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ORIGINAL PAPER

Runoff response to the glacier shrinkage in the Karatal river basin, Kazakhstan

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Abstract The fresh water lack in Central Asian countries with fast-growing population is one of the most critical problems in this region, where runoff of most rivers closely depends on supply of glaciers melting water. However, the impact of glacier shrinkage on the river runoff remains poorly understood. In this paper, we took the Karatal river basin, Tien Shan, as a model for investigation interrelation between dramatic decreasing of glaciers (−1 % annually) and river runoff. We investigated long-term observed climatic and runoff data for different sub-basins of the river, having various glaciated area and used non-parametric Mann-Kendall test for our analyses. Analyzing weather station climatic data, we found a significant increase in temperature and quite stable trends for precipitation during study period. Positive trends in annual discharge were detected in almost all glacierized tributaries of Karatal river. This obvious upward trend in river runoff is likely connected with a general trend of increasing temperatures and intensive melting of glaciers in Tien Shan.

Keywords Runoff · Climate change · Glacier shrinkage · Karatal river basin · Mann-Kendall test

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Introduction

Global climate has changed on both regional and global scales, with a mean increase in annual temperature of 0.74 from 1906 to 2005 and a predicted increase of 1.1 °C−6.4 by °C 2100 (Solomon et al. 2007). This increase in surface temperature has important consequences for the hydrological cycle, particularly in regions where water supply is provided mostly by melting ice or snow (Barnett et al. 2005). Even a low fraction of glacier covered within a basin has tremendous impact on hydrology (Jansson et al. 2003).

Glaciers play a crucial role in Central Asia's hydrological cycle (Viviroli et al. 2003; Kaser et al. 2010; Sorg et al. 2012). It has been demonstrated that even a basin whose glacier fraction is less than 5 % can provide a significant contribution from ice melt to summer runoff (Hagg et al. 2007). when water is most needed for irrigation (Sorg et al. 2012). The cryosphere is widely acknowledged to be an important water storage component in Central Asia contributing substantially to river runoff (e.g., Armstrong 2010). While the seasonal snow pack stores water mainly on the intra-annual timescale, glaciers store water for decades and centuries, thus partly compensating inter-annual fluctuations of precipitation and snowmelt contribution to river runoff (Unger-Shayesteh et al. 2013)

The difference between the glacierized and non-glacierized catchments is that the runoff derived from the non-glacierized catchment is precipitation-dominated while the glacierized catchment is energy-dominated (Chen and Ohmura 1990; Jansson et al. 2003; Chen 2014).

Only a limited number of studies currently address the timing and evolution of expected glacier shrinkage and related changes in runoff (Sorg et al. 2012). Although glacier changes of Mt Zhetysu Alatau (Eastern Tien Shan) in this region have been investigated (e.g., Cherkasov 2004; Severskiy et al. 2012; Vilesov et al. 2013), little is known about the whole

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variation characteristics of glaciers and glacier runoff in the KRB basin during recent decades. Runoff in a warmer climate will, at first, increase owing to higher temperatures and more meltwater. However, this effect is gradually reduced when the glacier area begins to decline as a result of continued glacier mass loss (Ye et al. 2003; Rango et al. 2007; Huss 2011). Runoff responses of glacierized catchments to glacier shrinkage show different results. For instance, the Small and Big Naryn basins showed contrasting flow trends in summer half-year (April-September) despite a comparable absolute glacier area loss since the 1970s (Kriegel et al. 2013). The trends of runoff of the rivers in Northwestern China have strong negative correlations with glacier coverage and the proportion of glacier water in runoff (Wang et al. 2013). In Switzerland, most basins with more than 10 % glacier cover have tended to exhibit increasing summer streamflow, while basins with less than 10 % glacier cover have exhibited negative trends (Birsan et al. 2005). Fleming and Clarke (2003) found similar contrasting trends in glacierized and unglacierized catchments in the western subarctic of Canada.

In this study, the glacier area shrinkage and the effects of dramatically decreasing glaciers on runoff for the sub-basins of Karatal river with different glaciation area are assessed. The three main parts of this study include detection of long-term trends of runoff, precipitation, and air temperature; estimation of glacier change; and assessment of the effects of glacier and climate changes on runoff.

