial support needed for sampling and analyses justify to some extent the lack of daily monitoring of karst groundwater parameters. It should also be noted that some parameters of the karst aquifer can be strongly dependent on the pluviographic regime. In most cases after a snowmelt or heavy and/or protracted rainfall there is an almost instantaneous increase in water levels and discharges of karst springs, and likewise a sudden increase in turbidity and/or total bacteria. In order to gain insight into the response and the dependence of the qualitative and quantitative parameters on precipitation, a sufficiently long time-series of daily monitoring of the parameters of interest is definitely needed. If such a long time-series is available, then certain approaches, such as autocorrelation and cross-correlation analyses, can be used to better understand the karst system itself.

The total bacteria recorded at the Banja Spring near Valjevo in Serbia, which was monitored daily from 1991 to 1995, is addressed in the paper to demonstrate the use of autocorrelation and cross-correlation analyses. Figure 1 is a parallel representation of the discharge, variation in total bacteria and synchronous precipitation representative of this spring’s catchment in 1991. The coefficient of correlation between the

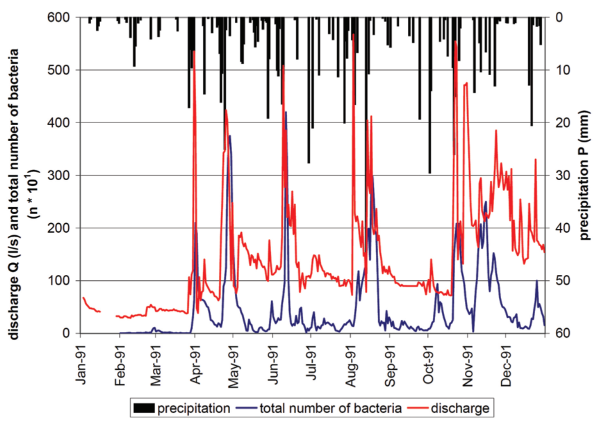

Fig. 1. Parallel representation of discharge, total bacteria at Banja karst spring and precipitation recorded in the catchment in 1991

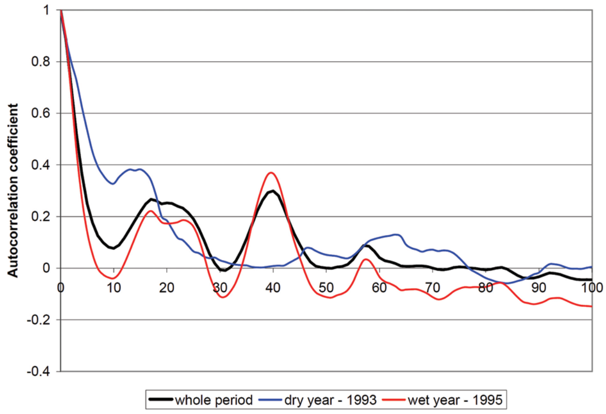

Fig. 2. Autocorrelogram of total bacteria

discharge and total bacteria in 1991 is 0.53. The lowest coefficients of correlation are typical of rainy years (r = 0.31 in 1995, when the annual precipitation total was as high as 1025 mm), whereas the highest coefficients of correlation are typical of dry years (r = 0.71 in 1992, when the annual precipitation total was only 675 mm). Given that extreme values are associated with extreme pluviographic events (dry and rainy years), autocorrelation and cross-correlation analyses are undertaken for the entire period (1991–1995) and for a typical dry year (1993) and typical wet year (1995). In this regard, Figure 2 shows the resulting autocorrelograms and Figure 3 the resulting cross-correlograms for the selected time periods.

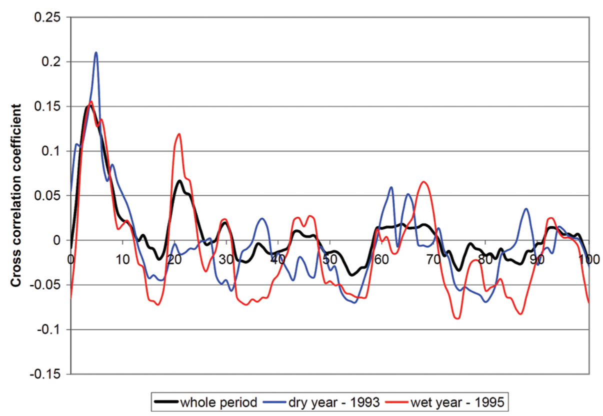

Fig. 3. Cross-correlogram of total bacteria

The autocorrelograms lead to the conclusion that the values of the autocorrelation coefficient decrease with increasing lag up to 10 days, after which there is a distinct increase and the formation of a peak after 20 days (entire period and wet year) and 14 days in the dry year. The autocorrelograms of the entire period and the wet year are similar. There is autocorrelation up to 5 days in the wet year and 6 days in the entire period. Thereafter, the system virtually loses memory (Mangin, 1984) and there is no persistence (Kresic, Stevanovic, 2010). With regard to cross-correlation, the effect of daily precipitation totals on the occurrence of bacteria at the Banja Spring is analyzed for all three time periods. As in the case of the autocorrelograms, the cross-correlograms of the entire period and the typical wet year are for the most part in agreement. However, the coefficients of cross-correlation are much lower and what is characteristic of all three cross-correlograms is that the strongest correlation between daily precipitation and bacteria in the water is observed after a time lag of 5 days. In addition, there is a distinct peak in the cross-correlograms after 20 days (also evident in the autocorrelograms). This is likely a result of snowmelt. It should be noted that the elevation of the catchment is not high (less than 500 m above sea level), such that any snow cover in the winter months does not stay in place for long.

These analyses are definitely useful when the regime of certain parameters, either quantitative or qualitative, is assessed. If sufficiently long time-series are available, it is also possible to use simulation models, such as autoregression, cross-regression and autocross-regression models, which can provide short-term forecasts and an indication of expected quantities, for example bacteria in the water tomorrow, based on recorded precipitation and the number of bacteria today and over the past several days.

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