ENVIRONMENTAL DATA SCIENCE SESSION

STRUCTURAL CHARACTERISTICS OF PARTICULATE MATTER TIME SERIES OBSERVED IN AN URBAN ENVIRONMENT

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Abstract:
In this study, we used the fractal and multifractal analysis to explore the structural characteristics of PM10 time series, among which self-similarity and invariance can be considered particularly important. The eXtreme Gradient Boosting method was used to fill in the missing data for multiscale multifractal analysis. The analysis has revealed self-similarity in PM_{10} time series with a positively correlated structure which was stable over a study period. Small fluctuations of PM_{10} levels were observed as a result of variations in local emissions and meteorological conditions. The uncoordinated and uncorrelated intervals in concentration time series were observed as a consequence of occasional pollution events in the areas dominated by industrial activities or as a consequence of the remote emission source activity when wind direction and speed were favorable.

Keywords:
Particulate Matter, Time Series Analysis, Multiscale Multifractal Analysis.

INTRODUCTION

According to the estimate from the World Health Organization, air pollution caused 4.2 million cases of premature death worldwide in the year 2015, whereas the recent estimates indicate that the mortality rate due to exposure to high levels of air pollutants is significantly higher and accounts for 8.9 million. In addition, research has indicated that in case the trend of low air quality continues and the approach to environmental issues is not fundamentally changed, the numbers could be twice as high by 2050.

Environmental science is facing many problems in achieving its mission to guarantee sustainable future in an increasingly complex and rapidly changing overpopulated world. The continuous pollution burden on the environment is dependent not only on the increasing pollutant load, but also on many known processes such as pollution transport, dispersion and deposition, atmospheric chemistry, meteorological factors, solar and cosmic radiation, topography, etc., as well as those which are not even known yet.

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DOI: 10.15308/Sinteza-2021-98-101

The issues that prevent the environmental science to fulfil its' mission are related to (1) complexity, non linearity, interactivity, and cross-compartment interconnectivity of environmental phenomena, (2) insufficiency of data-driven knowledge, especially the knowledge derived as a result of global-scale and multi-compartment research, (3) asymmetric access to data, information, and knowledge, (4) lack of adequate infrastructures regarding environmental big data, (5) barriers and gaps to technological innovation access, (6) high pressure on human and institutional capacities regarding innovation, *etc*.

Particulate matter (PM) emitted from different both natural and anthropogenic emission sources can remain in the air for a few hours or days depending on local meteorological conditions, susceptibility to chemical and physical transformations, and factors that contribute to sedimentation and precipitation. Self-similarity and invariance are important features of pollutant concentration time-series. These structural characteristics of PM time series revealed by using fractal and multifractal analysis could be considered when assessing their behavior patterns in the present and predicting their behavior in the future [1], [2], [3], [4], [5], [6], [7]. These analyses assume that phenomena and dynamic behavior of the system do possess the property of self-similarity and that the features of the system on one scale resemble the ones on different scales [8], [9], [10].

The atmosphere of the urban environment contains up to several hundred types of particulate matter, some of which are toxic, mutagen and, carcinogen. Adequate consideration of air quality is significantly limited by relying on data on gaseous inorganic oxides, or the concentration data of only the coarse PM fraction (PM_{10}) and several of its constituents. European Union countries measure concentrations for as much as 40 pollutants, as well as numerous constituents of three PM fractions (PM_{10}, $PM_{2,5}$, and PM_1).

In this paper, we investigate the fractal behavior of PM_{10} time-series across Belgrade area by the use of multiscale multifractal analysis (MMA) with the aim to obtain a more comprehensive understanding of the particulate matter behavior and environmental fate.

2. MATERIALS AND METHODS

Analysis of the structural characteristics of PM time series (fluctuation, self-similarity, and invariance) has been performed using MMA. The analysis of the characteristic parameters of the MM-spectrum (Hurst exponent, multifractal parameter, and scale) provided information on particularities of air pollution dynamics at a given location. A detailed description of the method is to be found elsewhere [11].

