

Climate Change Over the Past 50 Years in the Yanqi Basin



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Abstract There has been evidence of warming and significant change in precipitation in northwest China, implying climate change in the vast arid/semiarid regions. This study showed that there was an increasing trend in air temperature over the period of 1960–2014 in the Yanqi Basin, and the warming was most pronounced since the mid-1990s. The warming rate varied over space and between seasons, with a greater rate in autumn (0.30–0.40 °C/10a) and winter (0.29–0.45 °C/10a) than in spring (0.13–0.26 °C/10a) and summer (0.17–0.24 °C/10a). There was also large interannual to decadal variability in precipitation in the Yanqi Basin and runoff in the Kaidu River. Precipitation showed an overall small increasing trend over the period of 1960–2014. The lower reaches of the Kaidu River experienced a significant increase in runoff since the mid-1990s, which might be primarily a result of warming that enhanced melting of snow and glacier in the surrounding mountains.

1 Introduction

There have been numerous studies of temporal variations of air temperature at various spatial scales (Brown et al. 2008; Hansen et al. 2002; Jones et al. 1999; Solomon 2007; You et al. 2011), which show a general warming trend in the global mean air temperature. Earlier studies indicated that the magnitude of warming in the Northern Hemisphere (0.30 °C/10a) was more than the double of the one (0.13 °C/10a) in the Southern Hemisphere during 1977–2001 (Jones and Moberg 2003; Luterbacher et al. 2004).

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There is evidence of difference in the warming trend over space and time in China. For example, the warming rate of air temperature was $0.25\text{ }^{\circ}\text{C}/10\text{a}$ for the period of 1951–2004 in China (Ren et al. 2005), but $0.35\text{ }^{\circ}\text{C}/10\text{a}$ in northwest China during the period of 1961–2006 (Chen et al. 2010; Klein Tank and Können 2003), which were much greater than the global average. Over the past 50 years, an increase in air temperature with a linear tendency of $0.28\text{ }^{\circ}\text{C}/10\text{a}$ was observed in Xinjiang, which was lower than that for northwest China (Li et al. 2011). These findings indicated that climate change in Xinjiang might have its own spatial and temporal characteristics due to its large extent and complex terrain.

Apart from the warming trend, there has been evidence that most regions in the world have experienced an increase in precipitation over the last few decades in the last century. Studies have showed significant changes in precipitation in the majority of China, with an overall increase in northwest China (Wang et al. 2004), with implications for the hydrological cycle in Xinjiang. The objective of this study is to investigate the spatial and temporal variability in air temperature, precipitation, and runoff and to explore the possible mechanisms responsible for these changes in the Yanqi Basin.

2 Data and Method

Daily air temperature dataset from four meteorological stations, i.e., the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, in the Yanqi Basin (including the Kaidu River Basin) with a rough data period from March 1, 1954, to December 31, 2014, were provided by the National Climatic Centre of China (NCCC), China Meteorological Administration (CMA). The quality of the data has been controlled before its release, and the homogeneity test has also been performed. Furthermore, in this study, the double mass curve method was used to check the data consistency (e.g., Li and Yan 2009). The result showed that all the data series in this study were consistent. In total, the missing data account for 0.01% of the data series. The missing data were filled using conventional statistical methods including: (1) If only one day had missing data, the missing data were replaced by the average value of its two neighboring values; (2) if consecutive two or more days had missing data, the missing data would be processed by simple linear regression between its neighboring stations (distance $<100\text{ km}$) without considering the effect of terrain altitude (Jiang et al. 2013). For temporal consistence and facilitating comparison, the period of temperature time series was restricted from January 1, 1961, to December 31, 2014.

In addition, two hydrological stations which are located in the Yanqi Basin and Kaidu River Basin were also chosen for this study (Fig. 1). Among them, the Bayinbuluke station is situated in the upper reaches of Kaidu River and the Dashankou station is in the lower reaches of the river. Monthly streamflow data from 1956 to 2010 of the two stations were obtained from the Xinjiang Administration of Hydrological and Water Resource. Basic information of these stations is given in Table 1, and the locations of the stations are shown in Fig. 1.

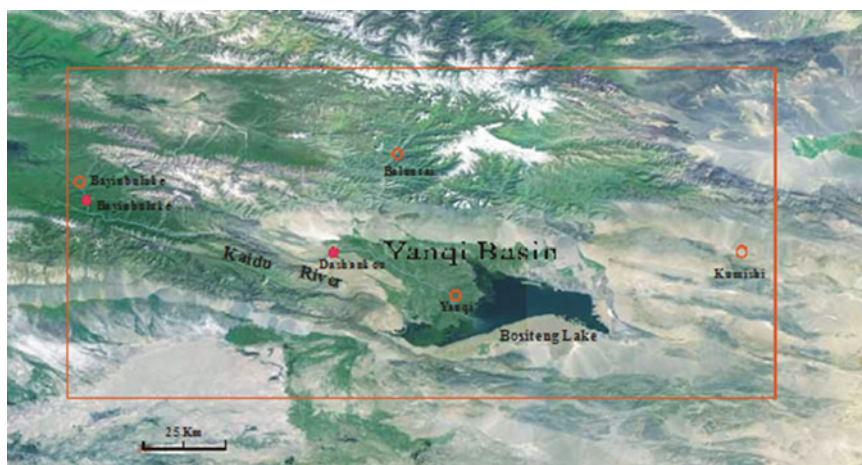


Fig. 1 Sketch map showing the locations of selected meteorological and hydrological stations

Table 1 Basic information of stations chosen for this study

Station	Type	Longitude	Latitude	Altitude (m)	Data period
Bayinbuluke	Weather	84.15	43.03	2458	1961–2014
Baluntai	Weather	86.30	42.73	1739	1961–2014
Kumishi	Weather	88.22	42.23	721	1961–2014
Yanqi	Weather	86.57	42.08	1055	1961–2014
Bayinbuluke	Hydrology	84.12	42.96	2495	1956–2010
Dashankou	Hydrology	85.72	42.25	1400	1956–2010

Ordinarily linear regression was employed to estimate long-term variations and/or trends in the annual and seasonal temperature, precipitation, and runoff. The coefficient of variation (Cv value) is used to reflect the interannual variability, which is calculated as follows: $Cv = \text{standard deviation}/\text{average}$.

3 Results and Discussion

3.1 Temporal Changes in Air Temperature

3.1.1 Seasonal Variations in Air Temperature

Viewing from the distribution of monthly average temperature during a year, the temperature in the Yanqi Basin and its neighboring mountains shows a gradual increase from January to July and a slightly faster decrease from August to December (Fig. 2).

