Analysis of Runoff Component Characteristics in Inland River Basins of Southwestern Tarim Basin under Climate Change: Postprint

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Abstract

Climate change has significantly impacted the water cycle in the high mountain regions of Central Asia, exacerbating regional water supply-demand conflicts. Understanding the characteristics of runoff components in inland rivers is crucial for water resource management. Based on meteorological and runoff data from the past 60 a (1957-2016) in the Tizinafu River basin in southwestern Tarim Basin, this study analyzed regional climate change characteristics and runoff component responses. The results show: (1) Over the past 60 a, basin temperature and mountain precipitation have exhibited significant increasing trends, with the regional warming and wetting trend becoming more pronounced since 2010. Under these changes, summer and autumn runoff in the Tizinafu River has shown significant growth. (2) Runoff separation results indicate that ice-snow meltwater, groundwater, and precipitation contribute 17%, 40%, and 43% to annual runoff, respectively; runoff components vary significantly across seasons, with precipitation making a particularly notable contribution to summer runoff in the basin. As a typical inland river in southwestern Tarim Basin, future regional climate change, particularly precipitation changes, will significantly impact the sustainable utilization of water resources in the Tizinafu River.

Full Text

Stream Component Characteristics of Inland River Basins in the Southwestern Tarim Basin Under Climate Change

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Abstract

Climate change has significantly impacted the water cycle in the alpine regions of Central Asia, intensifying regional water resource supply-demand conflicts. Understanding runoff component characteristics in inland rivers is crucial for water resource management. Based on meteorological and runoff data from the Tizinafu River Basin in the southwestern Tarim Basin over the past 60 years (1957-2016), this study analyzed regional climate change trends and runoff component responses. Results indicate that warming and humidification trends have become more pronounced since 2010, leading to significant increases in summer and autumn runoff in the Tizinafu River. Using isotope samples, we investigated variations in isotopic signatures across different water sources and analyzed source contributions via isotope hydrograph separation. Meltwater, groundwater, and precipitation contributed 17%, 40%, and 43% to annual streamflow, respectively. Runoff components showed distinct seasonal differences, with precipitation contributions being particularly significant during summer. As a typical alpine inland river in the southwestern Tarim Basin, future regional climate change—especially precipitation changes—will substantially affect the sustainable utilization of Tizinafu River water resources.

Keywords: Tizinafu River Basin; climate change; runoff; isotope; hydrograph separation; Tarim Basin

1 Introduction

Water resources are essential for human production and livelihoods, exerting profound influence on sustainable societal development [citation]. In inland regions characterized by harsh environments, scarce water resources, arid climates, low precipitation, and high evaporation, water supply-demand contradictions are particularly acute [citation]. Over the past century, global climate change has significantly impacted Central Asian inland river basins [citation]. Research demonstrates that inland river basins in arid northwestern China respond markedly to climate change [citation], with clear correlations between climatic factor variations and runoff changes [citation]. Studies indicate that since the late 1980s, the entire arid inland region has experienced pronounced warming [citation]. Accompanied by rising temperatures, runoff in inland rivers heavily reliant on alpine meltwater has fluctuated significantly [citation], while precipitation variability has further complicated annual runoff patterns [citation], increasing challenges for regional water resource management. Consequently, systematically understanding runoff and its component characteristics in arid inland river basins under climate change has become a research priority both domestically and internationally [citation].

