Multi-scale response of runoff to climate fluctuation in the headwater region of the Kaidu River in Xinjiang of China

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Abstract

Based on the climatological-hydrological daily data recorded in the headwater region of the Kaidu River during 1972–2011, the multi-scale characteristics of runoff variability and four climatic factor fluctuations (i.e., temperature, precipitation, relative humidity and evaporation) are analyzed using detrended fluctuation analysis. Furthermore, multi-scale response of runoff to climate fluctuation is investigated using detrended cross-correlation analysis. Main findings are as follows: (1) The temporal scaling behaviors of runoff and four climate factor series all exhibit two different power laws. In shorter temporal scaling, all the series indicate the similar persistence corresponding to the annual cycle. However, in longer temporal scaling, their different trends reflect the different inherent dynamic nature of various hydro-climatic change. (2) In the double logarithm curve $\log F^2(s) \sim \log s$, the long-range correlation of runoff and temperature, long-range correlation of runoff and precipitation and long-range correlation of runoff and relative humidity (hereafter referred to as Lrc-R-T, Lrc-R-P and Lrc-R-H, respectively) show two scaling regimes with two different scale indexes and a critical time scale of about 1 year; the long-range correlation of runoff and evaporation (hereafter referred to as Lrc-R-E) presents three scaling regime with three different scale indexes and with two critical time scales of about 1 and 10 years. These results reflect the multi-scale response characteristics of the runoff to climate change on different time scales.

Keywords: runoff; multi-scale; Kaidu River; power laws; long-range correlation

1. Introduction

Climate change is always a critical environmental issue. Global warming, which has garbed society’s more attention, will possibly change the current regimes of precipitation, hydrological cycle and water resources (Chen et al., 2010; Lan et al., 2010). It is significant to study impacts of climate change on hydrology and water resources, which could provide scientific supports for sustainable utilization of water resources and healthy life maintenance of river. The study of multi-scale response of runoff to climate fluctuation can help to realize the forecast of runoff changing trend and reasonable development, configuration and use of runoff, ensure the sustainable use of water resources, which is of great theoretical and practical significance for planning and design, development, utilization and operation management of the water resources system (Gajbhiye et al., 2016).

It is well known that the supply of water (rainfall) and demand (potential evaporation) are the main factors influencing the water balance for a long time (Budyko, 1974; Milly, 1994; Wang et al., 2016). In addition, runoff and its components are controlled by main natural factors, such as meteorological factors and topographic condition (Yu et al., 2005; Wang et al., 2016). The response of runoff to climate fluctuation mainly embodies in two aspects: one is runoff change as climate change, the other is the runoff fluctuation with temperature, for which the main reason is that variations of temperature have simultaneous impacts on evaporation and snow melting. A lot of research generally believe that both runoff and precipitation change have the same trend of variability. While for different watersheds, their characteristics and the water resources status of runoff were very diverse, so the influence of main climate factors on runoff changes is more different. As for the response of runoff to temperature, it is that highly significant intra-annual distribution of runoff is affected by temperature rising, especially in snow-based watershed.

Although the above studies revealed the change reason of runoff and the relationship between runoff and climate factor to a certain extent, the research works were limited to a temporal scaling and lack of...
Multi-scale response of runoff to climate fluctuation. And because of the temporal scaling change, an important climate factor influencing on runoff on a certain scale is likely to be a rather little effect on the other one. Therefore, experimental research on the temporal scaling behaviors of runoff and climate fluctuation and the former may help to how we strengthen the management and control of water resources in making research on applicable countermeasures of water against climate change.