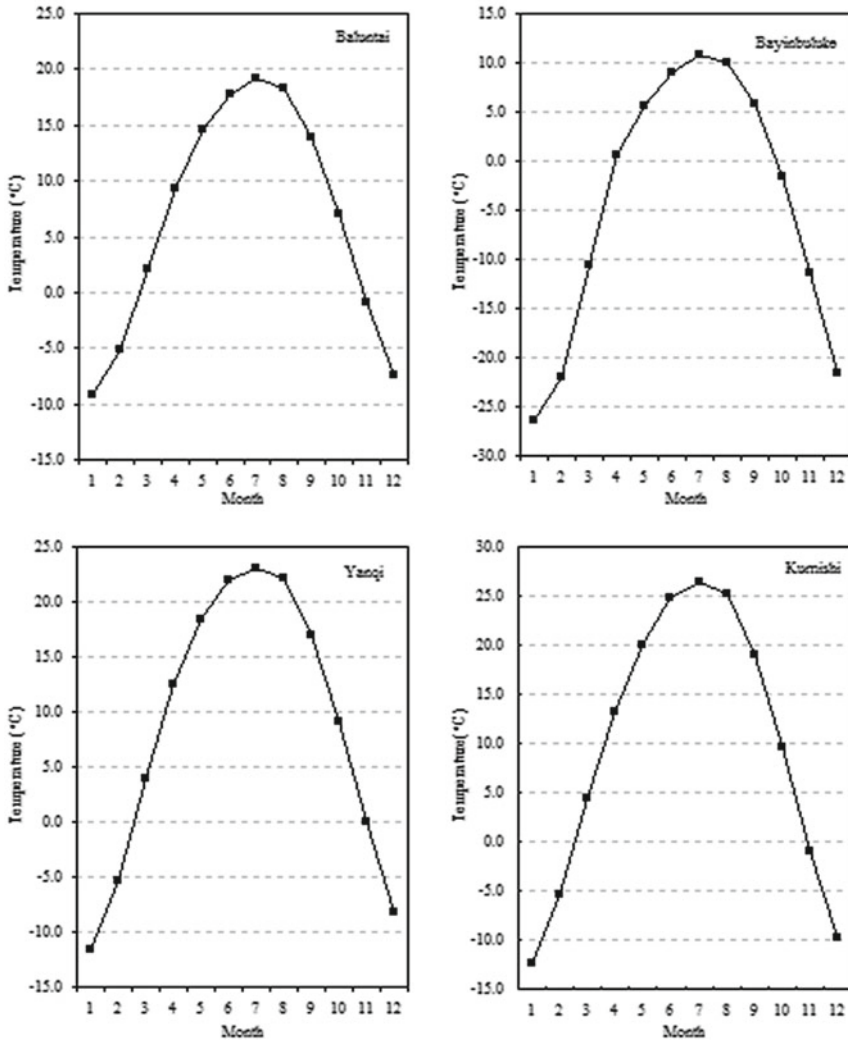


Fig. 2 Climatology of monthly mean temperature at the four weather stations

Overall, the Bayinbuluke station has the lowest temperature year-round, with the mean temperature being $-20\text{ }^{\circ}\text{C}$ in winter and $10\text{ }^{\circ}\text{C}$ for summer (Table 2); the Kumishi station reveals highest temperature in all the seasons, i.e., $12.6, 25.5, 9.3,$ and $-6.0\text{ }^{\circ}\text{C}$ for spring, summer, autumn, and winter, respectively.

In general, summer is usually the period with the smallest variability in temperature, while the fall and winter seasons are the periods of largest variability in the Yanqi Basin. However, spring is the period with the highest variability for

Table 2 Mean, standard deviation (Std), and coefficient of variation (Cv) of the temperature for different seasons

Station	Spring			Summer			Autumn			Winter		
	Mean	Std	Cv	Mean	Std	Cv	Mean	Std	Cv	Mean	Std	Cv
Bayinbuluke	-1.5	1.5	0.99	10.0	0.6	0.06	-2.4	1.5	0.62	-20.0	2.6	0.13
Baluntai	8.6	1.0	0.11	18.4	0.8	0.04	6.7	1.2	0.18	-5.1	1.4	0.28
Yanqi	11.6	0.9	0.08	22.4	0.5	0.02	8.7	0.9	0.10	-5.6	1.3	0.24
Kumishi	12.6	0.9	0.07	25.5	0.6	0.02	9.3	1.5	0.24	-6.3	1.5	0.24

Table 3 Decadal changes in mean annual temperature (°C) at the four stations

Station	1960s	1970s	1980s	1990s	2000s	Mean (1961–2014)
Bayinbuluke	−4.5	−4.2	−5.1	−4.2	−3.4	−4.4
Baluntai	6.3	6.1	6.1	6.8	7.8	6.6
Yanqi	8.2	8.1	8.4	8.9	9.2	8.9
Kumishi	9.4	9.0	9.4	9.8	10.1	9.6

the Bayinbuluke station (Table 2). This may be related to the topography of the mountain basin and instability of the local atmospheric stratification.

3.1.2 Decadal Changes in Air Temperature

Our analyses show that the Yanqi Basin experienced a small decrease in temperature from the 1960s to the 1970s and an overall increasing trend in temperature from the 1970s to the 2010s except at the Bayinbuluke station that showed a significant decrease from -4.2 °C in the 1970s to -5.1 °C in the 1980s, followed by a significant increase to -3.4 °C in the 2000s. Among the four stations, the Baluntai station is characterized by its largest increase in temperature, 1.5 – 1.7 °C from 1961s to 2010s, while the Kumishi station appears a slightly increasing trend in temperature, i.e., 0.5 – 0.9 °C from 1961s to 2010s (Table 3).

3.1.3 Interannual Variability and Change Trend in Different Seasons

Figure 3 shows large interannual variability in spring mean temperatures at all four stations although there was an overall increasing trend from 1961 to 2014. It appears that there was no clear trend prior to the 1980s, but an increasing trend starting in 1987, which is coincident with the conclusion that a change point of temperature time series could be occurred in the middle of the 1980s (Li and Jiang 2007). The linear tendency rate of spring temperature over the period of 1961–2013 was 0.13, 0.19, 0.26, and 0.16 °C/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively, which was not statistically significant (Table 4).

