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DYNAMICS OF CHEMICAL POLLUTION IN THE FORESTED WATERSHEDS: NEW DATA ON CORRELATION DIMENSION AND CHAOS ELEMENTS IN TIME SERIES

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An improved theoretical scheme for sensing temporal and spatial structure of the chemical pollution substances in the forested watersheds is theoretically investigated and applied to an analysis and modelling the concentrations of phosphates and nitrates. The effects of stochasticity and chaotic features in the chemical pollution structure of the watersheds are discovered on the basis of the correlation dimension approach to empirical time series data. As the concrete example, there are studied a dynamics of the daily values of the concentrations of phosphates and nitrates, water flows (forested watershed Maleno, Small Carpathians, Slovakia) in 1991/1992 years and the relationship between the correlation dimension and embedding dimension is computed. The finite correlation dimensions obtained for the two series indicate that they all exhibit chaotic behaviour. The presence of the deterministic chaos elements at each of the two studied scales suggests that the dynamics of transformation of the chemical pollution component between these scales may also exhibit chaotic behaviour. This, in turn, may imply the applicability (or suitability) of a chaotic approach for transformation of the the pollution component data from one scale to another. Thus, for hydroecological systems it can be principally possible a scenario of so-called automodelity.

Key words: chemical pollution substances, concentrations of phosphates and nitrates, forested watersheds, correlation dimension, stochastic elements, chaos

1. INTRODUCTION

This paper devoted to development of the an improved theoretical scheme for sensing temporal and spatial structure of the chemical pollution substances in the forested watersheds. Let us underline that a problem of environment protection, including atmosphere, hydrosphere and other environments, remains on of the most complex and actual problems in a modern ecology and related sciences [1-26].

Despite of a great number of different as a rule, simplified mathematical models, including different probability and stochastic models, hitherto it is absent a comprehensive quantitatively correct treating the environment pollution problem. As it was indicated in [22] carrying out new, effective schemes for sensing air pollution field structure in atmosphere in general and atmosphere of industrial cities in particular is one of the most actual and complex problems of modern atmosphere and environmental science (see also [3-20]). Generally specking a modern state of art stimulates a development of principally new approached to problem of environment treating and protection, including development and using non-standard numerical models.

Earlier we have presented a new scheme for studying temporal and spatial structure of the air pollution fields in the industrial city's atmosphere on the basis of correlation integral method and fractal formalism. The last methods are part of the modern powerful non-linear analysis tools, which include advanced techniques such as a wavelet analysis, mutual information approach, false nearest neighbour algorithm, the Lyapunov exponent's analysis, and surrogate data method, stochastic propagators formalism, memory functions methods and others (see, for details, [1,2]). A great number of different experimental methods are used in studying the atmosphere and hydrosphere pollution. The standard methods are based on the physical-chemical analysis. In problem of air pollution , in last years a great interest attracts using laser emission analysis schemes.

In this paper we present an improved theoretical scheme for sensing temporal and spatial structure of the chemical pollution substances in the hydroecological system, namely, the forested watersheds and applied it to an analysis of the concentrations of phosphates and nitrates. The effects of stochasticity and chaotic features in the chemical pollution structure of the watersheds are discovered on the basis of the correlation dimension approach to empirical time series data [27,28].

As the concrete example, there are studied a dynamics of the daily values of the concentrations of phosphates and nitrates, water flows (forested watershed Maleno, Small Carpathians, Slovakia) in 1991/1992 years and the relationship between the correlation dimension and embedding dimension is computed. The finite correlation dimensions obtained for the two series indicate that they all exhibit chaotic behaviour.

The presence of the deterministic chaos elements at each of the two studied scales suggests that the dynamics of transformation of the chemical pollution component between these scales may also exhibit chaotic behaviour. This, in turn, may imply the applicability (or suitability) of a chaotic approach for transformation of the the pollution component data from one scale to another. Thus, for hydroecological systems it can be principally possible a scenario of so-called automodelity. It opens new perspectives in studying the systems, for which it is characteristic an absence of the detailed data on pollution etc.