Interpreting river runoff responses to climatic factors requires in-depth knowledge of runoff component characteristics. Runoff separation methods effectively quantify mixing proportions of multiple water bodies in streamflow [citation]. Traditional approaches include graphical methods, time-step methods, electronic filtering, hydrological modeling, and water balance methods. While each offers advantages, their inability to be scientifically validated through experiments has generated considerable controversy among theories and methods [citation]. Environmental isotope technology, an emerging hydrological research tool, has been widely applied to investigate hydrological processes and climate issues, providing insights into hydraulic connections, mixing ratios, and water vapor sources across different water bodies [citation]. Since isotope techniques were first integrated with runoff separation methods, their physical basis has effectively reduced subjectivity inherent in graphical approaches, leading to broad application [citation]. In recent years, isotope-based runoff separation has combined with other hydrological methods to form comprehensive multi-source runoff separation models with established error control protocols [citation]. However, isotope runoff separation research has progressed slowly in northwestern China [citation], with existing studies focusing primarily on typical inland river basins in the Tianshan Mountains and Hexi Corridor, while research on the southwestern Tarim Basin remains limited [citations]. This region represents the intersection of two major geomorphic units in China, featuring complex and variable climate conditions and serving as the source of multiple inland rivers. The area also hosts concentrated ethnic populations with relatively developed oasis agriculture, substantial water demand, and significant water supply-demand conflicts, necessitating urgent research on runoff component characteristics of inland rivers in this region.

This study selected the Tizinafu River Basin in the southwestern Tarim Basin as a representative research area. Using meteorological data (temperature, precipitation) from the past [years], we analyzed regional climate change trends. Based on stable isotope observations from different water bodies, we applied an isotope runoff separation model to analyze runoff composition during a normal water year, exploring the response mechanisms of runoff processes to climate change in the southwestern Tarim River region. This research provides important theoretical support for regional water resource utilization and Central Asian water cycle mechanism studies.

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2 Methods

2.1 Data Collection and Sample Analysis

Meteorological data were obtained from the China Meteorological Science Data Sharing Service Network, while hydrological data were sourced from local hydrological stations (Table 1). Water samples from different water bodies were collected during [year], a normal water year that well represents the river’ s average conditions. Specific sampling protocols were as follows:

Precipitation samples: Collected at Jiangka Hydrological Station on an event basis throughout [year], totaling [number] samples. Rainwater collection prevented evaporation, avoided pollution sources, excluded direct sunlight on collectors, and maintained sampling ports at least [height] above ground, with precipitation amounts recorded. Snow samples were collected using bucket containers, melted at room temperature, and stored.

Glacier and meltwater samples: Glacier ice was collected from Muztag Peak in the Karakoram Mountains. To avoid surface ice contamination, deep ice cores were extracted using ice augers, placed in brown glass bottles, and melted for preservation. Bottles were sealed with parafilm, refrigerated at [temperature], and stored. Meltwater samples were collected during autumn and spring snowmelt periods from snowmelt areas within the basin, totaling [number] glacier and meltwater samples.

River water samples: From March to December 2016, [number] river water samples were collected at Jiangka Station using a vertical sampler. After collection, samples were immediately sealed with parafilm, placed in insulated containers, with concurrent records of temperature, humidity, and geographic coordinates.

Groundwater samples: From civilian wells located at Jiangka and Kudi within the basin, [number] groundwater samples were collected monthly from each well, totaling [number] samples.

The Tizinafu River Basin is located in the southwestern Tarim Basin (36°31 - 38°54 N, 76°27 -79°04 E). The river originates from the Karakoram Mountains at Kakelakedaban Pass (elevation 5518 m), flows out of the mountains at Jiangka Hydrological Station in Yecheng County, Kashgar Prefecture, passes through Yecheng, Shache, and Maigaiti counties, and ultimately joins the Yeerqiang River, serving as a vital water source for oases on the southern margin of the Tarim Basin [citation]. The basin’ s average elevation is [value] m, with mountainous river sections showing steep gradients, creating distinct vertical climate zones. Mountainous areas have low temperatures and relatively high precipitation (multi-year average 186.9 mm), while downstream plains are arid and hot with scarce precipitation (53.1 mm), representing typical temperate continental climate. The Tizinafu River has a total length of 335 km, with 190 km above the Jiangka Station outlet, and a runoff depth of 165.2 mm.