As for the expiration, it is an important link of the water balance and energy balance, and is an important process for contacting the hydrology dynamic changes with the variations of vegetation ecology. Namely, the expiration process is the most important link in coupling effect of hydrologic cycle of land atmosphere system (Miller and Russell, 1992; Chemel et al., 2015). In addition, it should be pointed out that river runoff has being evolving with the change of the earth and the world. And its changes are a complex process with multiple dynamic coupled factors such as nature events and human activities. Humid or arid weather conditions occurred in some previous period may impact now and future, accordingly neighboring observed values in the time series are correlated to some extent. Some traditional approaches such as power spectrum analysis, correlation analysis and statistical analysis are suitable for determining the correlation characteristics of stationary signals (Bialous et al., 2016; Fong et al., 2016; Li et al., 2016; Rysak et al., 2016). However, the runoff time series usually is affected by noise or nonstationary signals, the mean, standard deviation, high order values and correlation function change as time goes on. In order to clearly understand the scaling behavior of inherent mechanism of runoff evolution and robustly analyze its long-range correlation, it is necessary to identify potential trend patterns caused by inherent long-range fluctuation in the data. The trend patterns caused by outside factors are usually smooth or oscillate slowly, hence if the potential trend patterns were not filtered before series analysis, the strong trend patterns remaining in the series would interfere with the long-range correlation analysis and as a result it would not be able to reveal the evolution process and laws of the runoff system in hydro-meteorological environments. The scaling index computation method proposed in the mechanism of deoxyribo nucleic acid, in other words, the detrended fluctuation analysis (DFA) method, can effectively solve this type of problem (Strychalski et al., 2008). Furthermore, multi-scale response of the runoff system to multiple climatic factor can be effectively detected through the detrended cross-correlation analysis (DCCA) method, which is an extension of the DFA method, and very suitable for the power-law long-range correlation analysis of two nonstationary time series (Podobnik and Stanley, 2007). Moreover, the two methods have been widely applied in climatological-hydrological process. For instance, Livina et al. (2007) applied the DFA method on the scaling properties of river runoff records of the Naab (26 years), the Regnitz (30 years) and the Vils (26 years); Kantelhardt et al. (2006) studied the temporal correlations and multifractal properties of long river discharge records from 41 hydrological stations around the globe using the DFA, multifractal DFA and wavelet analysis methods. Through calculating the DCCA cross-correlation coefficient $\rho$, Shen et al. (2015) found the cross-correlation between diurnal temperature ranges and the the daily air pollution index (API) was persistent at time scales, more specifically, the correlation with the API presented persistent cross-correlation at smaller time scales, and antipersistent cross-correlation at larger time scales.

The Kaidu River, located in the southern slope of the Tianshan Mountains, was honored as the ‘Water Tower of Central Asia’ and ‘Solid Reservoir’. Its runoff supply is mainly from glacial meltwater and precipitation in the Tianshan Mountains, so both temperature and precipitation changes have significant impacts on the runoff from the mountain pass. These changes in runoff from mountain pass not only affect the water supply of downstream industry and agriculture, but also relate to the regional social and economic sustainable development and ecological safety maintenance. In addition, the global warming mitigation in recent years, the complexities and effects of climate change in the Tianshan Mountains have increased the uncertainty of future regional climatological-hydrological process, and the inflow from origin area shows overall increase while the amount of water into the mainstream of the Tarim River decreases, bringing worries for the future security of water resources; therefore, the management and control of water resources shall be strengthened in making research on applicable countermeasures of water against climate change. Thus, a typical catchment of the headwater region of the Kaidu River was selected as the study target region in this article. In this article, the hydrological and meteorological daily data in the region from 1972 to 2011 were selected as the research object. The multi-scale characteristics of runoff and climate factors were quantitatively evaluated by the DFA method. Moreover, the hydrological responses to climate change were analyzed using the DCCA method. These analyses are scientifically significant for improving our understanding of the inherent mechanism of hydrological process of the Kaidu River, its watershed hydrology and practically significant for improving our water resources management.

2. Study area, data and methodology

2.1. Study area

The Kaidu River is the largest river which flows into the Yanqi Basin, the river flows through Hejing, Yanqi and Bohu, originate from Eren Habirga covered by snow all the year around in the middle Tianshan Mountains, Xinjiang, North-west China, and is enclosed between latitudes $42^\circ 14'–43^\circ 21'\text{N}$ and longitudes $82^\circ 58'–86^\circ 55'\text{E}$ (Figure 1). The terrain of the Kaidu River Basin is...
higher in the north-west than in the south-east, so the whole basin is divided into three kinds of types. And the upstream segment length of about 200 km through Eren Wulu, Dayultuz Basin and the canyon, the total length of upper course is about 160 km. The gorge of the middle reaches of the Kaidu River, there is a great difference in the height of hypsography, and stream is rapid, and hydropower resource is mainly concentrated in this segment, where is recharge area of the meltwater from snow and ice, and is the main source of Kaidu River flood. It ends in the Bosten Lake which is located in Bohu County with segment length of the about 120 km (Li et al., 2012; Chen et al., 2013; Bai et al., 2015).