2. NON-LINEAR MULTI-FRACTAL ANALYSIS APPROACH

As it has been earlier noted [1,4,8], a hydroecological system as many other ecological, geophysical, biological systems (and the dynamics of their key characteristics fluctuations) can be described as a mechanical dissipative multi-level system, which are fundamentally non-linear. It is well known that the similar dynamical dissipative systems very often have parameter ranges, in which the dynamics is chaotic. Non-linear systems typically have a long-term behaviour, which is described by an attractor in phase space. At the same the chaotic dynamics in details is often unknown. It is well known that an attractor is called strange attractor if its dimension is non-integer, i.e. fractal. Non-linear systems of fractal objects like interfaces or time-series is their scaling property related to invariance under magnification. For uniform fractals one-fractal exponents, the so-called fractal dimension, uniquely describe the scaling. For non-uniform fractals one must say about multi fractal dimension spectrum. This phenomenon was discovered in many systems (c.f.[1-8]).

As the key methods of the modern non-linear-analysis technique has been in details presented earlier here, we are limited only the key elements of the multifractal approach to determination of structure of the chemical pollutions in hydroecological system on an example of the forested watershed. Below we follow our presentation [22]. The presence of chaos in the time series of the chemical pollutant concentrations in the watershed dynamics is investigated by employing the correlation dimension method (c.f.[1]).

The correlation dimension is a representation of the variability or irregularity of a process and furnishes information on the number of dominant variables present in the evolution of the corresponding dynamical system. It can indicate not only the existence of chaos in the air pollution variability process, if any, but also reveal whether the process is deterministic or stochastic, if not chaotic [1,8,22,23].

The correlation dimension method uses the correlation integral (or function) to distinguish chaotic and stochastic systems. The Grassberger-Procaccia algorithm [11] employed in the present study for estimating the correlation dimension of the pollution series, uses the concept of phase-space reconstruction. For a scalar time series $X\,i$, where i = 1, 2, ..., N, the phase-space can be reconstructed using the method of delays, according to [4,8]

$$Y_j = (X_j , X_{j+t} , X_{j+2t} , ..., X_{j+(m-1)t}) \quad (1)$$

where j = 1, 2, ..., N-(m-1)t/Dt; m is the dimension of the vector Yj , also called the embedding dimension; and t is a delay time.

For an m-dimensional phase-space, the correlation function C(r) is given by [11]

$$C(r)= \lim_{N\to\infty} \frac{2}{N(N-1)} \sum_{i,j} H(r-|Y_i - Y_j|). \quad (2)$$

Here H is the Heaviside step function, with $H(u)$ = 1 for $u > 0$, and $H(u) = 0$ for $u \le 0$, where $u = r-|Y_i-Yj|$; r is the radius of sphere centred on Y_i or Y_j and $1<i<j<N$.

If the time series is characterised by an attractor (a geometric object which characterises the long-term behaviour of a system in the phase-space) then, for positive values of r, the correlation function $C(r)$ is related to the radius r by: $C(r) \sim ar^n$, where a is constant and n is the correlation exponent or the slope of the *log C(r)* versus *log r* plot given by

$$\nu= \lim_{r_i\sim 0, N\sim A} \frac{\log C(r)}{\log r}. \quad (3)$$

The slope is generally estimated by a least-squares fit of a straight line over a certain range of r, called the scaling region. The presence/absence of chaos can be identified using the correlation exponent versus embedding dimension plot. If the correlation exponent saturates and the saturation value is low, then the system is generally considered to exhibit low-dimensional chaos. The saturation value of the correlation exponent is defined as the correlation dimension of the attractor. The nearest integer above the saturation value provides the minimum number of variables necessary to model the dynamics of the attractor. On the other hand, if the correlation exponent increases without bound with increase in the embedding dimension, the system under investigation is generally considered as stochastic.

3. RESULTS AND CONCLUSIONS

As the concrete example, we e studied a dynamics of the daily values of the concentrations of phosphates and nitrates, water flows for the forested watershed of Maleno, (Small Carpathians, Slovakia) in 1991/1992 years and computed the relationship between the correlation dimension and embedding dimension. . As a first step, the present study investigates the chemical pollution variability series of different (temporal) scales. Data of four different temporal scales, i.e. daily, 1-week, 0,5-month, and 1-month, over a period of about 20 years observed at the Maleno [28] are analysed (independently) to investigate the existence of stochasticity (chaos). The underlying assumption is that the individual behaviour of the dynamics of the processes at these scales provides important information about the dynamics of the overall dusty air pollution transformation between these scales. More specifically, if the pollution variability processes at different scales exhibit chaotic behaviour, then the dynamics of the transformation between them may also be chaotic.