Study area

The Karatal river basin (Fig. 1), which is the largest basin in Zhetysu Alatau, covers an area of 19,100 km^2, with a catchment area of 5300 km^2 (Kudekov 2002). The Karatal river originates on the northwestern slopes of the Zhetysu Alatau central ridge. It is formed by the confluence of the Kora, Chizhin, and Tekeli rivers (Vilesov et al. 2013). while further on the plain, it meets with its largest tributary, the Koksu river, to form a united stream ('GI' USSR 1980).

The Karatal river basin is located on the outer ranges of Zhetysu Alatau, where the elevations of the highest mountain ridges fluctuate between 3800 and 3850 m above sea level ('GI' USSR 1980). Most glaciers found here are small in size (less than 1 km^2). In addition, the Karatal basin is close to urban areas, which are located approximately 60 km from the lowest glaciers (Vilesov et al. 2013).

The climate of Zhetysu Alatau is formed by exchanges of air masses from arctic, temperate, and tropical areas. The arctic air masses flow from the north and northwest during winter, decreasing air temperature in this region. The temperate air masses are formed over western Siberia, Kazakhstan, and the Turanian Plateau, as well as over the Atlantic Ocean, which has the greatest impact on the Zhetysu Alatau climate during the entire year. The tropic air masses are formed in the air from the intensely heated Turanian Plateau; however, their incursions into the region during the summer season are very rare.

The mean annual air temperature is −5–7 °C in the high-altitude zone of Zhetysu Alatau; January is the coldest month, with −13–14 °C. The spatial distribution of precipitation is controlled by altitude and varies from 1000 to 1600 mm a^{-1}, with maximum amounts occurring at elevations of 1800–2200 m a.s.l. ('GI' USSR 1980).

Data and methods

Remotely sensed data and glacier delineation

Landsat TM and ETM+ images were used in glacier delineation. We applied a well-established semi-automated approach using the TM3/TM5 band ratio to produce glacier outlines (Paul et al. 2013). Misclassified areas, such as snow patches, cast shadows, and lakes, were corrected manually using false-color composite (TM bands 5, 4, and 3) on the Landsat imagery. All of the images were obtained for cloud-free conditions and for the ablation period when the extent of snow cover was minimal to reduce potential uncertainly in glacier boundary delineation due to seasonal snow cover. Changes in the extent of glaciers were assessed with regard to images from 1989, 2001, and 2012 and analyzed according to the surface area.

The repeated mapping of glacier samples with different surface areas using different types of imagery has shown that the error of estimation of individual glacier area was below 5 %. An assessment by Paul et al. (2003) shows that this accuracy allows one to achieve an error of less than 3 % for large (over 100) samples of glaciers. We mapped only glaciers that were larger than 0.01 km^2, as a smaller threshold would include many features that were, most likely, snow patches. Where a glacier had split into several fragments, the net area change in a studied period was based on the total area of the individual fragments.

For more detailed analyses of the glacier changes and their impact on river runoff, we subdivided the Karatal river basin into four sub-regions (Koktal, Koksu, Chizhin, and Kora) according to landscape differences and river basins (Fig. 1). Results of glacier areas obtained for each sub-basin were compared with the same glacierized areas defined in the first glacier inventory for 1956. Information about the glacier characteristics from the first glacier inventory was available only as tables and schematic maps. Glaciers smaller than 0.1 km^2 were treated as bulk samples in the Catalogue of Glaciers, without information about their locations. We did not include these small-sized glaciers for our calculation of the total glacierized area and showed them separately for all study regions.