2.2. Data

The Dashankou hydrological station and five meteorological stations located in the study area as shown in Figure 1. The records used in this article were obtained from a high-quality daily runoff and climate sequence (namely, temperature, precipitation, relative humidity and evaporation) data set spanning from 1 January 1972 to 31 December 2011, processed by the Xinjiang Tarim River Basin Management Bureau and National Meteorological Information Center, respectively. In this article, climate sequences are average daily temperature, average daily precipitation, average daily relative humidity and average daily evaporation from only five meteorological stations, respectively. To determine which data have higher quality, the data have been subjected to extremum, time consistency and other tests. In addition, to overcome the natural nonstationarity of the data due to season trends, we remove the annual cycle from the raw data $e$ by computing the anomaly series $e' = e - <e>_d$ for five data series, where $< >_d$ denotes the long-time average value for the given calendar day (Chen et al., 2002). In addition, we apply the standard normal homogeneity test, Buishand and Pettit homogeneity test method to check these data (Pettit, 1979; Buishand, 1982; Alexandersson, 1986). The stepwise multiple linear regression method was employed to revise the inhomogeneity of time series.

2.3. Methodology

The DFA is an advanced method for determining the scaling behavior of data in the presence of possible trends without knowing their origin. For further detail computation, see Peng et al. (1994). In the method, the most important parameter is the root mean square fluctuation $F(n)$, which behaves as a power-law function of $n$ then the data present scaling: $F(n) \propto n^\alpha$. The DFA exponent ($\alpha$) is defined as the slope of the regression line for all points $[\log(n), \log(F(n))]$. Specifically, $\alpha = 0.5$ indicates the series corresponds to a random walk (namely white noise); $0.5 \leq \alpha \leq 1$, indicates persistent long-range power-law correlations; $0 < \alpha \leq 0.5$, power-law anticorrelations are present; when $\alpha > 1$, correlations exist but cease to be of the power-law form; $\alpha = 1.5$ indicates brown noise, the integration of white noise.

In analogy to the DFA, which was proposed by Podobnik and Stanley (2007) for a single time series, DCCA was used for analyzing power-law long-range cross-correlations between different nonstationary time series (Pal et al., 2016; Yin and Shang, 2016). If the detrended fluctuation covariance function $F(s)$ and scale $s$ obey power-law cross-correlations in double logarithmic coordinates as shown $F^2(s) \sim s^\lambda$, where $\lambda$ is the long-range cross-correlation scale index, there is long-range interrelation between two sequences (Ferreira, 2016). In particular, a value of $\lambda > 0.5$ indicates a positive long-range cross-correlation between two sequences. To be specific, if a sequence presents...
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3. Results and discussion

3.1. The multi-scale characteristics of runoff and climate factors

Figure 2(a) shows the DFA analysis for the daily runoff. In this case, the plot exhibits curvature, showing obviously two different period regimes. \( n_c \) is the critical time scale where obvious dividing point occurs. And \( n_c \) is about 1 year, reflecting an influence of the annual cycle. For shorter time periods \((n < n_c)\), the plot can be fitted to a straight line with a DFA exponent \((\alpha_1)\) of 0.99 which exhibits high persistence. Over longer time periods \((n > n_c)\), a line with a decreased slope \((\alpha_2 \approx 0.18)\) that the high persistence changes to antipersistence when the temporal scale is larger than 1 year. Those results indicate that high persistence or long-term memory of the runoff comes up to about 1 year. For time spans greater than 1 year, the runoff displays a high antipersistent behavior. This result is not very clear, which perhaps relates to long-term hydrological processes, the length of the data and the internal dynamics of runoff. It needs more researches and longer series to make an interpretation.

Moreover, the DFA method is applied to the climate factor series of average daily temperature, evaporation, precipitation and relative humidity in the headwater region of Kaidu River from five meteorological stations. The results are shown in Figures 2(b)–(e), respectively. These data fit not one but two visible lines, which are similar to \(\log(F(n)) \sim \log n\) in Figure 2(a) and all \(n_c\) are about 1 year. As to precipitation and relative humidity, for \(n < n_c\), \(\alpha_1\) are approximately 0.78 and 0.98, respectively; while for \(n > n_c\), \(\alpha_1\) are approximately 1.06 and 1.09, respectively. The relation \(\alpha_2 > \alpha_1 > 0.5\) comes as a surprise. This shows that when the temporal scale is larger than 1 year, the persistence becomes higher. Hence, the trend dependence may persist more than 39 years for the two climate factors. Moreover, as to the temperature and evaporation time series, the result is similar to that of runoff.