Figure 1 shows the variation of the quart-daily values of the concentrations of phosphates and nitrates, water flows (forested watershed Maleno, Small Carpathians, Slovakia) in 1991/1992, respectivelys. The correlation functions and the exponents are computed for the three series. The delay time, t, for the phase-space reconstruction is computed using the auto correlation function method and is taken as the lag time at which the auto correlation function first crosses the zero line.

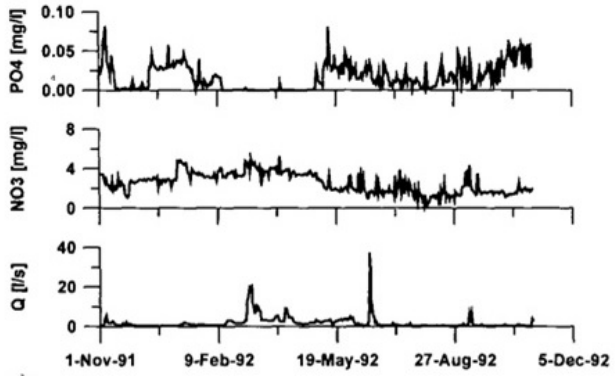

Fig. 1 – Daily values of the concentrations of phosphates and nitrates, water flows (forested watershed Maleno, Small Carpathians, Slovakia) in 1991/1992, respectively.

For the quart-daily phosphates pollutant component series, figure 2 shows the relationship between the correlation integral, C(r), and the radius, r, for embedding dimensions, m, from 1 to 10. For all the series, the correlation exponent value increases with the embedding dimension up to a certain dimension, beyond which it is saturated; this is an indication of the existence of deterministic dynamics. More exact saturation values of the correlation exponent (or correlation dimension) for the three quart- daily pollutants and water flows series are respectively, 2.7, 2.9, 3.2.

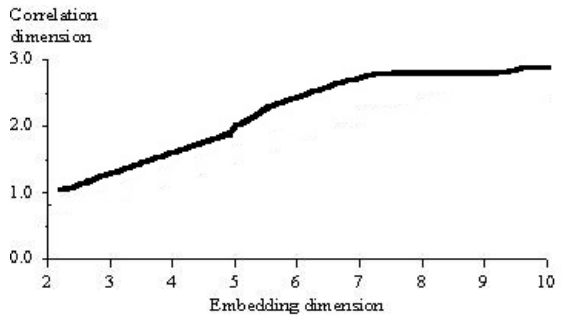

Fig. 2 - The relationship between the correlation dimension and embedding dimension (phosphates pollutant series)

Obviously, that one should wait for the finite correlation dimensions obtained for the three series and it indicate that they all exhibit chaotic behaviour. The presence of the deterministic chaos elements at each of the studied scales (quart-daily, half-daily, daily) suggests that the dynamics of transformation of the chemical pollution component between these scales may also exhibit chaotic behaviour. This, in turn, may imply the applicability (or suitability) of a chaotic approach for transformation of the the pollution component data from one scale to another. Conclusion is to be obvious. Namely, the found features allow making conclusion about fractal properties of the the phosphates and nitrates pollutions concentration series, as it has been earlier indicated in [2,8]. The further work should include a total non-linear analysis, modeling and predictions with using an advanced techniques such as a wavelet analysis, mutual information approach, false nearest neighbour algorithm, the Lyapunov exponent's analysis, and surrogate data method, stochastic propagators formalism, memory functions methods and others (see, for details, [1-18]).