Hydrogen and oxygen stable isotopes were analyzed at the State Key Laboratory of Desert and Oasis Ecology, Chinese Academy of Sciences, using a Los Gatos Research DLT-100 liquid water isotope analyzer with precision of $±$0.5‰ for δ¹⁸O and $±$0.2‰ for δD. Results are expressed in standard δ-notation relative to VSMOW.

2.2 Runoff Separation

Isotope hydrograph separation is commonly applied to two-source, three-source, and multi-source hydrograph partitioning. Based on mass balance and concentration balance equations, the multi-source isotope hydrograph separation method can be expressed as [citations]:

$$Q = \sum_{m=1}^{n} Q_m$$

$$C_{bQ} = \sum_{m=1}^{n} C_{bm} Q_m$$

where Q represents total runoff from multiple water sources, Q_m represents the m-th runoff component, and C_{bm} represents tracer b in component m. Two key considerations for parameter C_{bm} are: (1) it must remain stable during the observation period, and (2) tracers with appropriate characteristics must be selected to minimize errors. This study employed [number] different tracers.

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3 Results

3.1 Temperature Changes

Over the past several decades, the Tizinafu River Basin exhibited a significant warming trend of $0.30°C \cdot (10a)^{-1}$. Average temperatures increased by $1.10°C$ in plain areas and $1.35°C$ in mountainous areas relative to multi-year averages. This warming trend critically impacts arid inland rivers where meltwater constitutes a major water source. Seasonal comparisons revealed that autumn temperatures in mountainous areas warmed fastest at $0.44°C \cdot (10a)^{-1}$. Conversely, plain area temperature increases during winter and spring substantially exceeded those in mountainous areas, while the opposite pattern occurred in summer and autumn, with mountainous areas showing more pronounced warming. Although spring temperatures increased most significantly across the basin, they also displayed the greatest variability. Kendall test results showed significant increasing trends in annual average temperature for both plain and mountainous areas (P<0.05). Mountainous area temperatures underwent rapid increase after a breakpoint around [year], consistent with the temperature mutation point for the entire Xinjiang region [citation]. Plain area temperature breakpoints occurred around [year]. Comparison of plain and mountainous temperature changes revealed lower annual temperature variation rates in plain areas, indicating more stable temperature conditions.

3.2 Precipitation Changes

Kendall test results indicated that mountainous precipitation exhibited a significant increasing trend (P<0.05), with a growth rate of 6.23. Mountainous precipitation increased rapidly from [year] at a rate of $7.30mm \cdot (10a)^{-1}$. Plain area precipitation showed greater variability compared to mountainous areas.

Seasonal precipitation analysis over the past [years] revealed that summer precipitation in mountainous areas displayed the most significant increasing trend (Fig. 3), with a growth rate of $4.95mm \cdot (10a)^{-1}$, followed by plain area summer precipitation at $3.72mm \cdot (10a)^{-1}$. In contrast, spring precipitation in mountainous areas showed the slowest increase at only $0.06mm \cdot (10a)^{-1}$. Since [year], the basin has experienced a significant overall precipitation increase. Kendall test results demonstrated significant increasing trends in annual average precipitation for both plain and mountainous areas (P<0.05). Mountainous precipitation increased more substantially (by 20 mm, 23.27 mm) compared to historical periods. This precipitation increase likely enhances the precipitation contribution to river runoff.

3.3 Runoff Changes

Based on multi-year runoff data from the Tizinafu River' s mountain outlet, Kendall test results showed that basin runoff exhibited a significant increasing trend over the past [years], with a mutation point around [year] followed by rapid increase. This lags behind the runoff mutation point for the entire Xinjiang region (1993) [citation], indicating that runoff on the northern slope of the Kunlun Mountains responds more slowly to climate change than the broader Xinjiang region.

Seasonal runoff comparisons (Fig. 4) showed that summer runoff increased fastest at $0.045 \times 10^8 m^3 \cdot (10a)^{-1}$ (or 0.55). Interannual variation analysis revealed that summer runoff had the smallest coefficient of variation, while autumn runoff showed the largest variation.