Hurst exponent (H) is used to describe the self-similarity of fractal properties, i.e., time series of pollutants in the presented analysis [12], [13]. In general, if H<0.5, the correlation between the intervals in the time series is a negative one, the change that occurs in the next moment will be opposite compared to the previous one, and the system has a pronounced tendency to fluctuate. The processes characterized by H=0.5 are random, similar to Brownian motion, and there is no correlation between the increments in the time series. If 0.5<H<1.5 is valid, there is a positive correlation between the shifts in the next moment will show similar tendencies as the previous one and the time series possess the property of self-similarity. Self-similarity is more pronounced the closer H gets to 1. When H>1.5 the time series is characterized by uncoordinated and uncorrelated intervals. In addition to the Hurst exponent, a multifractal parameter with both negative and positive values can be used to assess the fractal characteristics. The higher the value of the parameter, the higher the degree of fluctuation, whereas the absence of fluctuations leads to the multifractal parameter value of 0 and represents monofractal behavior.

The eXtreme Gradient Boosting method was used to fill in the missing data for the MMA application. The study used method implementation within the Python software environment. A detailed description of the method is to be found elsewhere [14].

3. RESULTS AND DISCUSSION

Characterization of PM10 time series observed in Belgrade has been performed by using MMA. At almost all monitoring stations, the value of Hurst exponent between 0.70 and 1.5 indicates self-similar time series PM_{10} with a positively correlated structure that is stable over a long period, Figure 1.

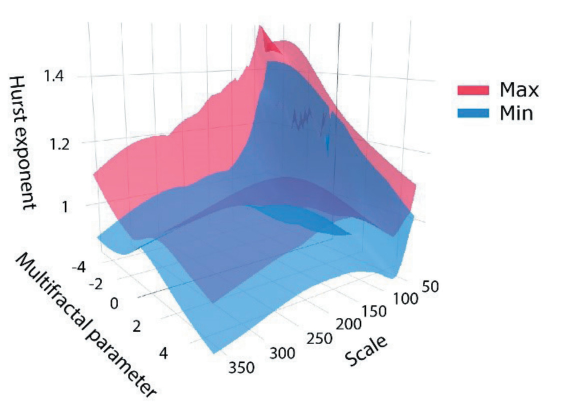

Figure 1 – PM_{10} Hurst exponent range in Belgrade 2017-2019.

Multifractal analysis of PM10 time series at monitoring stations at the Institute of Public Health of Belgrade and Obrenovac are presented in Figures 2 and 3.

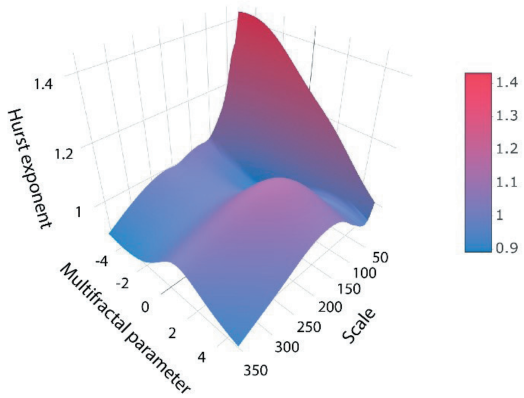

Figure 2 – Structural characteristics of time series of concentrations PM_{10} at monitoring place at the Institute of Public Health of Belgrade for the period from 2017 to 2019.

After reaching the maximums, values of Hurst exponent plummet to the value of 1 in the areas of small and large fluctuations and a time scale of up to 120 hours, thus indicating the most stable fractal nature of PM_{10} time series with a correlated structure over a prolonged period of time, i.e., the existence of the "long-term memory". This trend generally continues on scales from 150 to 350 hours with episodes of higher fluctuations (multifractal parameter = -0.5 – 1.8) for the period from 130 to 245 hours, in which the values of Hurst exponent do not exceed 1.13.