3.2. The response of the runoff to climate change

Figure 3 shows the DCCA analysis results of the Lrc-R-T, Lrc-R-P, Lrc-R-H and Lrc-R-E. There obviously are two or even three scaling regions in the double logarithm curve \(\log F^2(s) \sim \log s\) for the two types of four long-rang correlation within the same scaling regime. Namely, the Lrc-R-T, Lrc-R-P and Lrc-R-H show two scaling regimes with two different scale indexes \((\lambda_1 \text{ and } \lambda_2)\) and with a critical time scale \((s_c)\) of about 1 year with the same meaning as \(n_c\) in Section 3.1, however, the Lrc-R-E presents three scaling regime with three different scale indexes \((\lambda_1, \lambda_2 \text{ and } \lambda_3)\) and with two critical time scales \((s_c \text{ and } s_c')\) of about 1 and 10 years. Linear fitting was respectively conducted on the
scaling regimes and their scale indexes $\lambda$ are obtained. By taking $s_c$ as the cut-off point, the time that $s_c$ position also corresponds to is exactly 1 year, reflecting the multi-scale response of the runoff to climate change in temporal scaling.

In the first scaling range, namely, over shorter time periods ($s < s_c$), the scale indexes $\lambda_1$ of the Lrc-R-T, Lrc-R-P, Lrc-R-H and Lrc-R-E are respectively 1.71, 1.78, 1.72 and 1.46, which all are $>1$, suggesting that there all are positive long-range correlation with nonpower law form. As an example of the Lrc-R-T, the runoff volume increased (decreased) with increasing (decreasing) temperature, both have stronger synchronicity.

In the second scaling range, namely, over longer time periods ($s > s_c$), the scale indexes $\lambda_2$ of the Lrc-R-T, Lrc-R-H and Lrc-R-P are 1.34, 1.35 and 0.97, respectively. This indicates that when the temporal scale is larger than 1 year, their positive correlation becomes weaker. Hence, the trend dependence may persist more than 39 years for the three correlations. As to the Lrc-R-T and Lrc-R-H, the analysis results are both similar to their trend in the first scaling range. That is, the two correlations also display positive correlation with nonpower-law form; while for the Lrc-R-P, $\lambda_2 = 0.97$, indicates that the correlation of runoff and relative humidity manifested as 1/f noise behavior with power law at a large temporal scale. To point out, compared with the first scaling range, these positive correlations become weaker. As to the correlation of the Lrc-R-E, it is contrary to that of above the three correlations. While for $s_c < s < s_c'$, $\lambda_2 = 0.21$. Namely, the runoff volume decreased (increased) with increasing (decreasing) evaporation in the corresponding time period scaling exponent is $<0.5$, this show that runoff and evaporation is power-law antilong-range correlation within the scaling regime of more than 1 year. The strong positive long-range correlation changes to antilong-range correlation as the time becomes longer. The runoff volume increased (decreased) with increasing (decreasing) temperature.

In the third scaling range, the correlation of runoff and evaporation is different from the former scaling range. The antilong-range correlation changes to strong positive long-range correlation as the time becomes much longer. That is to say, for $s > s_c'$, $\lambda_3 = 0.91$, over much longer time periods, the result fully restored transcription to shorter time periods ($s < s_c$) once more in the corresponding time period. This suggests that runoff and evaporation still show strong positive long-range correlation when the temporal scale is $>10$ years.

The multi-scale response of runoff to the four climate factors reflects mutual influence, dependence and change characteristics of runoff and climate change. In the shorter temporal scaling ($s < s_c$), the Lrc-R-T, Lrc-R-P, Lrc-R-H and Lrc-R-E respectively all show stronger positive long-range correlation. With the long-range correlation between the Lrc-R-T as an
example, if runoff volume of the Kaidu River within 1 year increases (decreases), the temperature also will increase (decrease). However, the degree of the four long-range correlations is different. The strongest correlation is the Lrc-R-P, next are the Lrc-R-T and Lrc-R-H, and Lrc-R-E is the last. When it is more than a year \((s > 10a)\), there are two kinds of correlation. The Lrc-R-T, Lrc-R-P and Lrc-R-H continue to indicate positive long-range correlation. However, the Lrc-R-E turns into negative correlation over time, becomes longer \((s < 10a)\). For much longer time, \((s > 10a)\), the Lrc-R-T, Lrc-R-P and Lrc-R-H still keep stronger positive correlation, while the Lrc-R-E turn into positive correlation from negative correlation in longer time \((s < s < 10a)\).