СПИСОК ЛИТЕРАТУРЫ

1. Бунякова Ю.Я. Анализ и прогноз влияния антропогенных факторов на воздушный бассейн промышленного города /. Ю.Я. Бунякова, А.В. Глушков. - Одесса: Экология, 2010.- 256 с.
2. Глушков А.В. Низкоразмерный хаос в временных рядах концентраций загрязняющих веществ в атмосфере и гидросфере / А.В. Глушков, В.Н. Хохлов, Н.Г. Сербов, Ю.Я. Бунякова, К. Балан, Е.Р. Баланюк // Вестник Одесского государственного экологического университета.-2007.-N4.- С.337-348.
3. Glushkov A.V., Svinarenko A.A., Buyadzhi V.V., Zaichko P.A., Ternovsky V.B. *Adv.in Neural Networks, Fuzzy Systems and Artificial Intelligence, Series: Recent Adv. in Computer Engineering*. Gdansk: WSEAS, 2014, vol.21, pp. 143-150. (Ed.: J. Balicki)
4. Khokhlov V.N., Glushkov A.V., Loboda N.S., Bunyakova Yu.Ya. Short-range forecast of atmospheric pollutants using non-linear prediction method. *Atmospheric Environment.* The Netherlands: Elsevier, 2008, vol. 42, pp. 7284–7292.
5. Glushkov A.V., Khokhlov V.N., Prepelitsa G.P., Tsenenko I.A. Temporal changing of the atmosphere methane content: an influence of the NAO. *Optics of atmosphere and ocean*, 2004, vol. 4, № 7, pp. 593-598.
6. Glushkov A.V., Khokhlov V.N., Bunyakova Yu.Ya. Renorm-group approach to studying spectrum of the turbulence in atmosphere. *Meteor. Climat. Hydrol*, 2004, no. 48, pp. 286-292.
7. Glushkov A.V., Khokhlov V.N., Tsenenko I.A. Atmospheric teleconnection patterns and eddy kinetic energy content: wavelet analysis. *Nonlinear Processes in Geophysics*, 2004, vol. 11, no. 3, pp. 285-293.
8. Glushkov A.V., Khokhlov V.N., Serbov N.G, Bunyakova Yu.Ya., Balan A.K., Balanjuk E.P. Low-dimensional chaos in the time series of the pollution substances concentrations in atmosphere and hydrosphere. *Herald of Odessa State Environmental University*, 2007, no. 4, pp. 337-348.
9. Serga E.N., Bunyakova Yu.Ya., Loboda A.V., Mansarliysky V.F., Dudinov A.A. Multifractal analysis of time series of indices of the Arctic, the Antarctic and the Southern Oscillation. *Ukr. gidrometeorol. ž - Ulrainian Hydrometeorology Journal,* 2013, no. 13, pp. 41-45.
10. Schreiber T. Interdisciplinary application of nonlinear time series methods. *Phys. Rep*., 1999, vol. 308, pp. 1-64.
11. Grassberger P, Procaccia I. Measuring the strangeness of strange attractors. *Physica D*, 1983, vol. 9, pp. 189–208.
12. Havstad J.W., Ehlers C.L. Attractor dimension of nonstationary dynamical systems from small data sets. *Phys. Rev. A*., 1989, vol. 39, pp. 845–853.
13. Berndtsson R., Jinno K., Kawamura A., Olsson J., Xu S. Dynamical systems theory applied to long-term temperature and precipitation time series. *Trends in Hydrol*, 1994, vol. 1, pp. 291–297.
14. Barnston A.G., Livezey R.E. Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon. Wea. Rev.,* 1987, vol. 115, pp. 1083-1126.
15. Morlet J., Arens G., Fourgeau E., Giard D. Wave propagation and sampling theory. *Geophysics,* 1982, vol. 47, pp. 203-236.
16. Nason G., von Sachs R., Kroisand G. Wavelet processes and adaptive estimation of the evolutionary wavelet spectrum. *J. Royal Stat. Soc.,* 2000, vol. B-62, pp. 271-292.
17. Glushkov A.V., Khokhlov V.N., Loboda N.S., Ponomarenko E.L. Computer modelling the global cycle of carbon dioxide in system of atmosphere-ocean and environmental consequences of climate change. *Environmental Informatics Arch,* 2003, vol.1, pp. 125-130.
18. Mandelbrot B.B. *Fractal Geometry of Nature*. N.-Y.: W.H. Freeman, 1982.
19. Bunyakova Yu.Ya., Glushkov A.V. Laser emission analysis of the fractal dusty atmosphere parameters. *Preprint of the I.I. Mechnikov Odessa Nat.Univ*., NIIF., N4.-Odessa, 2004.
20. Inhaber H. A set of suggested air quality indices for Canada.