The PM10 concentration variability characterized by H values from 0.73 to 1.54 and values of multifractal parameter from -5 to 5 at the Obrenovac sampling site are shown at Figure 3. In the domain of lower fluctuations (multifractal parameter ≈-5), two peaks stand out: H>1.5 between 165 and 240 hours and H=1.3 on a time scale of up to 30 hours.

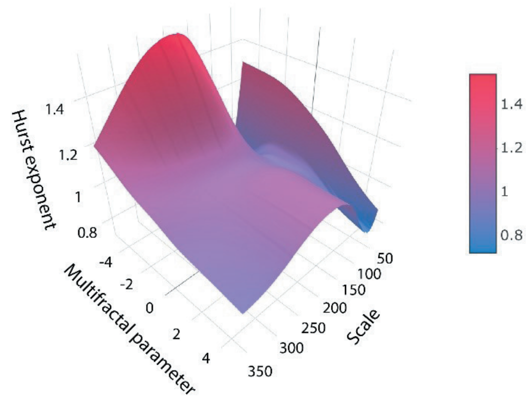

Figure 3 – Structural characteristics of time series of concentration PM_{10} at the monitoring station Obrenovac for the period from 2017 to 2019.

The time series characterized by H-values greater than 1.5 consists of uncoordinated and uncorrelated intervals which can be attributed to occasional emission intensification in the areas dominated by industrial activities or to impacts of remote emission sources when wind direction and speed were favorable. At the monitoring station Obrenovac, the most significant impacts can be attributed to emissions from the power plant "Nikola Tesla", as well as to works on construction sites of the A2 highway over the course of the observed period. Upon reaching the maximum values, steep slopes were observed in the domains of higher and lower fluctuations on the time scale of up to 350 (H up to 1.03) and 75 hours (H up to 0.72), respectively. The results indicated that the variability of PM time series decreased when the environment factors weaken and that there is a positive correlation between time intervals demonstrating similar dynamics.

4. CONCLUSION

There is an urgent need to stimulate new practices of interdisciplinary evidence-based research and innovation in which the research, design, development, deployment, and the use of advanced statistical, and numerical methods is anchored in environmental science. Further progress of environmental science and environmental pollution research will certainly depend on its integration with other scientific disciplines, among which high-performance computing seem to be of extreme significance. Moreover, the modern science requires infrastructure being data-based, efficient, real-time responsive, scalable, flexible, and robust enough to allow the understanding of the evolution of global pollution impact and climate change in real-time and to anticipate future trends and challenges for the sake of global sustainability.

Application of MMA indicated self-similarity in PM10 time series with a positively correlated structure which was stable over a longer period of time at almost all monitoring stations. The results from AMS Institute of Public Health of Belgrade and AMS Obrenovac were taken as representative for further interpretation. At the AMS Institute of Public Health of Belgrade, the most pronounced variations were recorded in the domain of low fluctuations and on small scales of up to 45 hours. Fluctuations of PM_{10} on small scales were impacted by the intensity of local emissions and meteorological conditions governing the processes of condensation and nucleation, as well as physicochemical transformations and formation of secondary aerosols. Upon reaching the above stated maximum, a stable and positively correlated fractal nature of PM_{10} time series over a longer period of time in the domain of lower and higher fluctuations was observed.

At the Obrenovac measurement site, variability of PM concentrations in the domain of lower fluctuations was evidenced, on a scale between 165 and 240 hours. The PM time series consisted of uncoordinated and uncorrelated intervals, as a consequence of occasional pollution events in the areas dominated by industrial activities or as a consequence of the impact of remote emission sources when wind direction and speed were favorable. Also, the results indicate that variability of PM time series decreases when the impact of environment factors weakens, and that there is a positive correlation between time intervals indicating similar dynamics.

5. ACKNOWLEDGEMENTS

The authors acknowledge funding provided by the Institute of Physics Belgrade, through the grant by the Ministry of Education, Science and Technological Development of the Republic of Serbia, the Science Fund of the Republic of Serbia #GRANT No. 6524105, AI-ATLAS, as well as the City of Belgrade, Department of Environmental protection of the city administration, Serbia, Air quality plan for the City of Belgrade.

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