It is shown in Fig. 4 that summer average temperature was increasing from 1961 to 2014 at the four stations. The linear tendency rate of summer temperature was 0.24, 0.17, 0.18, and 0.17 °C/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively (Table 4). The increasing trend was significant at the Bayinbuluke station ($P < 0.01$) and the Yanqi station ($P < 0.05$).

Figure 5 shows considerable interannual variation in autumn temperature at all four stations in the Yanqi Basin. In general, autumn average temperature was all increasing from 1961 to 2014. The linear tendency rate in autumn was 0.32, 0.40, 0.33, and 0.30 °C/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations,

Table 4 Change trend ($^{\circ}\text{C}/10\text{a}$) of mean temperature and its coefficient (R) for different seasons

Station	Spring		Summer		Autumn		Winter		Annual	
	Trend	R	Trend	R	Trend	R	Trend	R	Trend	R
Bayinbuluke	0.13	0.02	0.24	0.46**	0.32	0.11	0.29	0.03	0.17	0.07
Baluntai	0.19	0.09	0.17	0.12	0.40	0.29*	0.45	0.25	0.27	0.26*
Yanqi	0.26	0.20	0.18	0.29*	0.33	0.34**	0.39	0.22	0.25	0.35**
Kumishi	0.16	0.07	0.17	0.20	0.30	0.22	0.26	0.07	0.17	0.18

* $P < 0.05$, ** $P < 0.01$

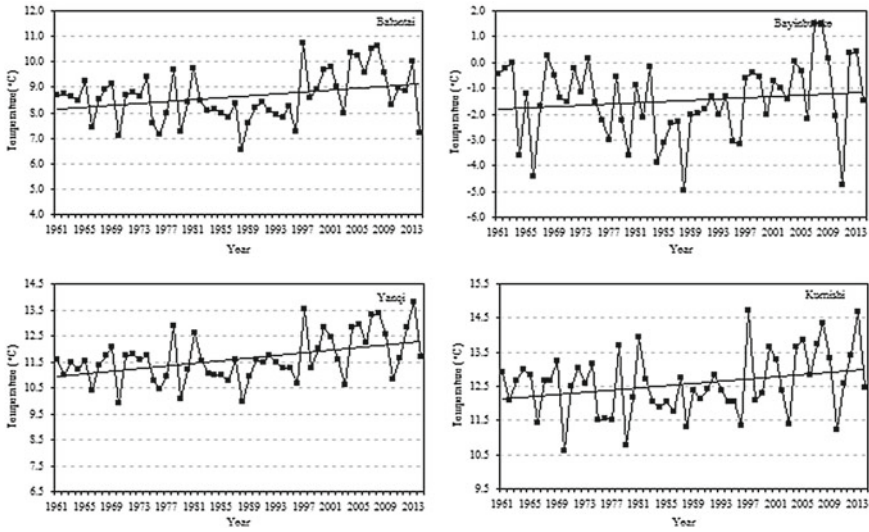


Fig. 3 Interannual variability of temperature and trend in spring at the four stations

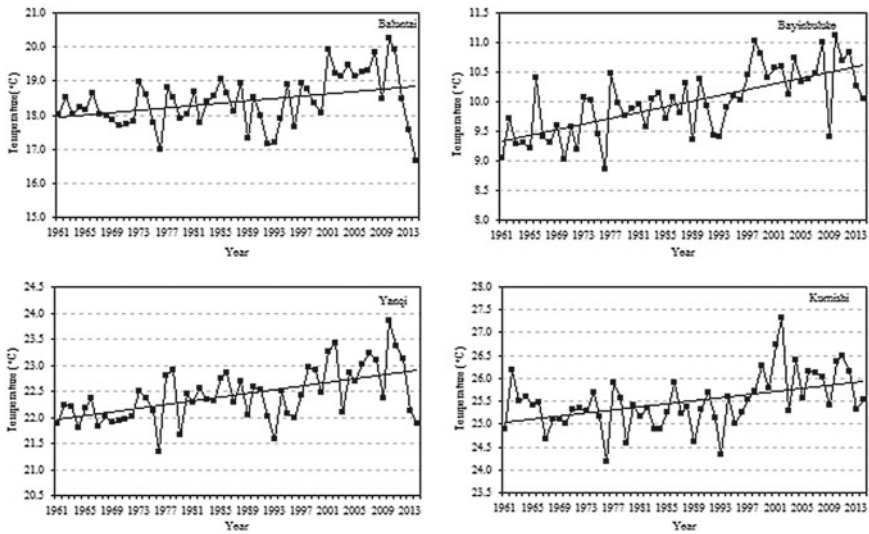


Fig. 4 Interannual variability and trend in summer temperature at the four stations

respectively, which was much greater than those in spring and summer (Table 4). The increasing trend was significant at the Baluntau and Yanqi stations.

There was interannual to decadal variability in winter temperature at all four stations (Fig. 6). Overall, winter average temperatures showed an increasing trend during the period of 1961–2014. The linear tendency rate was 0.29, 0.45, 0.39,

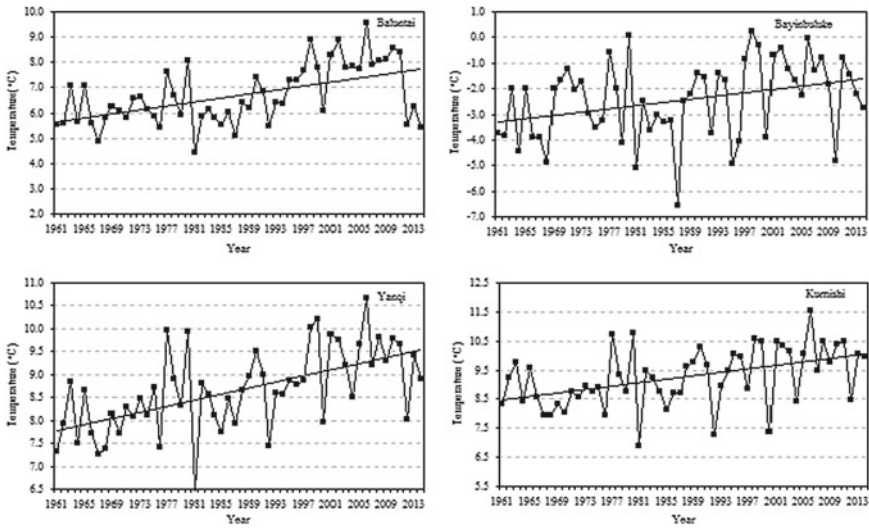


Fig. 5 Interannual variability and trend in autumn temperature at the four stations