3.4.1 Stable Isotopes and Hydrochemistry of Different Water Bodies

Hydrochemical analysis showed that precipitation in the Tizinafu River Basin had relatively low mineralization, with TDS values ranging from 70-130 $mg \cdot L^{-1}$. The primary anion was [missing], while [missing] was the dominant cation. River water TDS ranged from 150-174 $mg \cdot L^{-1}$, with [missing] as the main anion and [missing] as the main cation. Groundwater TDS values ranged from 370-410 $mg \cdot L^{-1}$, with [missing] as the primary anion and [missing] as the dominant cation.

Stable isotope monitoring of different water bodies at Jiangka Station showed $\delta^{18}O$ values ranging from [missing]‰ to -7.00‰, with a weighted average of [missing]‰. Clear seasonal variations were evident across the basin. Precipitation $\delta^{18}O$ was depleted (Table 4). Snowmelt water in spring and autumn (March, September-December) contained higher stable isotope concentrations than summer (June-August). Groundwater $\delta^{18}O$ values ranged from [missing] to [missing]‰, with maximum values occurring in spring. This enrichment likely results from seasonal snowmelt and permafrost thawwater infiltration.

Like most inland rivers, Tizinafu River water exhibited significant seasonal variation in hydrogen and oxygen stable isotopes, with $\delta^{18}O$ ranging from -37.77‰

to -6.88‰ and δD ranging from [missing] to [missing]‰. Minimum $\delta^{18}O$ values appeared in [month].

3.4.2 Runoff Component Characteristics

The southwestern Tarim Basin has experienced significant warming and humidification trends in recent years, inevitably altering runoff components in alpine inland rivers. To understand runoff response to climate change, this study employed isotope hydrograph separation based on stable isotopes and hydrochemical parameters from multiple water bodies to comprehensively analyze Tizinafu River Basin runoff components. Research shows that runoff in northwestern China' s arid inland rivers primarily originates from mountain precipitation, meltwater, and groundwater (including fractured bedrock water), with component characteristics varying across basins due to differences in geology, geomorphology, and latitude [citations].

Isotope hydrograph separation results detailed contributions from precipitation, meltwater, and groundwater to basin runoff during the study period (March–December 2016). Figure 6 shows that precipitation and groundwater contributions to Tizinafu River runoff increased from March to [month], followed by a decline. Groundwater contributions exceeded precipitation and meltwater during [month]–[month]. Meltwater contributions displayed a bimodal pattern, with peaks in [month] and [month]. The [month] peak resulted from substantial alpine meltwater input during summer, while the [month] peak likely stemmed from seasonal snowfall melting (when surface temperatures remained unfavorable for snow accumulation). Precipitation contributions exceeded concurrent groundwater and meltwater contributions.

Analysis revealed complex intra-annual runoff component variations sensitive to temperature and precipitation fluctuations. Meltwater contributions peaked in [month] at the highest level during the observation period.

Using isotope hydrograph separation results combined with seasonal runoff volumes, we calculated quarterly runoff component characteristics (Fig. 7). In spring (March–May), meltwater contributed [value]% to Tizinafu River runoff. During summer, precipitation dominated as the primary water source, contributing [value]% to summer runoff. Groundwater (including fractured bedrock water) also contributed substantially to summer flow at [value]%. Weighted by annual runoff volume, precipitation constituted the largest annual runoff proportion at [value]%, followed by groundwater at [value]%. Meltwater contributed [value]% as an important water source.

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4 Discussion

Research results demonstrate that Tizinafu River runoff is jointly controlled by meltwater, groundwater, and precipitation. Summer represents the primary precipitation period, and interannual precipitation variability constitutes the main cause of annual runoff variation. If current climate change trends persist, policy responses should be formulated promptly, including strengthening rational allocation of irrigation and domestic water resources and constructing supporting water conservancy infrastructure to better address potential climate change impacts on basin water resource security.