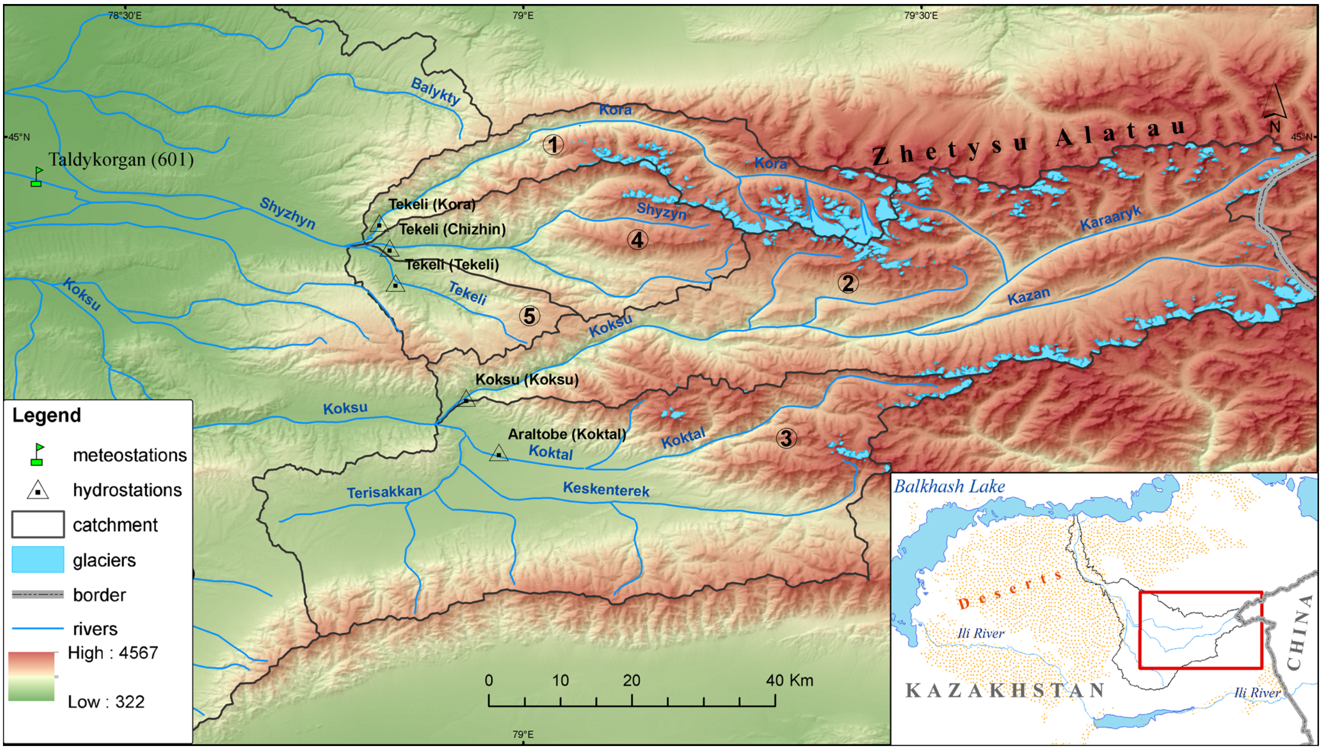

Fig. 1 Location of the study area; map based on SRTM3-DEM; sub-basins with glacier: *1*—Kora; *2*—Koksu; *3*—Koktal; *4*—Chizhin; *5*—Tekeli; Weather station—Taldykorgan (air temperature, precipitation)

Hydrometeorological data and trend analysis

In order to determine and analyze the potential drivers of glacier changes and investigate the changes in river runoff over the past decades, a trend analysis using the Mann-Kendall test (Kendall 1975) was carried out for the time series of air temperature, precipitation, and runoff at selected climate and hydrological stations. For more detailed analyses of the impact of dramatically decreasing glacier to the runoff variation, we used hydrological data from four stations for each glacierized sub-basin (Kora, Koksu, Koktal, and Chizhin) and one station from non-glacierized catchment Tekeli (see Fig. 1, Table 1).

We acquired data from the Taldykorgan weather station, which was the closest weather station available to our study area. This station is situated in the foothills and provided long-term temperature and precipitation records since 1960. The accumulative deviation test was applied to detect trends in air temperature at the Taldykorgan weather station. Test results showed that the temperature had step change point occurrence in 1977. Therefore, the data series was divided into two periods before and after 1977. Both periods included data series of more than 20 years, which is acceptable for the nonparametric Mann-Kendall test. The multi-temporal trend analysis by Stojković et al. (2014) has shown that the trend direction and magnitude depend on the length of time series and the position of the sub-series within the whole series. Therefore, the conclusions about the trend significance can be quite different depending on the period covered in the analysis. It has also been shown that the long-term periodicity affects the direction and the intensity of the trend (Stojković et al. 2014).