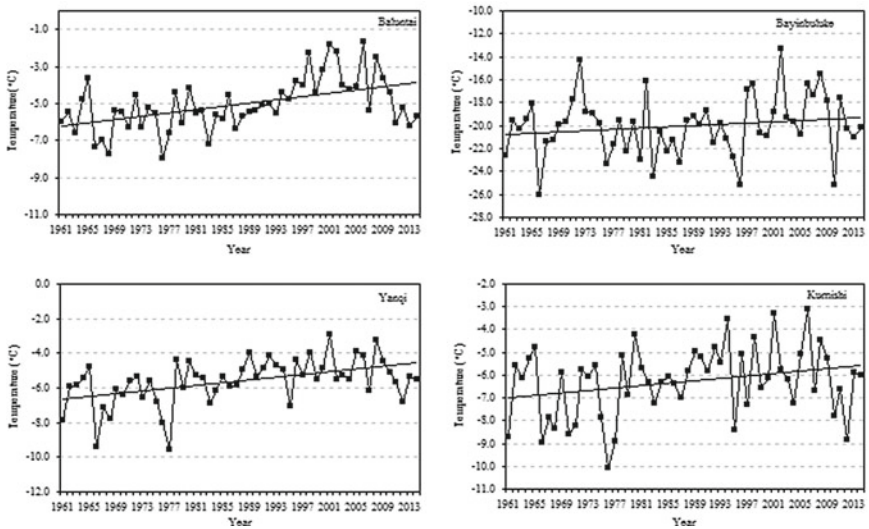


Fig. 6 Interannual variability and trend in winter temperature at the four stations

and 0.26 °C/10a at the Bayinbulake, Baluntai, Yanqi, and Kumishi stations, respectively (Table 4), although the change trend was not statistically significant. The most obvious warming occurred in autumn and winter, which is in agreement with some previous studies (Long et al. 2016; Wang et al. 2012).

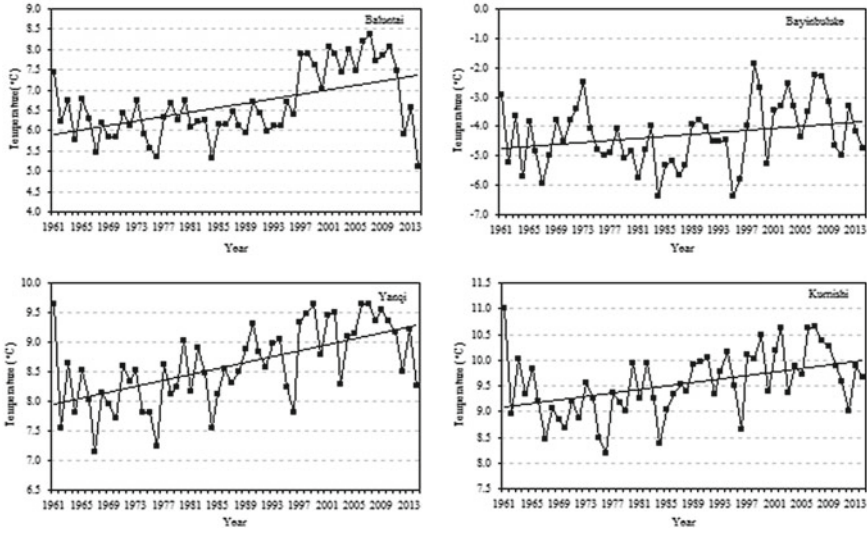


Fig. 7 Interannual variability and trend in annual mean temperature at the four stations

3.1.4 Variability and Trend in Annual Mean Temperature

Figure 7 shows large interannual variations in annual mean temperature at the four stations in the Yanqi Basin. It can be seen that a decreasing trend occurred from the beginning to the late of 1960s, then a gradually increasing trend appeared in the period of 1970–2009 (except at the Bayinbuluke station), and finally, a decreasing trend took place since 2010. Overall, there was an increasing trend for four stations from 1961 to 2014, and the linear tendency rate was 0.17, 0.27, 0.25, and 0.17 °C/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively. The increasing trend was significant at the Baluntai ($P < 0.05$) and Yanqi stations ($P < 0.01$) (Table 4).

3.2 Temporal Changes in Precipitation

3.2.1 Monthly Variations in Precipitation

There is strong seasonality in precipitation in the Yanqi Basin, with the largest in July and extremely low rate (<3 mm/month) during the period of November–March at all the stations (Fig. 8). Clearly, precipitation is much higher at the Bayinbuluke and Baluntai stations than at the Yanqi and Kumishi stations. In particular, July’s rainfall is greater than 55 mm in the former, but less than 20 mm in the latter.

The variation coefficient of seasonal precipitation is commonly used to characterize intra-annual variability of precipitation in a given region. A smaller variation

