Response Characteristics of Mountain-Outflow Runoff from Arid Inland Rivers in China to Basin Meteorological Elements and Global Climate Indices: Postprint

Authors: Xiaofan Qi, Li Wenpeng

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Abstract

Analysis of mountain runoff from arid inland rivers and its influencing factors is of great significance for watershed water resources assessment and watershed economic and ecological security. Based on data of mountain runoff, precipitation, and temperature from the "three headstreams" of the Tarim River Basin and the Heihe River Basin during 1960–2012, as well as monitoring data from four global meteorological indices, this study employs wavelet analysis to investigate the periodic characteristics of various hydro-meteorological elements and the response characteristics of watershed mountain runoff to meteorological elements and meteorological indices. The results indicate that: (1) Most hydro-meteorological factors exhibit 1–2 significant periods, primarily within the 2–7 a scale range. (2) The mountain runoff of the Yarkant River and Heihe River shows significant relationships with watershed precipitation at periods of 6–17 a and 2–16 a, respectively. The differences in multi-scale resonance periodicity between various mountain runoff and watershed precipitation and temperature reflect differences in runoff source composition and their interannual dynamics with meteorological elements. (3) The response characteristics of mountain runoff from various watersheds to meteorological indices differ, which is manifested in aspects such as significant time-frequency domains and runoff response time lags. This study can provide a basis for eco-hydrological process responses and water resources management in arid inland river basins under climate change conditions.

Full Text

Preamble

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Journal: Arid Land Geography
Study Area: 73.45°-96.38°E, 34.84°-43.36°N, covering 1.31×10 km²
Institutions: Center for Hydrogeology and Environmental Geology Survey, CGS, Baoding 071051, Hebei, China; China Institute of Geo-Environment Monitoring, Beijing 100081, China

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1. Introduction

This study investigates the multi-scale periodicities and response characteristics of mountainous runoff in China' s arid inland river basins to watershed meteorological elements and global climate indices. The analysis focuses on three major sub-basins within the Tarim River Basin (TRB)—the Aksu River Basin (ARB), Yarkand River Basin (YRB), and Hotan River Basin (HTRB)—as well as the Heihe River Basin (HRB). The combined watershed area spans 73.45°-96.38°E and 34.84°-43.36°N, encompassing 1.31×10 km². The region' s hydrological monitoring network includes stations distributed across diverse mountainous terrain, with data series extending from 1960 to 2012 providing robust temporal coverage for wavelet-based time-frequency analysis.

The research employs continuous wavelet transform (WT), cross-wavelet transform (XWT), and wavelet coherence (WTC) methods to systematically examine periodic structures in runoff, precipitation, and air temperature, and to quantify teleconnections with four key climate indices: the Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO), Arctic Oscillation (AO), and Pacific Decadal Oscillation (PDO). These methods enable identification of both the dominant periodicities and the time-lagged coherence between hydrometeorological variables and large-scale climate patterns, which is essential for understanding water resource dynamics in these ecologically vulnerable arid regions.

2. Data and Methods

2.1 Data Sources

The hydrological dataset comprises monthly runoff records from mountainous hydrometric stations in each basin, covering the period 1960–2012. Meteorological data include precipitation and air temperature from watershed weather stations with consistent observation protocols. The climate indices—SOI, NAO, AO, and PDO—were obtained from NOAA' s Climate Prediction Center (CPC) and the National Centers for Environmental Prediction (NCEP), providing synchronous 53-year records for comparative analysis.

2.2 Wavelet Analysis Methods

The study applies three complementary wavelet techniques: (1) Continuous Wavelet Transform (WT) to isolate intrinsic periodicities in individual time series; (2) Cross-Wavelet Transform (XWT) to detect phase-locked periodicities and relative phase differences between paired variables; and (3) Wavelet Coherence (WTC) to quantify localized correlation strength in time-frequency space. These methods collectively reveal how runoff responds to precipitation, temperature, and climate indices across interannual to decadal scales, with significance testing following Torrence and Compo [18] and Grinsted et al. [19] protocols.

3. Results

3.1 Periodic Characteristics of Climate Indices

Wavelet analysis reveals distinct multi-scale periodicities in the climate indices. The Southern Oscillation Index (SOI) exhibits significant power at 3–5 year and 11–12 year scales, while the Pacific Decadal Oscillation (PDO) shows dominant periods of 4–6 years and 9–10 years. Both the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) display strong 2–4 year periodicities during the 1960s, with NAO also showing a pronounced ~60-year multidecadal oscillation. These periodic structures provide the climatic forcing framework against which hydrological responses are evaluated.

3.2 Periodicities of Hydrometeorological Variables

Precipitation across all basins demonstrates consistent periodicities at 2–4 year and 4–7 year scales, reflecting regional atmospheric circulation patterns. Air temperature exhibits 2–5 year cycles, with longer-term trends superimposed. Mountainous runoff in the ARB, HTRB, and HRB shows strong 2–5 year periodicities, whereas the Yarkand River displays more complex, non-stationary behavior with less distinct periodic clustering. The wavelet power spectra indicate that interannual variability (2–8 years) dominates over decadal scales in most hydrological series, consistent with the region’ s precipitation-driven runoff regime.

