Impact Analysis of Human Activities on Runoff Variation in the Yue River Basin, Qinling Mountains: Postprint

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Abstract

Climate change and human activities are the primary driving forces of river runoff variation. Under similar climate conditions, human activities are the dominant factor affecting basin runoff variation, and quantifying the mechanism of human activities' impact on runoff variation is crucial for in-depth investigation of runoff variation characteristics. This study focuses on the Yue River basin in the Qinling Mountains, and based on water balance principles and under similar climate conditions, combines land use/cover change (LUCC) and normalized difference vegetation index (NDVI) variations to analyze runoff changes in the Yue River basin and quantify the degree of human activities' impact on runoff. Results indicate that: (1) The average runoff in the basin from 1960 to 2018 was 8.3$ $\times 10^8 m^{\{3\}}$, and the overall runoff showed a decreasing trend, though the trend was not statistically significant. (2) Under similar clim
compared with 2000. (4) During the period of the 3rd group of similar year-pair, 25,751.4 hm^2 of cropland was converted to forest, and the forest land area increased by 24,998.9 hm^2. (5) The change in NDVI was mainly caused by human activities; within the same period, the area of NDVI increase was 242,652.0 hm^2, and the trend of NDVI change was opposite to that of runoff change. This study provides a theoretical basis for analyzing the impact of human activities on river runoff variation in the Qinling Mountains.

Full Text

Analysis of the Impact of Human Activities on Runoff Variation in the Yue River Basin of the Qinling Mountains

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Abstract

Climate change and human activities constitute the primary driving forces of river runoff variation. Under similar weather conditions, human activities emerge as the dominant factor governing basin discharge changes, making quantitative identification of their mechanisms crucial for understanding runoff dynamics. This study investigates the Yue River basin in the Qinling Mountains, applying water balance principles under similar climatic conditions while integrating Land-Use and Land-Cover Change (LUCC) and Normalized Difference Vegetation Index (NDVI) variations to quantify human impacts on runoff. The results demonstrate that: (1) Six paired-year groups were identified under similar weather conditions, with average annual runoff from 1960–2018 reaching 8.3$\times10^{8}$ m^3, showing a non-significant decreasing trend overall. (2) Among the six paired-year groups, three exhibited increased annual runoff while two showed decreases. (3) Using the third paired-year group (2000 and 2016) as an example to quantitatively distinguish climate change from human activity impacts, runoff decreased by 4.7$\times10^{8}$ m^3 in 2016 compared to 2000. (4) During this period, 25,751.4 hm^2 of cropland converted to forest, increasing forest area by 24,998.9 hm^2. (5) NDVI changes were primarily attributable to human activities, with NDVI increasing by 242,652.0 hm^2 during the same timeframe, showing an inverse trend to runoff variation. This study provides a theoretical foundation for analyzing human activity impacts on river runoff changes in the Qinling Mountains region.

Keywords: Yue River Basin; human activities; similar weather condition; LUCC; NDVI

Introduction

River runoff represents a core component of the water cycle and a vital water resource that drives natural ecosystem development and evolution from multiple perspectives. Consequently, investigating the main drivers of runoff variation has become critical for global water resource forecasting and forms the basis for sustainable freshwater resource utilization. Under the dual influence of climate change and human activities, many rivers have experienced significant alterations in recent decades. Separating the contributions of these two factors from altered hydrological elements has emerged as a key focus and challenge in current watershed hydrology research.

Previous studies have demonstrated substantial human impacts: research on the Yellow River indicates that intense human activities have altered its runoff regime; investigations in the Haihe River basin reveal that strong anthropogenic interference has dramatically changed underlying surface characteristics, modifying runoff generation and concentration processes; studies in the Wujiang River basin show that hydraulic engineering projects regulate runoff, altering its original spatial-temporal distribution; and research on the Weihe River basin demonstrates that human activities dominate runoff variation while climate change effects show insignificant increasing trends.

Current methods for separating climate and human impacts include: the Budyko hypothesis-based elasticity coefficient method, hydrological modeling, component investigation methods, and paired watershed analysis. While widely applied, the elasticity coefficient method produces varying partial derivative calculations, introducing errors. Hydrological models, though physically robust with numerous parameters, face difficulties in calibration and high uncertainty. Component investigation methods require extensive water use data and quantitative human activity impacts, making comprehensive consideration of all disturbances challenging and compromising reliability. Paired watershed analysis, though effective, remains costly and applicable only to small watersheds.

Wang et al. proposed a method for determining similar weather conditions by analyzing precipitation and evaporation quantity and process similarity between different periods to quantify climate and human contributions to runoff and sediment changes. This approach effectively distinguishes their impacts on river discharge. The Qinba Mountains region, located in China's north-south transitional zone and serving as the water source for the South-to-North Water Transfer Project, exhibits sensitive runoff responses to climate change. Therefore, this study selects the Yue River basin on the southern slopes of the Qinling Mountains as the research area. Based on water balance principles, we identify similar climate year groups and analyze runoff variations within these groups, incorporating LUCC and NDVI changes to investigate climate and human activity impacts on runoff, aiming to quantitatively assess human activity effects under similar climatic conditions.