The rank-based nonparametric Mann-Kendall test is commonly used to assess the significance of monotonic trends in hydrometeorological time series (e.g., Hirsch and Slack 1984;

Table 1 Characteristics of sub-basins with discharge records available

River	Gauging station	Basin area (km^2)	Elevation of station (m)	Glacierisation in 1956 (%)	Length of discharge record	Mean runoff (m^3/s)
Kora	Tekeli	484	1030	14	1940–2013	14.1
Koksu	Koksu	1590	1260	7	1955–2013	39.2
Koktal	Araltobe	293	2020	5	1946–2013	9.3
Chizhin	Tekeli	479	1060	2	1929–2006	11.6
Tekeli	Tekeli	193	1100	0	1940-2012	2.2

Gan 1998; Xu et al. 2010; Wang et al. 2013; Yao et al. 2014). In this test, the standard normal statistic Z is estimated and compared with the standard normal deviate $Z_{\alpha/2}$. The test statistic Z is not statistically significant if $-Z_{\alpha/2}<Z<Z_{\alpha/2}$. Correspondingly, this test shows a statistically significant trend if $Z<-Z_{\alpha/2}$ or $Z_{\alpha/2}<Z$ (Gan 1998). The confidence levels fixed at $\alpha=0.95$ and critical z values for two-sided test are −1.96 and +1.96. The standard normal statistic Z is estimated by the following formula as (Hirsch and Slack 1984; Gan 1998)

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0 & , S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases} \quad (1)$$

where

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \operatorname{sgn}(x_k - x_i) \quad (2)$$

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & , \theta > 0 \\ 0 & , \theta = 0 \\ -1, & \theta < 0 \end{cases} \quad (3)$$

$$\operatorname{var}[S] = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right] \Big/ 18 \quad (4)$$

in which the x_k and x_j are the sequential data values, n is the length of the data set, and t is the extent of any given time. The magnitude of the trend is given as

$$\beta = \operatorname{Median}\left(\frac{x_i - x_j}{i - j} \right) \quad , \forall j < i \quad (5)$$

in which $1<j<i<n$. A positive value of β indicates an "upward trend," and a negative value of β indicates a "downward trend."

In addition, the relationship between hydrological and meteorological variables was explored by using Pearson's correlation coefficient. The correlations calculated were tested for statistical validity at the 95 % significance level.

Results

Changes in temperature and precipitation

Annual mean temperature and total precipitation over the 47-year period of 1960–2007 were analyzed from the Taldykorgan weather station, situated close to the study area (Fig. 1). The linear trend analysis of mean temperature indicated that the average rate of temperature increase was 0.43 °C $(10a)^{-1}$, while the summer (JJA) temperature rose 0.28 °C $(10a)^{-1}$ (Fig. 2). From 1960 to 2007, records at the same station displayed a slight decrease in annual precipitation. The results of Mann-Kendall test applied to annual and seasonal data series showed statistically significant trends during the period 1960–2007. Trends in summer and autumn seasons were higher than those in winter and spring. Monthly highest positive trend was for August, September, and October months (Table 2).

Changes in glacier area

We identified 243 glaciers in 1989, 226 in 2001, and 214 in 2012 that were listed in the Catalogue of Glaciers with total areas of 142.8, 122.2, and 109.3 km^2, respectively. Thus, the summarized area change for the period 1956–1989, based on our defined mountain regions, was equal to −28 %, area change for 1989–2001 was −14 %, and area change for 2001–2012 was −11 %; for the whole period, the total glacierized area decreased from 285 glaciers with a total area of 199.2 km^2 in 1956 to 214 glaciers with a total area of 109.3 km^2 in 2012, which resulted in shrinkage of 45 % during the last 56 years (Table 3). During our study period, 71 glaciers listed in the Catalogue of Glaciers and 39 small glaciers not listed were not found again. All of the glaciers decreased continuously, both in area and in length, throughout all of the periods of the study. Our results indicated that glacier area loss in the Karatal river basin reached −23 %, or −1.02 % per year, for 1989–2012. The Kora sub-basin had the largest glaciers, with a mean size of 0.873 km^2, while the smallest glaciers were located in the Koktal sub-basin, with a mean size of 0.403 km^2 (Table 3). Koktal had the highest rate of shrinkage, reaching 39 % from 1989 to 2012. The decreasing number rate was significantly higher (more than −40 %) for the Koktal and Chizhin glacierized areas during the studied period.