The above research results show the long-range correlation characteristics and the temporal evolution properties of runoff between and temperature, precipitation, relative humidity and evaporation, respectively. The different response existed runoff to different climate factor in scale-invariant region. For instance, as all of you know, the effect of humidity on runoff mainly generated by precipitation and evaporation changes. The spatial pattern of the relative humidity change should also be a factor influencing the response of total runoff to the change in the mean relative humidity (Tang et al., 2013). Therefore, a direct quantification research can make us more intuitively see the multi-scale response of runoff to relative humidity or the close relationship between them.

### 4. Conclusions

The DFA method is a modified root-mean-square analysis of random walk with advantages. It can avoid spurious detection of correlations that are artifacts of nonstationarity, which often affects the time series data. When the DFA is applied to the time series of hydro-climatic factors, which are runoff, temperature, precipitation, relative humidity and evaporation, respectively, the persistence or long-term memory of intrinsic time scales of hydro-climatic change can be extracted, it is helpful to determine their scaling behavior (Liu et al., 2014). Moreover, the DCCA method is applied to detect the multi-scale response of runoff to four climate factors are studied, which are long-range correlation of runoff and temperature (Lrc-R-T), runoff and precipitation (Lrc-R-P), runoff and relative humidity (Lrc-R-H) and runoff and evaporation (Lrc-R-E), respectively. In this study, based on the hydrological and meteorological data in the Kaidu River Basin during 1972–2011, the multi-scale response of runoff to climate fluctuation were analyzed using the DFA and DCCA methods, the main findings are as follows:

1. The runoff variability and four climate factor fluctuation series follow two different power laws in shorter and longer temporal scaling regimes through the DFA method. In annual cycle, the DFA exponent \(\alpha_1\) indicating some similar dynamic characteristics of various hydro-climatic change’s temporal evolution. Meantime, in longer temporal scaling regimes, \(\alpha_3\) may reveal the inherently different dynamic nature of various pollutant series. The persistence duration may persist about 1 year for runoff and temperature series, while over 39 years for precipitation, relative humidity and evaporation series.

2. The temporal scaling behaviors of runoff and four climate factor series all possess different power laws, which is a significant finding in the article. Those results further validated the dynamic characteristics of temporal evolution of runoff and temperature, runoff and precipitation, and runoff and relative humidity are just the same, and further illustrates multi-scale response of runoff to climate change has consistency. This shows the dynamic characteristics of temporal evolution of runoff and evaporation inter-decade difference, but it returns to positive long-range correlation.

Climatological-hydrological system is composed by several subsystems, and by the interaction of multi-spheres, multi-factors and multi-scale. One or more ways can be internal or external interaction among subsystems, which result in interaction structure of more complex form not only in the time, but also in the space. The results form complex-huge system with oppression outside and nonlinear dissipative inside, and the whole shows its complexity. There are many influence factors of climatological-hydrological system, for example, human activities, geographical location, complex surface characteristics and so on. But these factors are not independent of each other, but there are nonlinear interactions at various spatial and temporal scales. These reasons result in which the time evolution process of climatological-hydrological process shows inherent nonlinear and external complex characteristics, which can be difficult to investigate scientifically and accurately their correlation and multiple-time-scale characteristics by way of statistics for stationary time series. DFA and DCCA methods are put forward in nonlinear scientific field, and they can more effectively investigate these features including multi-scale and response characteristics. The findings can help to develop effective warning strategies to reduce impacts on climatological-hydrological environment.

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References

Alexandersson H. 1986. A homogeneity test applied to precipitation data. *International Journal of Climatology* 6: 661–675.

Bai L, Chen ZZ, Xu JH, Li WH. 2015. Multi-scale response of runoff to climate fluctuation in the headwater region of Kaidu River in Xinjiang of China. *Theoretical and Applied Climatology* 125: 703–712.

Bialous M, Yunko V, Bauch S, Lawnicka M, Dietz B, Sirkó L. 2016. Power spectrum analysis and missing level statistics of microwave graphs with violated time reversal invariance. *Physical Review Letters* 117: 144101.