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5 Conclusions

1. The Tizinafu River Basin has experienced significant temperature increases and notable precipitation increases in mountainous areas. Consequently, runoff shows an increasing trend, with summer runoff increases being most pronounced.

2. Runoff component results show that meltwater, groundwater, and precipitation contribute [value]%, [value]%, and [value]%, respectively, to annual runoff in the Tizinafu River Basin.

3. Runoff component characteristics exhibit significant seasonal differences. Summer runoff contains a large precipitation proportion, and annual runoff variation responds significantly to precipitation changes. Future climate change, particularly precipitation fluctuations, may substantially impact regional runoff.

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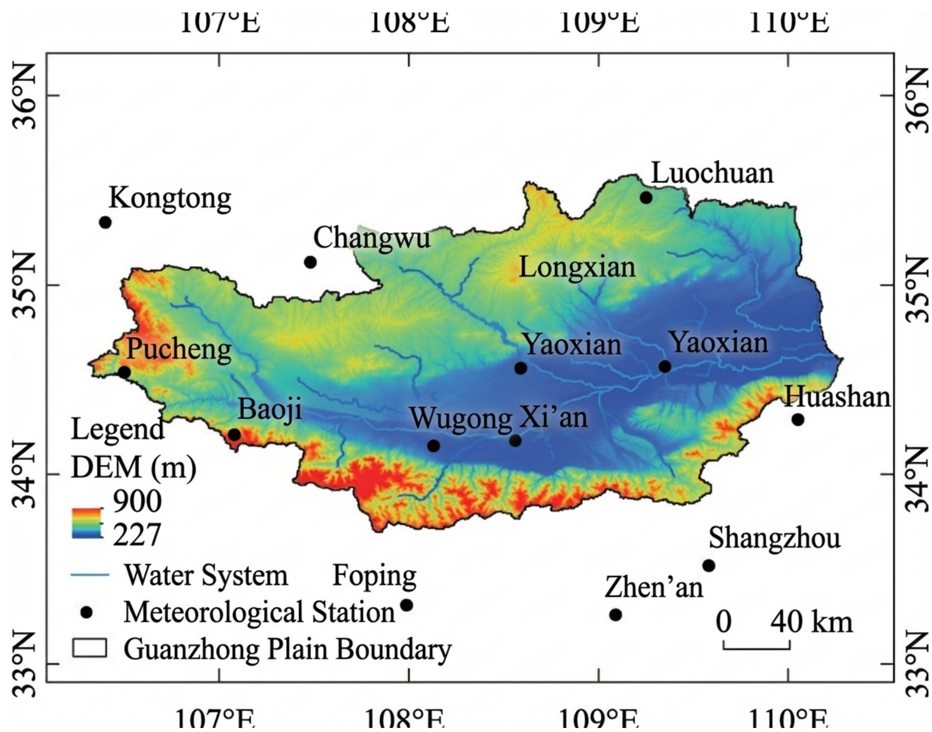
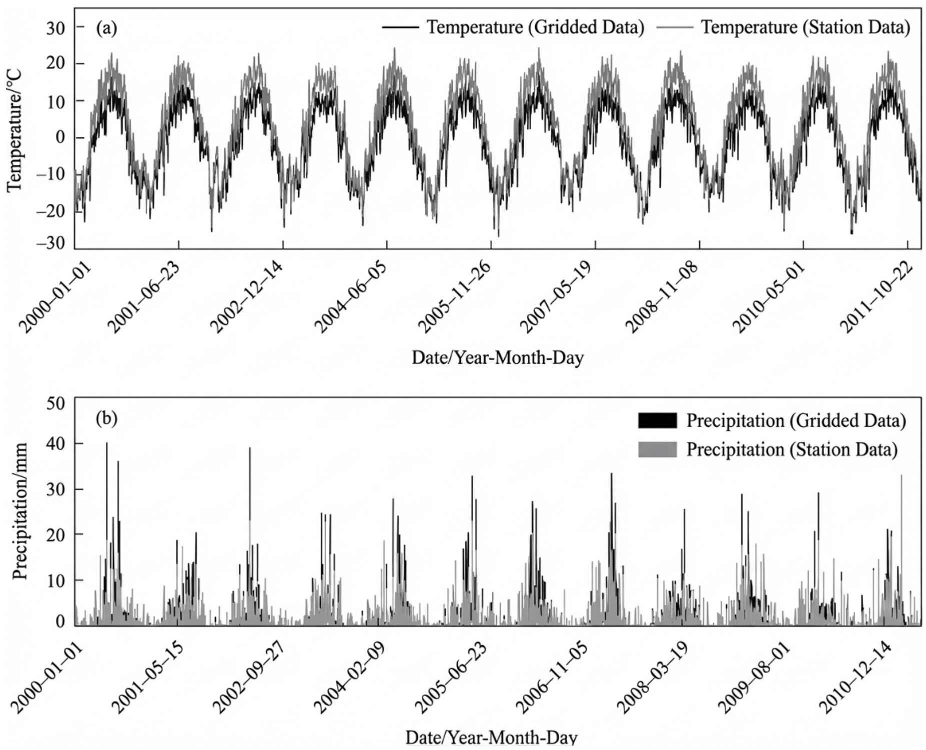