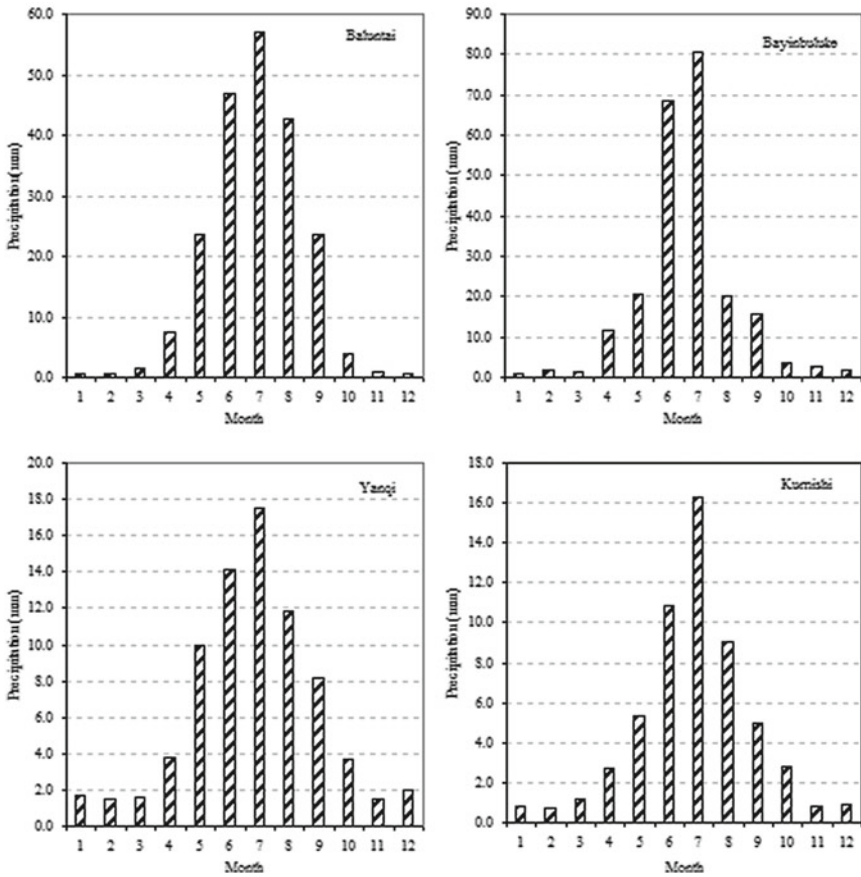


Fig. 8 Climatology of monthly precipitation in the Yanqi Basin

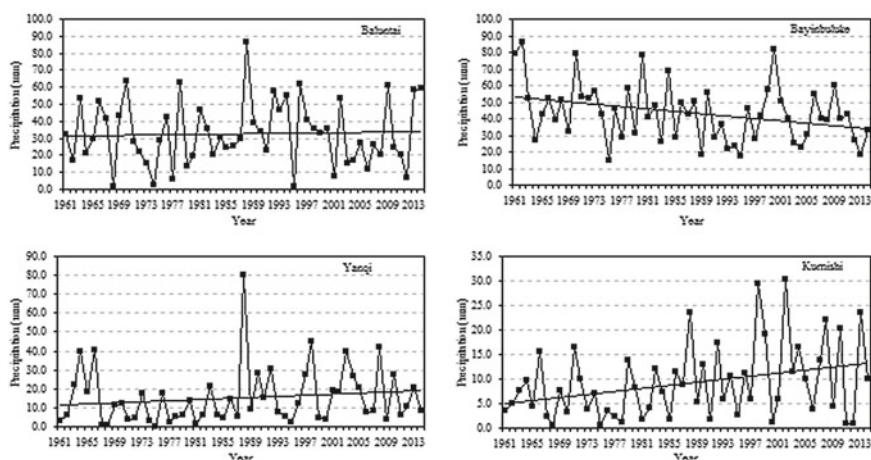
coefficient indicates a smaller interannual variation of precipitation and a higher utilization value of precipitation resources. It is given in Table 5 that in the Yanqi Basin, seasonal precipitation variability was high. Specially, summer is usually the period with the minimum precipitation variability, while the fall and winter seasons are the periods with maximum precipitation variability, demonstrating a greatly interannual fluctuation in precipitation during winter and autumn seasons.

Table 5 Mean, standard deviation (Std), and coefficient of variation (Cv) of precipitation at the four stations

Station	Spring			Summer			Autumn			Winter		
	Mean	Std	Cv	Mean	Std	Cv	Mean	Std	Cv	Mean	Std	Cv
Bayinbuluke	43.3	17.5	0.40	183.8	43.5	0.24	36.8	17.1	0.46	11.8	7.2	0.61
Baluntai	32.7	18.9	0.58	149.1	53.5	0.36	27.9	20.7	0.74	1.7	1.9	1.13
Yangqi	15.2	14.9	0.98	43.9	23.5	0.54	13.0	14.9	1.14	4.9	5.5	1.11
Kumishi	9.2	7.5	0.82	36.5	15.4	0.42	8.2	8.6	1.05	2.2	2.8	1.25

Table 6 Interdecadal changes in mean annual precipitation at the four stations in/near the Yanqi Basin

Station	1960s	1970s	1980s	1990s	2000s	Mean (1961–2014)
Bayinbuluke	261.0	258.7	259.2	281.9	302.0	301.9
Baluntai	190.9	204.5	184.8	253.3	226.2	207.2
Yanqi	72.5	62.3	82.2	96.4	81.1	58.1
Kumishi	47.7	45.6	50.3	74.4	59.6	59.4

**Fig. 9** Temporal variation and trend in spring mean precipitation at the four stations

3.2.2 Decadal Changes in Precipitation

The Yanqi Basin experienced considerably decadal changes in precipitation over the period of 1961–2014. There was a clear increasing trend (from ~260 mm in the 1960s to ~300 mm in the 2000s) at the Bayinbuluke station and an overall increasing trend prior to 2000, followed by a decrease from the 1990s to the 2000s at the other three stations (Table 6).

3.2.3 Trend in Different Seasons

It is shown in Fig. 9 and Table 7 that the change trend in spring precipitation is different among the four stations, i.e., an increasing trend at the Kumishi (1.56 mm/10a), Yanqi (1.40 mm/10a), and Baluntai (0.43 mm/10a) stations, but a decreasing trend at the Bayinbuluke (−3.55 mm/10a) station. The largest variability in spring precipitation is found at the Kumishi station and smallest at the Baluntai station (Table 7).

Table 7 Change trend of mean precipitation and its coefficient (*R*) for different seasons

Station	Spring		Summer		Autumn		Winter	
	Trend	<i>R</i>	Trend	<i>R</i>	Trend	<i>R</i>	Trend	<i>R</i>
Bayinbuluke	-3.55	0.10	9.62	0.12	2.31	0.05	1.30	0.08
Baluntai	0.43	0.00	9.32	0.07	-0.57	0.00	0.24	0.04
Yanqi	1.40	0.02	-0.45	0.00	-0.15	0.00	0.57	0.03
Kumishi	1.56	0.11	2.06	0.04	0.20	0.00	0.48	0.07

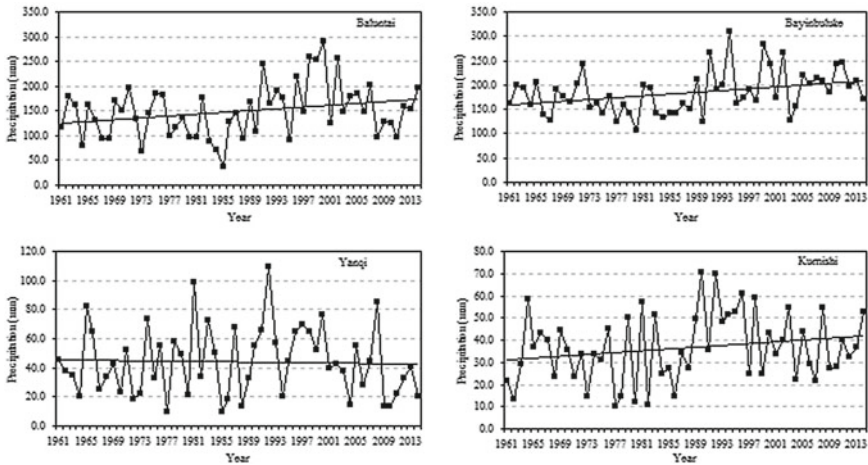


Fig. 10 Temporal variation and trend in summer mean precipitation at the four stations

Figure 10 shows the temporal variation of summer precipitation at the four stations in the Yanqi Basin. It can be seen that there is an increasing trend in summer precipitations at the Baluntai, Bayinbuluke, and Kumishi stations, but a slightly decreasing trend at the Yanqi station from 1961 to 2014. The linear tendency rates of summer precipitation are 9.62, 9.32, -0.45, and 2.06 mm/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively (Table 7).