Trends of runoff

Trends in monthly and annual runoff for the sub-basins of Karatal river were analyzed. Discharge trend analysis was calculated for three periods: full observed time and for periods before and after 1977 (step change year) for each hydrological station. Annual runoff of the almost all sub-basins showed increasing trend for annual, melting, and frozen seasons for the entire observed time (see Table 4(A)). Increasing discharge trend was statistically significant in more glacierized catchments (Kora, Koksu, and Koktal). Trends of runoff for the melting season were similar to those in the annual cycle. However, runoff for the frozen season exhibited higher changes during entire observed time for all sub-basins, but the absolute changes remained small. Less glacierized (Chizhin) and non-glacierized sub-basins (Tekeli) show lower increasing trend in the melting season and annual time.

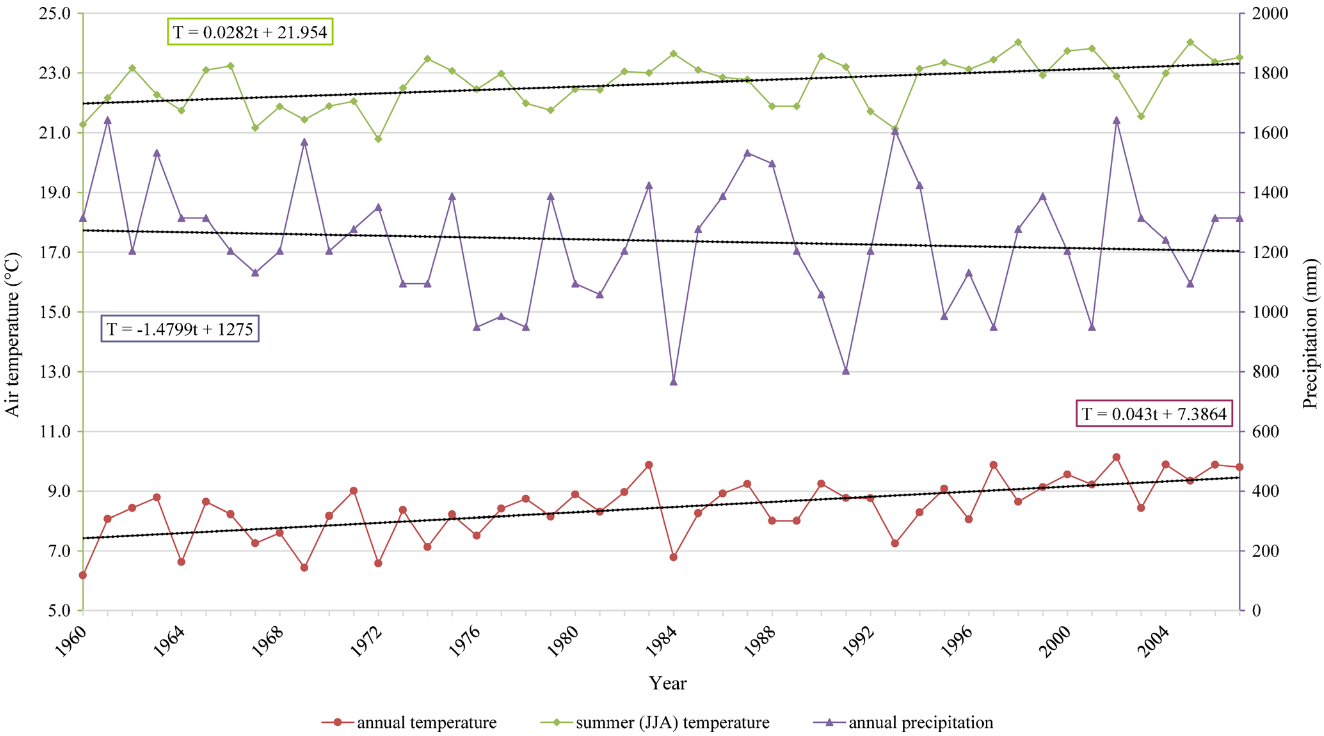

Fig. 2 Annual and summer (JJA) temperature and annual precipitation of Taldykorgan station (Kaldybayev et al. 2016)

The discharge trend for the first period, before step change year (1977), showed slightly negative trend in annual and melting cycle. Positive trend was only for two stations, Chizhin and Tekeli. Neither positive nor negative trend was statistically significant during the first period for annual and melting cycles. However, trend for cold months and frozen season was different. Discharge trend was increased in Koktal and decreased in Chizhin, and both trends were statistically significant (Table 4(B)).