Figure 1: Figure 1



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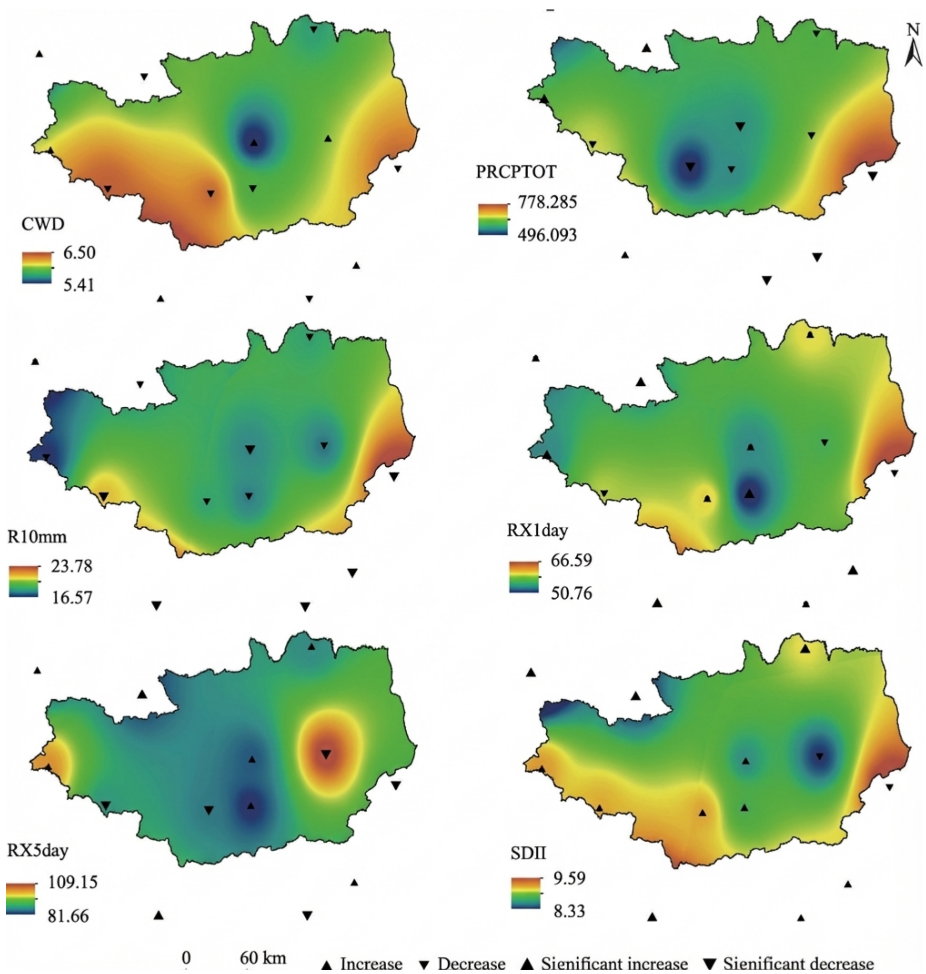