The autumn precipitation shows an increasing trend at the Bayinbuluke and Kumishi stations, but a slightly decreasing trend at the Yanqi and Baluntai stations from 1961 to 2014 (Fig. 11). The linear tendency rates of autumn precipitation are 2.31, -0.57, -0.15, and 0.20 mm/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively (Table 7).

As shown in Fig. 12, there was a large interannual to decadal variability in winter precipitation despite an increasing trend at all four stations from 1961 to 2014. The linear tendency rate was 1.30, 0.24, 0.57, and 0.48 mm/10a at the Bayinbuluke, Baluntai, Yanqi, and Kumishi stations, respectively (Table 7).

Figure 13 shows temporal variation in annual mean precipitations at the four stations in the Yanqi Basin. There was a large interannual variability but also an overall increasing trend in annual mean precipitation, indicating a potential climate

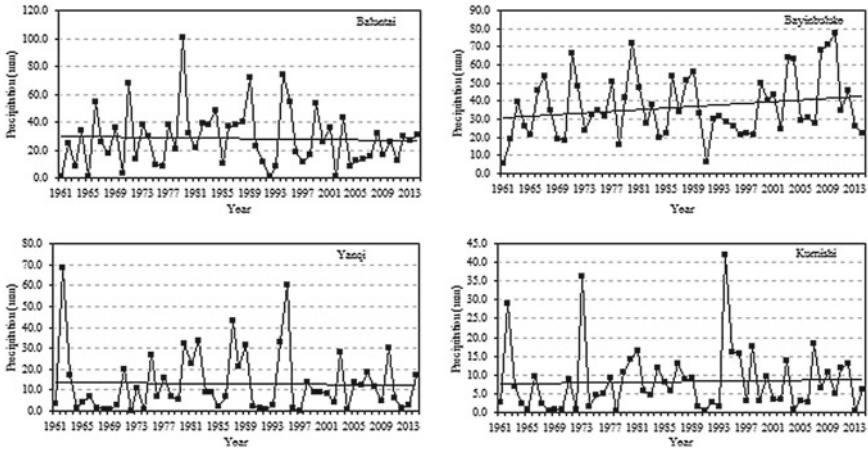


Fig. 11 Temporal variation and trend in autumn mean precipitation at the four stations

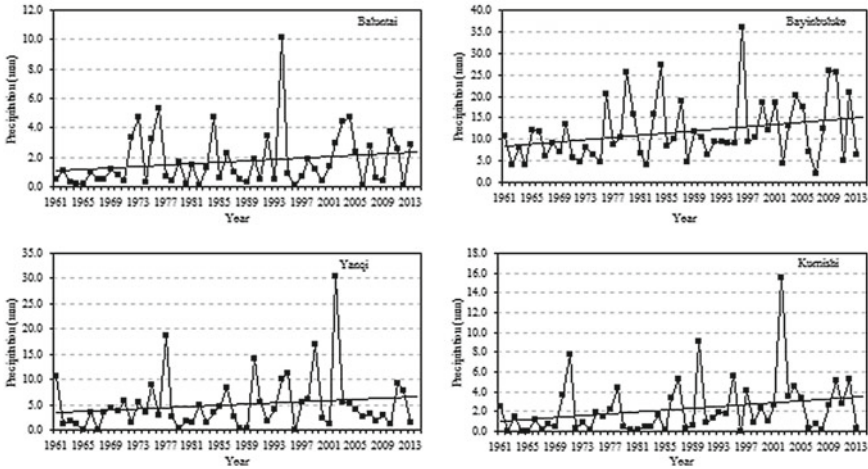


Fig. 12 Temporal variation and trend in winter mean precipitation at the four stations

regime shift from drier climate to wetter climate, which was in agreement with previous studies (Jiang et al. 2013; Shi 2003; Zhang et al. 2012; Zhen and Jiang 2007). The linear tendency rate of annual mean precipitation was 9.73, 8.88, 1.55, and 4.23 mm/10a at the Bayinbulake, Baluntai, Yanqi, and Kumishi stations, respectively.

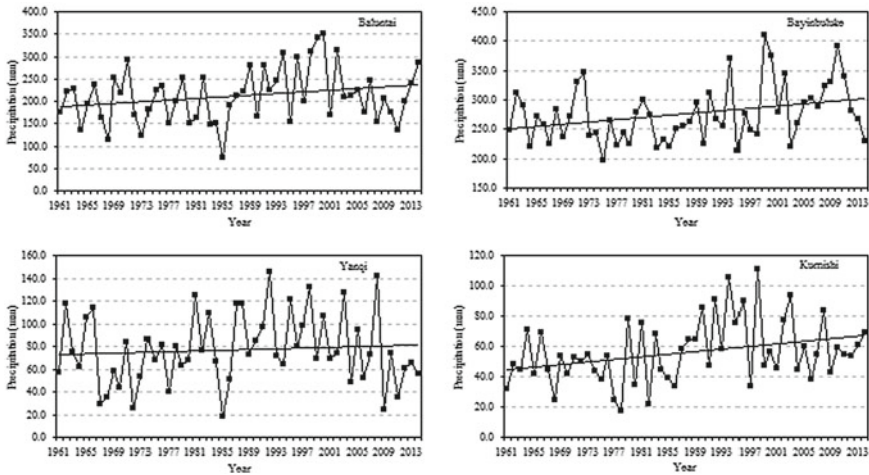


Fig. 13 Temporal variation and trend in annual mean precipitation at the four stations

4 Runoff in the Kaidu River

4.1 Kaidu River: An Introduction

The Kaidu River is an important source of water for the Tarim Basin. The sources of the Kaidu River are located on the central southern slopes of the Tian Shan from where it flows through the Yulduz Basin and the Yanqi Basin into Lake Bosten for which it is the most important tributary (Fig. 1). The full length and the catchment area of Kaidu River is 560 km and $2.2 \times 10^4 \text{ km}^2$, respectively. The Kaidu River Basin belongs to the arid and semiarid climate, and water sources are from natural precipitation, snow, and glacier melting water. Annual mean runoff of the Kaidu River is $34.12 \times 10^8 \text{ m}^3$. Bayinbuluke is the upstream station of Kaidu River, and Dashankou is the downstream station, which controls the total water amount of Kaidu River.

