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# Effect of urbanization on the long-term persistence of streamflow records

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## HIGHLIGHTS

- Streamflow records in urban basins exhibit temporal scaling.
- Heavily urbanized basins are less correlated than basins with little urbanization.
- Loss of persistence due to reduced filtering capacity in heavily urbanized basins.
- Multifractality strength is not appreciably affected by the urbanization process.

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## ABSTRACT

We investigate here the effect of urbanization on the temporal behavior of streamflow records. To this end, we analyzed daily streamflow records from 22 urban basins using the scaling exponents for long-term correlated records and the multifractality strength. Additionally, we separated the streamflow into fast and slow components and performed the analysis separately on each of these time series. Overall, results indicate that in the most urbanized basins, with percent impervious cover greater than 25, the long-term correlation exponents for streamflow are generally lower than in the least urbanized basins (percent impervious cover less than 10), while the multifractality strength does not seem to be appreciably affected by the urbanization process. Based on the correlation exponents, we also found that in the most urbanized basins streamflow records tend to be more similar to quickflow and precipitation than in the least urbanized basins. Thus, the loss of long-term persistence in the most urbanized basins may be explained by their lesser ability, due to the combined presence of impervious surfaces and conventional stormwater infrastructure, to filter the precipitation forcing. We conclude that the correlation exponents can be useful for assessing the temporal alteration of streamflow in urban basins.

## 1. Introduction

Streamflow and freshwater ecosystems affected by urbanization exhibit many forms of perturbations and degradations [1–5]. The detrimental effects of urbanization on stream quality and ecology, alongside changes in the hydrologic drivers (e.g., the flow regime) [6,7], are often termed the urban stream syndrome [5], given the overwhelming evidence that

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a similar set of pathologies is exhibited by urban basins across the globe [8–10]. In diagnosing these pathologies, the characterization of hydrologic alteration plays a critical role as an indicator of systemic (i.e., covering the set of pathologies) impact.

Streamflow records are often used as aggregate signals representing the overall hydrologic alteration induced by urbanization [11–15], since direct and accessible information about the historical spatial changes in urban land use and related water infrastructure are seldom available [16,17,13,18]. Various streamflow measures have been used to characterize hydrologic alteration in urban basins with a strong emphasis on short-term behavior. Flood volumes, peaks, and the time to peak are often employed [19–21,2,22] as well as low flow measures [23–27,13]. Other measures seek to quantify streamflow flashiness or the degree of streamflow variability [28,25,27], the fraction of streamflow above a specified threshold [29], and changes in the distribution of streamflow magnitudes [27].

Streamflow metrics of hydrologic alteration have thus far been focused on the analysis of streamflow magnitudes, e.g., different characteristics of the streamflow probability density function (pdf), while alterations to the temporal behavior of streamflow have been largely unstudied [30,15]. Additionally, a common and challenging complication in this case, when determining streamflow metrics, is dealing with the nonstationarity of streamflow records in urban basins [20,23,31–34].

Measures of temporal behavior such as the degree of correlation (e.g., the Hurst exponent [35]) and multifractality have a long and rich history in modern hydrology [36–45]. Recently, other disciplines have been employing these measures to characterize pathological behaviors or deviations in complex dynamical systems. For example, measures of long-term correlation and multifractality have been used to characterize and distinguish different sick and pathological states in biomedical time series data [46,47], as well as levels of stock market efficiency in financial time series data [48]. We suggest that these measures may be useful for assessing temporal alterations in urban streamflow records.

Thus, our goal here is to assess the effect of urbanization on the long-term persistence of streamflow. For this, we use the scaling exponents for long-term correlated records, determined using multifractal detrended fluctuation analysis (MF-DFA) [49], and the multifractality strength, determined using a generalized binomial multifractal model [50]. We employ MF-DFA because it accounts for nonstationary conditions [49]. With this study, we seek to answer the following questions: Does the Hurst exponent for streamflow depend on the level of urbanization? If so, what does this tells us about the role played by runoff mechanisms (fast and slow components) on the long-term persistence of streamflow? Can the urbanization process affect the multifractality strength of streamflow? Does the structural complexity associated with stormwater infrastructure in urban basins lead to increased streamflow complexity, i.e. a stronger multifractality strength? The next section (Section 2) describes the methods used to determine the scaling exponents for correlated records and the multifractality strength while Section 3 describes the study area and datasets used. In Section 4, we present and discuss key findings. The main conclusions are outlined in Section 5.

## 2. Methods

### 2.1. Scaling exponents for long-term correlated records

We use the scaling exponents for long-term correlated records to assess the effect of urbanization on the long-term persistence of streamflow. We employed MF-DFA to determine the scaling exponents. MF-DFA is a generalization of the more familiar detrended fluctuation analysis (DFA) (see Ref. [51] for a detailed description of DFA) that allows the consideration of statistical moments of different order $q$ [49]. Like DFA, MF-DFA can distinguish between long-term correlated behavior and nonstationarities due to polynomial trends. This is relevant since streamflow records affected by increasing urbanization tend to exhibit nonstationarities [20,23,31,33,34] and conventional scaling approaches for correlated records (e.g., the autocorrelation function [30] or power spectrum [52]) do not account directly for trends.

Thus, we used the polynomial detrending step in MF-DFA to account for the nonstationarities induced by increasing urbanization on the streamflow records. We note that a similar detrending or adjustment step is often employed in the analysis of annual maximum streamflow series affected by increasing urbanization [20,32,33]. Further, MF-DFA has been tested thoroughly for a wide range of conditions [49,53,54] and implemented successfully using diverse and complex time series data, including precipitation and streamflow records [55,56,50,57]. However, these latter implementations have been conducted on natural basins or have not distinguished between natural and managed (urban) basins.

To implement MF-DFA, one first removes from the original time series of length $N$, $\{Y_i : i = 1, \ldots, N\}$, the seasonal trend by standardizing the series as follows:

$$\phi_i = \frac{Y_i - \langle Y_i \rangle}{\left(\langle Y_i^2 \rangle - \langle Y_i \rangle^2\right)^{1/2}}, \tag{1}$$

where $\phi_i$ and $Y_i$ are the deseasonalized and original time series value at $i$, respectively. The mean, $\langle Y_i \rangle$, and standard deviation, $\left(\langle Y_i^2 \rangle - \langle Y_i \rangle^2\right)^{1/2}$, in Eq. (1) are computed for each calendar day using the entire record. There are other ways of deseasonalizing but Eq. (1) has proven effective for streamflow records [58,56,57]. Using the deseasonalized data, the so-called profile of the series can be generated using the cumulative sum of $\phi_i$ such that

$$W(i) = \sum_{k=1}^{i} \phi_k, \quad i = 1, \ldots, N, \tag{2}$$

where $W(i)$ is the profile value at $i$.