Atmos. Environ., 1975, vol. 9, pp. 353–364.
21. Ott W.R., Thom G.A. Critical review of air pollution index systems in the United States and Canada. *J. Air Pollut. Contr. Assoc.,* 1976, vol. 26, pp. 460–470.
22. Bunyakova Yu.Ya. Air pollution field structure in the industrial city's atmosphere: New data on stochasticity and chaos. *Ukr. gìdrometeorol. ž - Ulrainian Hydrometeorology Journal,* 2014, no. 15, pp. 22-26.
23. Глушков А.В. Хаос-геометрический подход к моделированию временных флуктуаций концентраций загрязняющих веществ в речной воде / А.В. Глушков, Н.Г. Сербов, А.К. Балан, И.А. Шахман, Е.П. Соляникова // Український гідрометеоророгічний журнал.-2014.-N15.-P.183-187.
24. Сербов Н.Г. Многофакторный системный и мультифрактальный подходы в моделировании экстремально высоких паводков (на примере р. Дунай) и временных флуктуаций концентраций загрязняющих веществ в речной воде / Н.Г. Сербов, А.К. Балан, Е.П. Соляникова // Вісник ОДЕКУ.-2008.-Вип. 6.-С.7-13.
25. Сербов Н.Г. Многофакторный системный и мультифрактальный подход к моделированию экстремально высоких паводков на примере р. Дунай/ Н.Г. Сербов, Д.Е. Сухарев, А.К. Балан // Український гідрометеор. журнал.-2010.-N7.-С.167-171.
26. Glushkov A.V., Khetselius O.Yu., Bunyakova Yu.Ya., Grushevsky O.N., Solyanikova E.P. Studying and forecasting the atmospheric and hydroecological systems dynamics by using chaos theory methods. *Dynamical Systems Theory.* Polland, 2013, vol. T1, pp. 249-258. (Eds.: J. Awrejcewicz et al).
27. Svoboda A., Pekarova P., Miklanek P. Flood hydrology of Danube between Devin and Nagymaros in Slovakia. Nat. Rep.2000 of the UNESKO. Project 4.1. *Intern.Water Systems,* 2000, 96 p.
28. Pekarova P., Miklanek P., Konicek A., Pekar J. Water quality in experimental basins.- Nat. Rep.1999 of the UNESKO.-Project 1.1. *Intern.Water Systems*, 1999, 98 p.