4.2 Statistics of Runoff in Kaidu River

The mean, maximum, and minimum of annual runoff were 23.02×10^8 , 38.08×10^8 , and $16.03 \times 10^8 \text{ m}^3$ in the upper reaches of Kaidu River for the period of 1956–2010, respectively, and 35.96×10^8 , 61.65×10^8 , and $24.56 \times 10^8 \text{ m}^3$, respectively, in the lower reaches (Table 8).

The variation coefficient (Cv value) of annual runoff ranges from 0.19 to 0.30, demonstrating a lower interannual variability in the annual runoff of the Kaidu River.

Table 8 Statistics of annual runoff in the Kaidu River

Station	Mean ($\times 10^8 \text{ m}^3$)	Maximum ($\times 10^8 \text{ m}^3$)	Minimum ($\times 10^8 \text{ m}^3$)	Std ^a	Cv ^b
Bayinbuluke	23.02	38.08	16.03	4.53	0.197
Dashankou	35.96	61.65	24.56	8.00	0.222

^aStd—Standard deviation; ^bCv—Coefficient of variation

The upstream station (Bayinbuluke) has a smaller Cv value than the downstream station (Dashankou) (Table 8). The main reason for the small interannual variation in the annual runoff of the Kaidu River is the small interannual variation of precipitation and the regulation of glaciers and mountain region (Eziz et al. 2014; Xie and Zhu 2011).

4.3 Variations in Annual Runoff

4.3.1 Variations in Runoff in the Upper Reaches of Kaidu River

In general, the upper reaches of Kaidu River experienced a slightly increasing trend in annual runoff from the 1960s to the 1970s, followed by a decreasing trend from the 1970s to the 1990s and then a rapidly increasing trend from the 1990s to the 2000s. Roughly, the 2000s was the decade with the maximum annual runoff, while the 1980s was the decade with the minimum annual runoff (Table 9).

Figure 14 shows the temporal variation in mean annual runoff in the upper reaches of the Kaidu River. There was a fluctuating upward trend in mean annual runoff during the period of 1956–1971, followed by a rapid downward trend from 1971 to 1977 and then a gradual upward trend during the period of 1977–2010. Generally, there was a decreasing trend in mean annual runoff from 1956 to 2010 at the Bayinbuluke station, and the linear tendency rate was $-0.153 \times 10^8 \text{ m}^3/10\text{a}$.

Figure 15 reveals the temporal variation of runoff in different seasons at the Bayinbuluke station, the upper reaches of Kaidu River. There was a slightly increasing

Table 9 Decadal variation of annual runoff in Kaidu River (10^8 m^3)

Station	1960s	1970s	1980s	1990s	2000s	Average (1956–2010)
Bayinbuluke (upper reaches)	23.21	24.66	19.57	21.71	25.09	23.02
Dashankou (lower reaches)	32.95	33.12	30.53	36.72	42.77	35.96

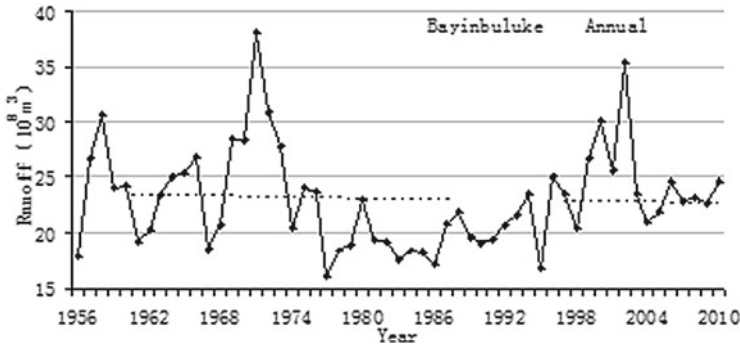


Fig. 14 Variation and trend of annual runoff at the Bayinbuluke station

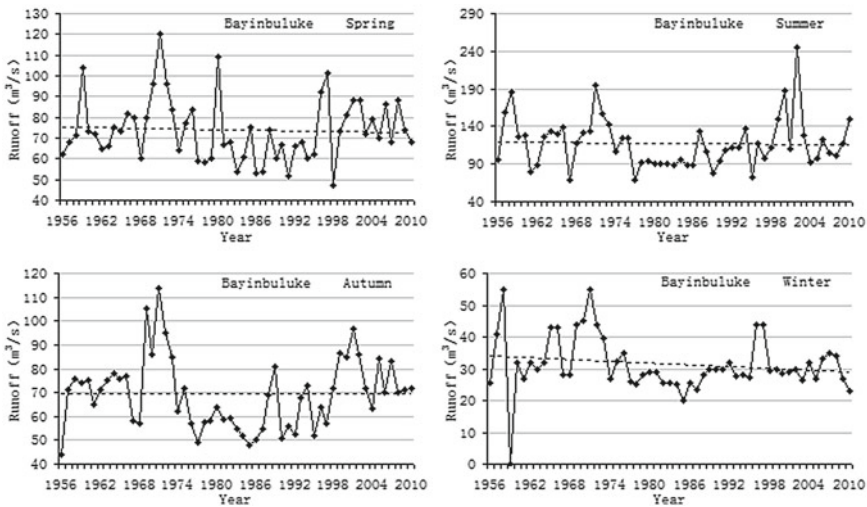


Fig. 15 Variation and trend of runoff in different seasons at the Bayinbuluke station

trend in spring runoff from 1956 to 1971, followed by a decreasing trend from 1971 to 1994 and a rapidly increasing trend from 1994 to 2010. The summer runoff experienced a large fluctuation during the period of 1956–1971, followed by a small fluctuation during the period of 1971–1997 and a fluctuating upward during the period of 1997–2010. The autumn runoff showed a fluctuating upward trend during the period of 1956–1972, followed by a rapid downward trend from 1972 to 1985 and a fluctuating upward trend during the period of 1986–2010. There was a large interannual variability in winter runoff prior to 1960, followed by a clear upward trend during the period of 1960–1972, then a rapid decrease from 1973 to 1985, and a fluctuating upward trend during the period of 1986–2010.