3.3 Runoff-Response to Climate Forcing

Cross-wavelet analysis identifies significant resonance periodicities between precipitation and runoff of 6–17 years in the Yarkand River Basin and 2–16 years in the Heihe River Basin, indicating strong basin-specific coupling. Temperature-runoff coherence shows significant 3–5 year bands in the ARB, YRB, and HTRB, revealing the role of snow and ice melt dynamics. The response characteristics vary markedly between basins: TRB tributaries exhibit rapid, precipitation-driven responses, while HRB shows lagged, temperature-modulated runoff generation. These differences reflect distinct source compositions—glacial melt versus rainfall-dominated inputs—and underscore the necessity of basin-tailored water resource management strategies under changing climate conditions.

References

[1] QI Xiaofan, WANG Yushan, YANG Lizhi, et al. Time lags and variance of groundwater level response to precipitation of Jinan karst spring watershed in recent 50 years [J]. Carsologica Sinica, 2016, 35(4): 384-393.

[2] QI Xiaofan, LI Wenpeng, LI Haitao, et al. Teleconnections between groundwater levels, precipitation, air temperature of the Jinan karst spring watershed and large-scale climate patterns [J]. Hydrogeology & Engineering Geology, 2015, 42(6): 18-28.

[3] QI Xiaofan, LI Wenpeng, LI Haitao, et al. Multiscale teleconnections between meteorological elements of Heihe River Basin and global climate indices [J]. Arid Land Geography, 2017, 40(3): 1-9.

[4] SANG Yanfang, WANG Zhonggen, LIU Changming. Research progress on the time series analysis methods in hydrology [J]. Progress in Geography, 2013, 32(1): 20-30.

[5] HUA Ting, WANG Xunming, LANG Lili, et al. Climate change and its significance on the runoff of major rivers in Gansu, China from 1961 to 2011 [J]. Journal of Desert Research, 2015, 35(3): 744-752.

[6] LIU Youcun, LIU Zhifang, HAO Yonghong, et al. Multi-timescale features of runoff on cross-wavelet transformation in the upstream of Urumqi River, Tianshan Mountain [J]. Journal of Glaciology and Geocryology, 2013, 35(6): 1564-1572.

[7] LI Qihu. Climate spatiotemporal features and impact on hydrological process in northwest arid area of China [D]. Shanghai: East China Normal University, 2012.

[8] QI Xiaofan, LI Wenpeng, LI Haitao, et al. Future climate change prediction of arid inland river basin based on CMIP5 model [J]. Arid Land Geography, 2017, 40(5): 987-996.

[9] Torrence C, Compo GP. A practical guide to wavelet analysis [J]. Bulletin of the American Meteorological Society, 1998, 79(1): 61-78.

[10] Grinsted A, Moore JC, Jevrejeva S. Application of the cross wavelet transform and wavelet coherence to geophysical time series [J]. Nonlinear Processes in Geophysics, 2004, 11(5/6): 561-566.

Abstract

Title: Response Characteristics of Mountainous Runoff of the Inland Rivers in the Arid Areas of China to Watershed Meteorological Elements and Global Climate Indices

Authors: QI Xiaofan[1,2], LI Wenpeng[2], LI Haitao[2], CUI Huqun[1], FENG Wei[2]
[1] Center for Hydrogeology and Environmental Geology Survey, CGS, Baoding 071051, Hebei, China;
[2] China Institute of Geo-Environment Monitoring, Beijing 100081, China

Abstract: Analysis of mountainous runoff of the inland rivers in the arid areas of China and their influence factors has great significance in the evaluation of their basin water resources and the insurance of basin economic and ecological safety. Based on mountainous runoffs, precipitation and air temperature data of three sub-basins in Tarim River Basin (TRB), the Aksu River Basin (ARB), Yarkand River Basin (YRB) and Hotan River Basin (HTRB), and Heihe River Basin (HRB), together with four climate indices, the Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Pacific Decadal Oscillation (PDO) from 1960 to 2012, multi-scale periodicities of the hydrological and meteorological elements, and the response characteristics of the mountainous runoffs to watershed meteorological elements and global climate indices are systematically investigated in this paper by adopting methods of wavelet analysis, including Continuous Wavelet Transform (WT), Cross Wavelet Transform (XWT) and Wavelet Coherence (WTC). The results show that the multi-scale periodicities of SOI are 3–5 years, 11–12 years and the multi-scale periodicities of PDO are 4–6 years, 9–10 years. The multi-scale periodicities of NAO and AO are 2–4 years in the 1960s. The periodicities of precipitation in all basins are 2–4 years, 4–7 years, and that of air temperature are 2–5 years. The periodicities of mountainous runoffs are 2–5 years except for the Yarkand River. Whole time significant resonance periodicity of 6–17 years is identified between precipitation and mountainous runoff in YRB, and periodicity of 2–16 years is identified in HRB. Significant resonance periodicities of 3–5 years are identified between air temperature and mountainous runoffs in ARB, YRB and HTRB. The multiple-scale resonance periodicities between runoffs and watershed precipitation and temperature reflect the differences of runoff source compositions and inter-annual dynamics of both runoffs and meteorological elements. The response characteristics of the runoffs to the climate indices are different, which have performance in the significant time-frequency domains and the runoff response time lags. The findings and methods presented here help understand the response of mountainous runoffs of the inland river basins in the arid areas to meteorological elements and climate indices, and expand the knowledge and usable toolbox of approaches that can be used by the related people and scientists to improve eco-hydraulic processes and water resource planning and operation under future climate uncertainty.

Keywords: mountainous runoff; climate indices; wavelet analysis; multi-scale

periodicity; arid inland river basin

Note: Figure translations are in progress. See original paper for figures.

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