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1. Materials and Methods

1.1 Study Area

The Yue River originates from Tiewadian, the main peak of Fenghuang Mountain on the southern slopes of the Qinling Mountains. The basin covers a control area of 2,826 km^2 with a river length of 112.6 km and a channel slope of 12.6‰, forming a first-order tributary on the north bank of the Han River (a Yangtze River tributary). The basin features mountainous terrain in the north, valley and hilly areas in the center, and mountainous regions in the south. With a temperate continental climate, the area experiences four distinct seasons, a long frost-free period, and significant precipitation variation, with multi-year average precipitation ranging 826.5–879.6 mm and average temperature of 15.1°C. The Changqiangpu hydrological station serves as the basin's control station.

1.2 Data Sources

Meteorological data were obtained from seven stations (Zhen'an, Xunyang, Ankang, Shiquan, Ningshaan, Hanyin, Ziyang) within and around the Yue River basin for 1960–2018 from the National Meteorological Science Data Center. Monthly runoff data from 1960–2018 were collected from the Changqiangpu hydrological station. Land-use data were derived from the China Land-Use/Cover Dataset (CLUD) based on Landsat imagery, classified into six types: grassland, cropland, shrubland, forest, water bodies, and impervious surfaces. NDVI data were obtained from the Chinese annual vegetation index spatial distribution dataset (1982–2018) from the Chinese Academy of Sciences' Resource and Environmental Science Data Center.

1.3 Methods

1.3.1 Basic Principle The water balance equation forms the theoretical foundation:

$$P = ET + R + \Delta W_{ground} + \Delta W_{soil}$$

where P represents basin precipitation, ET is potential evaporation, R is surface runoff, W_{ground} is groundwater storage, and W_{soil} is soil water storage. Runoff variation is jointly driven by underlying surface and climatic factors. When precipitation and evaporation reach equilibrium, runoff changes primarily reflect underlying surface alterations. Over short timescales, topographic factors evolve slowly, making human activities the dominant factor altering underlying surface properties. Land-use/land-cover change (LUCC) affects watershed hydrological cycles by modifying surface evapotranspiration, soil infiltration capacity, and vegetation interception. Under similar precipitation and potential evaporation conditions (encompassing temperature, humidity, wind speed, and sunshine), human activity impacts on runoff can be isolated and quantified.

1.3.2 Potential Evaporation Calculation We employed the FAO56 Penman-Monteith equation to calculate potential evaporation at each meteorological station:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_0 is potential evaporation ($\mathrm{mm \cdot d^{-1}}$), R_n is net surface radiation ($\mathrm{MJ \cdot m^{-2} \cdot d^{-1}}$), G is soil heat flux ($\mathrm{MJ \cdot m^{-2} \cdot d^{-1}}$) considered negligible relative to R_n, γ is the psychrometric constant ($\mathrm{kPa \cdot {}^\circ C^{-1}}$), T is mean daily temperature (℃), e_a is saturation vapor pressure (kPa), e_d is actual vapor pressure (kPa), and Δ is the slope of the saturation vapor pressure-temperature curve (kPa ·

℃$^{-1}$). Monthly potential evaporation was calculated and accumulated to obtain annual values.

1.3.3 Similar Year Group Determination Climate change and human activities are the primary factors affecting runoff variation. Under similar climatic conditions, runoff changes mainly reflect human activity impacts. This study defines similar year groups with temporal spacing \$ \$5 years, considering human activity continuity. Following established research, year groups with similar basin-average precipitation and potential evaporation differences within \$±\$10% were classified as quantity-similar groups. Within these, groups showing \$ \$90% linear correlation between precipitation and potential evaporation were designated as process-similar groups. Year groups satisfying both criteria were selected for analysis.

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2. Results and Analysis

2.1 Meteorological Element Analysis

2.1.1 Annual Precipitation and Potential Evaporation Trends From 1960–2018 in the Yue River basin, average annual precipitation and potential evaporation were 912.6 mm and 873.1 mm respectively, with variation coefficients of 0.19 and 0.20, indicating small interannual variability. Precipitation showed an increasing trend with a linear rate of 6.14 mm · (10a)$^{-1}$, while potential evaporation decreased at 8.11 mm · (10a)$^{-1}$. The interannual variation amplitude of potential evaporation exceeded that of precipitation, though neither trend reached statistical significance [Figure 2: see original paper].

2.1.2 Intra-Annual Precipitation and Evaporation Variation Based on interpolated monthly data, multi-year average monthly distributions show uneven and concentrated patterns. Precipitation concentrates in July (peak: 176.6 mm) and minimizes in December (4.9 mm). Potential evaporation follows a similar uneven distribution, peaking in July (133.8 mm) and reaching minimum in December (27.5 mm) [Figure 3: see original paper].

2.2 Hydrological Element Statistics

Annual runoff averaged 8.3\$×10^{8}\$ m^3 with a variation coefficient of 0.83, indicating substantial interannual variability. Maximum runoff reached 19.2\$×10^{8}\$ m^3 while minimum was 1.7\$×10^{8}\$ m^3. The overall trend showed non-significant decrease [Figure 4: see original paper].