REFERENCES

1. Bunyakova Yu.Ya., Glushkov A.V. *Analysis and forecast of the impact of anthropogenic factors on air basin of an industrial city*. Odessa: Ecology, 2010. 256 p. (In Russian)
2. Glushkov A.V., Khokhlov V.N., Serbov N.G., Bunyakova Yu.Ya., Balan A.K., Balanyuk E.P. Low-dimensional chaos in the time series of concentrations of pollutants in an atmosphere and hydrosphere. *Visn. Odes. derž. ekol. unìv.– Bulletin of Odessa state environmental university*, 2007, no. 4, pp. 337-348. (In Russian)
3. Glushkov A.V., Svinarenko A.A., Buyadzhi V.V., Zaichko P.A., Ternovsky V.B. *Adv.in Neural Networks, Fuzzy Systems and Artificial Intelligence, Series: Recent Adv. in Computer Engineering*. Gdansk: WSEAS, 2014., vol.21, pp. 143-150. (Ed.: J. Balicki)
4. Khokhlov V.N., Glushkov A.V., Loboda N.S., Bunyakova Yu.Ya. Short-range forecast of atmospheric pollutants using non-linear prediction method. *Atmospheric Environment.* The Netherlands: Elsevier; 2008, vol.42, pp. 7284–7292.
5. Glushkov A.V., Khokhlov V.N., Prepelitsa G.P., Tsenenko I.A. Temporal changing of the atmosphere methane content: an influence of the NAO. *Optics of atmosphere and ocean*, 2004, vol.4, №7, pp. 593-598.
6. Glushkov A.V., Khokhlov V.N., Bunyakova Yu.Ya. Renorm-group approach to studying spectrum of the turbulence in atmosphere. *Meteor.Climat.Hydrol*, 2004, no. 48, pp. 286-292.
7. Glushkov A.V., Khokhlov V.N., Tsenenko I.A. Atmospheric teleconnection patterns and eddy kinetic energy content: wavelet analysis. *Nonlinear Processes in Geophysics*, 2004, vol. 11, no. 3, pp. 285-293.
8. Glushkov A.V., Khokhlov V.N., Serbov N.G, Bunyakova Yu.Ya., Balan A.K., Balanjuk E.P. Low-dimensional chaos in the time series of the pollution substances concentrations in atmosphere and hydrosphere. *Herald of Odessa State Environmental University*, 2007, no. 4, pp. 337-348.
9. Serga E.N., Bunyakova Yu.Ya., Loboda A.V., Mansarliysky V.F., Dudinov A.A. Multifractal analysis of time series of indices of the Arctic, the Antarctic and the Southern Oscillation. *Ukr. gìdrometeorol. ž - Ulrainian Hydrometeorology Journal,* 2013, no. 13, pp. 41-45.
10. Schreiber T. Interdisciplinary application of nonlinear time series methods. *Phys. Rep*., 1999, vol. 308, pp. 1-64.
11. Grassberger P, Procaccia I. Measuring the strangeness of strange attractors. *Physica D*, 1983, vol. 9, pp. 189–208.
12. Havstad J.W., Ehlers C.L. Attractor dimension of nonstationary dynamical systems from small data sets. *Phys. Rev. A*., 1989, vol. 39, pp. 845–853.
13. Berndtsson R., Jinno K., Kawamura A., Olsson J., Xu S. Dynamical systems theory applied to long-term temperature and precipitation time series. *Trends in Hydrol*, 1994, vol. 1, pp. 291–297.
14. Barnston A.G., Livezey R.E. Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon. Wea. Rev.,* 1987, vol. 115, pp. 1083-1126.
15. Morlet J., Arens G., Fourgeau E., Giard D. Wave propagation and sampling theory. *Geophysics,* 1982, vol. 47, pp. 203-236.
16. Nason G., von Sachs R., Kroisand G. Wavelet processes and adaptive estimation of the evolutionary wavelet spectrum. *J. Royal Stat. Soc.,* 2000, vol. B-62, pp. 271-292.
17. Glushkov A.V., Khokhlov V.N., Loboda N.S., Ponomarenko E.L. Computer modelling the global cycle of carbon dioxide in system of atmosphere-ocean and environmental consequences of climate change. *Environmental Informatics Arch,* 2003, vol.1, pp. 125-130.
18. Mandelbrot B.B. *Fractal Geometry of Nature*. N.-Y.: W.H. Freeman, 1982.
19. Bunyakova Yu.Ya., Glushkov A.V. Laser emission analysis of the fractal dusty atmosphere parameters. *Preprint of the I.I. Mechnikov Odessa Nat.Univ*., NIIF., N4.-Odessa, 2004.
20. Inhaber H. A set of suggested air quality indices for Canada. *Atmos. Environ*., 1975, vol. 9, pp. 353–364.
21. Ott W.R., Thom G.A. Critical review of air pollution index systems in the United States and Canada. *J. Air Pollut. Contr. Assoc.,* 1976, vol. 26, pp. 460–470.
22. Bunyakova Yu.Ya. Air pollution field structure in the industrial city's atmosphere: New data on stochasticity and chaos. *Ukr. gìdrometeorol. Ž - Ulrainian Hydrometeorology Journal,* 2014, no. 15, pp. 22-26.
23. Glushkov A.V., Serbov N.G., Balan A.K., Shakhman I.A., Solyanikova E.P. Chaos-geometric approach to modeling the temporal fluctuations of the concentration of pollutants in the river water. *Ukr. gìdrometeorol. ž - Ulrainian Hydrometeorology Journal,* 2014, no. 15, pp. 183-187. (In Russian).
24. Serbov N.G., Balan A.K., Solyanikova E.P. Multivariate system and multifractal approaches in modeling extreme high floods (for example, r. Danube) and temporal fluctuations in the concentrations of pollutants in the river water. *Visn. Odes. derž. ekol. unìv.– Bulletin of Odessa state environmental university*, 2008, no. 6, pp. 7-13. (In Russian).
25. Serbov N.G., Sukharev D.E., Balan A.K. Multivariate system and multifractal approach to modeling an extremely high floods on the example of the river. Danube. *Ukr. gìdrometeorol. Ž - Ulrainian Hydrometeorology Journal,* 2010, no. 7, pp. 167-171. (In Russian).
26. Glushkov A.V., Khetselius O.Yu., Bunyakova Yu.Ya., Grushevsky O.N., Solyanikova E.P. Studying and forecasting the atmospheric and hydroecological systems dynamics by using chaos theory methods. *Dynamical Systems Theory.* Polland, 2013, vol. T1, pp. 249-258. (Eds.: J. Awrejcewicz et al).
27. Svoboda A., Pekarova P., Miklanek P. Flood hydrology of Danube between Devin and Nagymaros in Slovakia. Nat. Rep.2000 of the UNESKO. Project 4.1. *Intern.Water Systems,* 2000, 96 p.
28. Pekarova P., Miklanek P., Konicek A., Pekar J. Water quality in experimental basins.- Nat. Rep.1999 of the UNESKO.-Project 1.1. *Intern.Water Systems*, 1999, 98 p.