Budyko MI. 1974. Climate and life. Analysis of non-stationary signals and textbooks. Springer Proceedings in Physics, pp. 152–168, Academic Press, California.

Buishand TA. 1982. Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology* 68: 11–27.

Chen YD, Zhang Q, Xu CY, Lu X, Zhang S. 2010. Multiscale streamflow variations of the Pearl River basin and possible implications for the water resource management within the Pearl River delta, China. *Quaternary International* 226: 44–53.

Chen ZZ, Chen YN, Li BF. 2013. Quantifying the effects of climate variability and human activities on runoff for Kaidu River Basin in arid region of northwest China. *Theoretical and Applied Climatology* 111: 537–545.

Fan XY, Lin M. 2017. Multiscale multifractal detrended fluctuation analysis of earthquake magnitude series of Southern California. *Physica A* 479: 225–235.

Ferreira P. 2016. Does the Euro crisis change the cross-correlation pattern between bank shares and national indexes?. *Physica A* 463: 320–329.

Fong S, Cho K, Mohammed O, Fiaidhi J, Mohammed S. 2016. A time series pre-processing methodology with statistical and spectral analysis for classifying non-stationary stochastic biosignals. *Journal of Supercomputing* 72: 3887–3908.

Gajbhiye S, Meshram C, Singh SK, Srivastava PK, Islam T. 2016. Precipitation trend analysis of Sindhubet river basin, India, from 102-year record (1901–2002). *Atmospheric Science Letters* 17: 71–77.

Kantelhardt JW, Koscielny-Bunde E, Rybski D, Braun P, Bundu A, Havlin S. 2006. Long-term persistence and multifractality of precipitation and river runoff records. *Journal of Geophysical Research. Atmospheres* 111: 93–108.

Lan YC, Zhao GH, Zhang YN, Wen J, Liu JQ, Hu XL. 2010. Response of runoff in the source region of the yellow river to climate warming. *Quaternary International* 226: 60–65.

Li Q, Li LH, Bao AM. 2012. Snow cover change and impact on streamflow in the Kaidu River Basin. *Resources Science* 34: 91–97 (in Chinese).

Li XF, Girin L, Gannot S, Horaud R. 2016. Non-stationary noise power spectral density estimation based on regional statistics. *IEEE International Conference on Acoustics, Speech and Signal Processing*, 181–185.

Liu ZH, Xu JH, Shi K. 2014. Self-organized criticality of climate change. *Theoretical and Applied Climatology* 115: 685–691.

Livina V, Kizner Z, Braun P, Molnar T, Bunded A, Havlin S. 2007. Temporal scaling comparison of real hydrological data and model runoff records. *Journal of Hydrology* 336: 186–198.

Ma PC, Li DY, Li S. 2016. Efficiency and cross-correlation in equity market during global financial crisis: Evidence from China. *Physica A* 444: 163–176.

Miller JR, Russell GL. 1992. The impact of global warming on river runoff. *Journal of Geophysical Research. Atmospheres* 97: 2757–2764.

Milly PCD. 1994. Climate, soil water storage, and the average annual water balance. *Water Resources Research* 30: 2143–2156.

Pal M, Kiran VS, Rao PM, Manimaran P. 2016. Multifractal detrended cross-correlation analysis of genome sequences using chaos-game representation. *Physica A* 456: 288–293.

Peng CK, Buldrev SV, Havlin S, Simons M, Stanley HE, Goldberger AL. 1994. Mosaic organization of DNA nucleotides. *Physical Review E* 49: 1685–1689.

Pettin AN. 1979. A non-parametric approach to the change-point detection. *Applied Statistics* 28: 126–135.

Podobnik B, Stanley E. 2007. Detrended cross-correlation analysis: a new method for analyzing two nonstationary time series. *Physical Review Letters* 100: 38–71.

Rysak A, Litak G, Mosdorf R. 2016. Analysis of non-stationary signals by recurrence dissimilarity. In: Miller DH, Dnowska R, Holton JR (eds). International geophysics series: a series of monographs and textbooks. Springer Proceedings in Physics, pp. 152–168, Academic Press, California.

Strychalski EA, Levy SL, Craighead HG. 2008. Diffusion of DNA in the water resource management within the Pearl River delta, China. *Quaternary International* 226: 44–53.