Figure 3: Figure 3

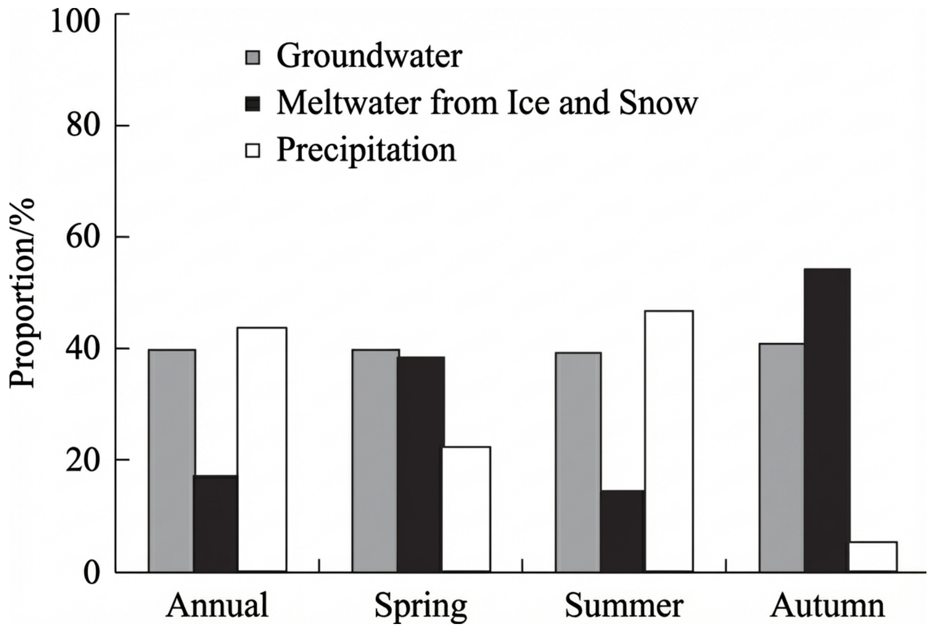

Figure 4: Figure 6

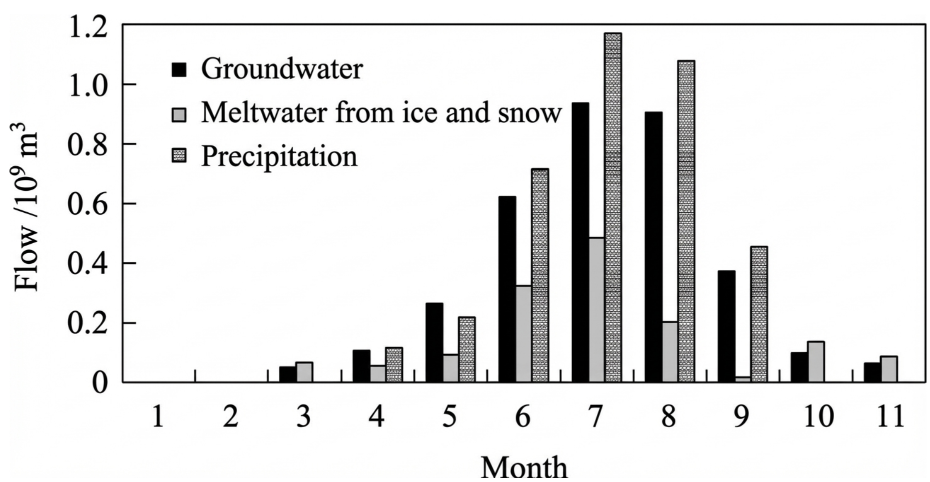

Figure 5: Figure 7

Figures