2.3 Similar Year Group Identification and Characteristics

This study identified six similar year groups with temporal spacing \$ \$5 years, covering all decades from the 1960s–2010s with year intervals ranging 5–19 years. These reflect varying precipitation-evaporation characteristics and long-term runoff changes. For instance, Group 1 (1961–1975) precipitation exceeded the multi-year average by 230 mm, while Group 3 (2000–2016) approximated the average .

2.4 Runoff Variation Under Similar Climate Conditions

Among six similar year groups, three showed increased runoff and two showed decreases. Group 3 exhibited the largest reduction (-5.0$\times10^{8}$ m^3), while Group 1 showed the greatest increase (6.4$\times10^{8}$ m^3). Runoff responses to human activities varied across groups, with Group 3 showing the most pronounced response [TABLE:2, TABLE:3].

2.5 Human Activity Impact Analysis

2.5.1 Land-Use/Cover Change In Group 3 (2000–2016), forest and cropland dominated (97.4% of total area). Forest area increased from 175,744.9 hm^2 to 200,743.8 hm^2, while cropland decreased from 98,439.7 hm^2 to 75,808.7 hm^2. Impervious surfaces, characteristic of urbanization and promoting runoff increases, grew by only 1,783.6 hm^2. The land conversion matrix reveals that forest and impervious surface expansion primarily originated from cropland conversion (26.2% of cropland to forest, minimal to impervious surfaces). Additionally, 2,106.4 hm^2 of grassland and 1,088.9 hm^2 of shrubland converted to forest [FIGURE:5, TABLE:4].

2.5.2 Water Conservancy Project Construction Water projects alter runoff generation, concentration patterns, and riverbed morphology. By 2016, the Yue River basin had constructed 138 reservoirs with total capacity 79,572$\times10^{4}$ m^3, including two medium-sized reservoirs (Guangyinhe and Huangshitan) and numerous small reservoirs. Water supply capacity reached 28,356$\times10^{4}$ m^3 through diversion projects and pumping stations. The Huangshitan Reservoir (constructed 2000–2010) represents a major factor contributing to runoff reduction during Group 3's timeframe.

2.5.3 NDVI Change Analysis Vegetation, a crucial geographical element, is influenced by climate, topography, soil, and human activities. Under similar climatic conditions with slow soil evolution, vegetation changes primarily reflect human activity impacts. NDVI serves as the optimal indicator for vegetation variation. In Group 3 (2000–2016), NDVI increased by 242,652.0 hm^2, showing an inverse relationship with runoff trends. This inverse correlation indicates that enhanced vegetation coverage reduces runoff generation capacity through increased surface roughness and improved soil structure [Figure 6: see original paper].

3. Discussion

Both climate change and human activities influence basin runoff, with human activities eliciting varying degrees of response. Quantifying these impacts is crucial for watershed protection and ecological stability. Previous Yue River basin research focused on aquatic ecosystem restoration, flood characteristics, and water resource optimization, with limited analysis of long-term runoff trends and human activity impacts.

Vegetation significantly drives watershed water cycling and regulates runoff generation and concentration. Vegetation coverage changes are largely constrained by human activities. Studies show that forest expansion reduces runoff while cropland expansion decreases infiltration and increases runoff. In the Yue River basin, cropland-to-forest conversion (57.0% of converted area) and grassland/shrubland-to-forest conversion collectively suppressed runoff increases.

The similar weather condition method effectively describes human activity mechanisms, though combining it with reliability evaluation 指标体系 would strengthen analyses. Future research should incorporate land-use data to examine how potential evaporation, vegetation cover, and soil infiltration affect runoff generation. Additionally, while this study treats human activities holistically, distinguishing between specific activities (engineering construction, agricultural production, socioeconomic restructuring) remains a research challenge due to their complex interactions.

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4. Conclusions

Based on meteorological data from seven stations and runoff data from Changqiangpu station (1960–2018), combined with LUCC and NDVI analysis under similar weather conditions, this study quantified human activity impacts on Yue River basin runoff variation:

1) Precipitation and potential evaporation showed uneven intra-annual distribution and non-significant interannual trends (precipitation increasing, evaporation decreasing). Annual runoff exhibited a non-significant decreasing trend with substantial interannual variability.

2) Runoff variation resulted from both climate change and human activities. Under similar weather conditions, human activity mechanisms were clearly demonstrated. Among six similar year groups, Group 3 (2000–2016) showed the most pronounced runoff change, indicating the strongest human activity impact during this period.

3) Runoff changes closely correlated with human activities. In Group 3, runoff decreased by 4.7×10^{8} m^3 while NDVI increased by 242,652.0 hm^2, showing opposite trends. During this period, 25,751.4 hm^2 of crop-

land converted to forest (increasing forest area by 24,998.9 hm^2), with additional grassland and shrubland conversions to forest. These land-use changes suppressed runoff generation.

This study quantifies varying degrees of human activity impacts on Yue River basin runoff changes, providing a methodological reference for similar watersheds.

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