ДИНАМИКА ХИМИЧЕСКОГО ЗАГРЯЗНЕНИЯ ЛЕСНЫХ ВОДОСБОРОВ: НОВЫЕ ДАННЫЕ ПО КОРРЕЛЯЦИОННОЙ РАЗМЕРНОСТИ И ЭЛЕМЕНТАМ ХАОСА ВО ВРЕМЕННЫХ РЯДАХ

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Изложен улучшенный теоретический подход для изучения временной и пространственной структуры химического загрязнения лесистых водосборов и рассмотрено его применение в случае задачи о временной динамике изменения концентраций фосфатов и сульфатов. Обнаружены хаотические особенности в структуре химического загрязнения водоразделов на основе метода корреляционной размерности, примененного к анализу эмпирических временных рядов. В качестве конкретного примера, численно изучена динамика четвертьсуточных значений концентраций фосфатов и сульфатов, расходов воды для лесистого водосбора Maleno (Малые Карпаты, Словакия) в 1991/1992 года. Численно оценены соотношения между корреляционной размерностью и размерностью вложения. Конечные значения корреляционной размерности для изученных рядов значений концентраций фосфатов и сульфатов, расходов воды показывают, что все они демонстрируют хаотическое поведение. Наличие элементов хаоса в каждом из исследованных временных рядов на рассмотренном временном интервале предопределяет возможность трансформации динамики концентраций загрязняющих веществ на другие временные масштабы, фактически переходя от одного локального временного масштаба к другому, в частности, более глобальному. Тем самым, для гидроэкологических систем принципиально возможным становится сценарий так называемой автомодельности.

Ключевые слова: химическое загрязнение, концентрации фосфатов и сульфатов, лесные водосборы, корреляционная размерность, стохастичность, хаос

ДИНАМІКА ХІМІЧНОГО ЗАБРУДНЕННЯ ЛІСОВИХ ВОДОДІЛІВ: НОВІ ДАНІ ПО КОРЕЛЯЦІЙНІЙ РОЗМІРНОСТІ І ЕЛЕМЕНТАМ ХАОСУ В ЧААСОВИХ РЯДАХ

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Викладено покращений теоретичний підхід для вивчення часової і просторової структури хімічного забруднення лісистих водозборів і розглянуто його застосування в разі завдання про часову динаміці зміни концентрацій фосфатів і сульфатів. Виявлені хаотичні особливості в структурі хімічного забруднення вододілів на основі методу кореляційної розмірності, застосованого до аналізу емпіричних часових рядів. Як конкретний приклад, чисельно вивчена динаміка чвертьсуточних значень концентрацій фосфатів і сульфатів, витрат води для лісистого водозбору Maleno (Малі Карпати, Словаччина) в 1991/1992 року. Чисельно оцінені співвідношення між кореляційною розмірністю і розмірністю вкладення. Кінцеві значення кореляційної розмірності для вивчених рядів значень концентрацій фосфатів і сульфатів, витрат води свідчать, що всі вони демонструють хаотичну поведінку. Наявність елементів хаосу в кожному з досліджених часових рядів на розглянутому часовому інтервалі зумовлює можливість трансформації динаміки концентрацій забруднюючих речовин на інші часові масштаби, фактично переходячи від одного локального тимчасового масштабу до іншого, зокрема, більш глобального. Тим самим, для гідроекологічних систем принципіально можливим стає сценарій так званої автомодельності.

Ключові слова: хімічне забруднення, концентрації фосфатів і сульфатів, лісові водозбори, кореляційна розмірність, стохастичність, хаос

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