Overall, there were similar downward trends in spring, summer, and winter runoffs. However, autumn runoff showed a slightly increasing trend. The linear

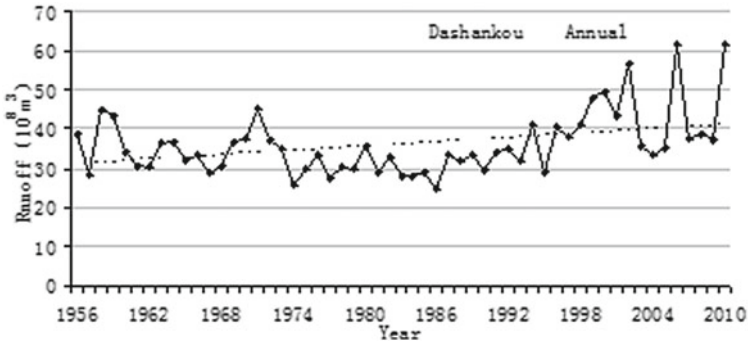


Fig. 16 Variation and trend of annual runoff at the Dashankou station

tendencies of spring, summer, autumn, and winter runoff were -0.15×10^8 , -0.48×10^8 , 0.002×10^8 , and -0.96×10^8 $m^3/10a$, respectively (Table 10).

4.3.2 Variation in Runoff in the Lower Reaches of the Kaidu River

The lower reaches of the Kaidu River experienced a slight increase in annual runoff from the 1960s to the 1970s, then a decrease from the 1970s to the 1980s, and a rapid increase from the 1980s to the 2000s. The maximum annual runoff was found in the 2000s, and the minimum annual runoff in the 1980s (Table 9).

Figure 16 shows that a fluctuating downward in annual mean runoff in the lower reaches of Kaidu River (Dashankou station) occurred during the period of 1956–1986, and a rapid upward appeared in the period of 1986–2010. Generally, there was an increasing trend in annual runoff from 1956 to 2010 at the Dashankou station. The linear tendency rate of annual runoff was 1.89×10^8 $m^3/10a$ at the Dashankou station. The linear tendencies of spring, summer, autumn, and winter runoff in the lower reaches of Kaidu River were 1.89×10^8 , 2.75×10^8 , 5.48×10^8 , and 6.68×10^8 $m^3/10a$, respectively (Table 10).

There was a large temporal variation in all four seasons at the Dashankou station (Fig. 17). However, the fluctuation of runoff was more pronounced in spring and summer than in autumn and winter. Overall, the lower reaches of Kaidu River experienced an increase in runoff post-mid-1990s despite the fluctuation. The summer runoff showed a fluctuating downward trend during the period of 1956–1985, followed by a fluctuating upward trend during the period of 1986–2002 and then much lower values with a slightly increasing trend during the period of 2002–2010. The autumn runoff experienced a small change during the period of 1956–1985, but a gradual upward trend from 1986 to 2000, followed by a remarkable fluctuation (between ~ 80 and ~ 280 m^3/s) over the period of 2001–2010. The winter runoff showed a similar temporal variation with less degrees of fluctuation to autumn runoff,

Table 10 Trend ($10^8 \text{ m}^3/10\text{a}$) of annual runoff and its coefficient (R) for different seasons

Station	Annual		Spring		Summer		Autumn		Winter	
	Trend	R	Trend	R	Trend	R	Trend	R	Trend	R
Bayinbuluke (upper reaches)	-0.15	0.00	-0.48	0.00	-0.52	0.00	0.00	0.00	-0.96	0.03
Dashankou (lower reaches)	1.89	0.14	2.75	0.05	5.48	0.03	8.95	0.14	6.68	0.26

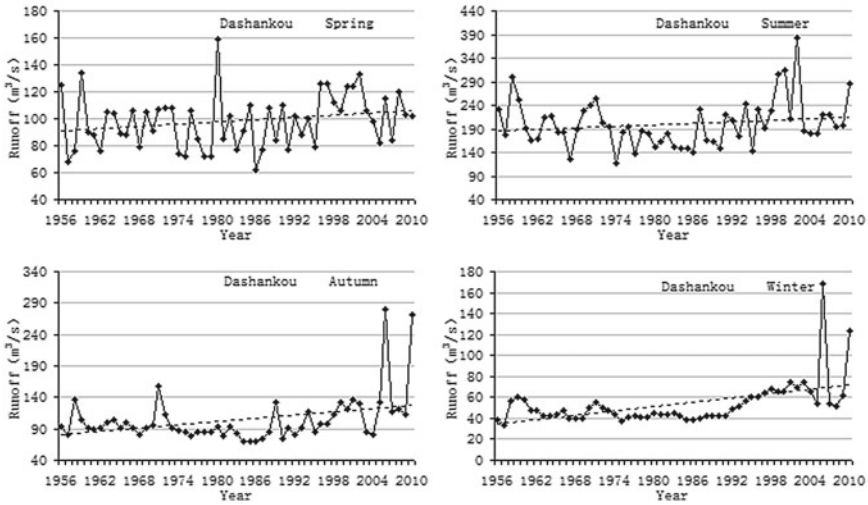


Fig. 17 Variation and trend of runoff in different seasons at the Dashankou station

with a little change during the period of 1956–1990 and an upward trend during the period of 1990–2000, and a large fluctuation during the period of 2000–2010.

5 Conclusions

This study demonstrated an increasing trend ($0.17\text{--}0.27\text{ }^\circ\text{C}/10\text{a}$) in air temperature during the period of 1960–2014 in the Yanqi Basin. However, there were some differences in the warming rate between seasons and over space. In general, warming was more pronounced in the areas of low elevation relative to high elevation; warming rate was much greater in autumn ($0.30\text{--}0.40\text{ }^\circ\text{C}/10\text{a}$) and winter ($0.29\text{--}0.45\text{ }^\circ\text{C}/10\text{a}$) than in spring ($0.13\text{--}0.26\text{ }^\circ\text{C}/10\text{a}$) and summer ($0.17\text{--}0.24\text{ }^\circ\text{C}/10\text{a}$). The greatest warming was observed since the mid-1990s.

There was large interannual to decadal variability in precipitation in the Yanqi Basin, which showed an overall small increasing trend over the period of 1960–2014. The lower reaches of the Kaidu River experienced a significant increase in runoff since the mid-1990s, which might be linked with the warming. Apparently, increasing temperature would lead to enhanced melting of snow and glacier in the surrounding mountains, resulting in more runoff in the Kaidu River.

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