Runoff data for the second period (after 1977) indicated trends that are more positive. In the Koksu sub-basin, where the most glaciers were located (108.6 km^2 in 1956), trend analysis exhibited statistically significant increasing for melting, frozen, and annual cycles. Three sub-basins, which were more glacierized, showed the slight increasing trend, while less glacierized had small decreasing trend during the melting season (Table 4(C)).

Surprisingly, the runoff trend in the Kora sub-basin showed the decreasing trend for July, August, and September months, in spite of relatively intensive glaciation (14 %) and statistically significant increasing temperature in these months. Detailed analysis of year-to-year variation of runoff from this station showed the anomaly increasing discharge for the 1988–2000 period. Mean discharge for this month during 1988–2000 was two times higher than mean level during 1940–2014. This is the anomaly impact to the trend analysis for the second period. Thus, despite the fact that there is a statistically significant positive trend during 1940–2014 for annual and melting

Table 2 Area changes of glaciers

Region	Glacier area (km^2)/number				Area change (%)/annual rate (%)					Mean size (km^2) in 1989
	1956	1989	2001	2012	1956–1989	1989–2001	2001–2012	1956–2012	1989–2012	
Koktal	14.1/36	8.4/21	6.5/21	5.1/17	−40/−1.22	−23/−1.96	−20/−1.8	−63/−1.13	−39/−1.68	0.403
Koksu	108.6/167	75.3/149	64.1/140	56.1/135	−31/−0.93	−15/−1.24	−13/−1.14	−48/−0.86	−26/−1.11	0.506
Chizhin	8.7/19	4.9/11	4.2/10	3.8/10	−44/−1.32	−15/−1.24	−9/−0.79	−56/−1.0	−22/−0.97	0.445
Kora	67.8/66	54.1/62	47.5/55	44.2/52	−28/−0.61	−14/−1.03	−7/−0.63	−35/−0.62	−18/−0.80	0.873
Total	199.2/285	142.8/243	122.2/226	109.3/214	−28/−0.86	−14/−1.20	−11/−0.96	−45/−0.81	−23/−1.02	0.588
Glaciers <0.1 in 1956	3.6/73	2.36/77	0.76/39	0.59/34	−34/−1.04	−68/−5.63	−22/−1.99	−83/−1.49	−75/−3.25	0.031

Table 3 Kendall test *Z* statistics for trends of monthly, annual, and seasonal temperature and for annual precipitation of Taldykorgan station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann T	Winter	Spring	Summer	Autumn	Ann P
Test *Z*	1.00	*2.46*	1.52	*2.32*	1.25	*2.84*	*2.37*	*3.14*	*3.24*	*3.03*	1.75	0.84	*4.51*	*2.27*	*2.00*	*3.49*	*3.65*	−0.60

Statistically significant trends are indicated in italics. Significant at $P < 0.05$. Critical value of $Z < -1.96$ and $> +1.96$ (two-sided)

season, trend for those was negative and positive during 1940–1977 and 1978–2014, respectively. This high runoff phenomenon during 1988–2000 might be technical mistakes during observation in the station or human factor impact. Neighboring sub-basins showed the quite stable trend during this period.

Discussion

The Pearson's correlation coefficient values (Table 5) show that the runoff of the lower glacierized sub-basins, such as Tekeli, Chizhin, and Koktal, has a strong and significant correlation with the precipitation. For the temperature, the correlations are much weaker and less significant, even for, comparatively, the most glacierized Kora.

Annual mean temperature and total precipitation over the 47-year period (1960–2007) were analyzed from the Taldykorgan weather station, situated close to the study area (Fig. 1). The linear trend analysis of mean temperature indicated that the average rate of temperature increase was 0.43 °C $(10a)^{-1}$, while the summer (JJA) temperature rose 0.28 °C $(10a)^{-1}$ (Fig. 2). From 1960 to 2007, records at the same station displayed a slight decrease in annual precipitation. Increasing temperature leads to (1) increasing energy available for ice and snow melt, (2) decreasing snow accumulation, and (3) lower albedo of the glacier surface (Ageta and Kadota 1992; Fujita and Ageta 2000; Wang et al. 2014, Kaldybayev et al. 2016). The temperature increase caused the rainfall rate to increase, rather than snowfall in the high-altitude glacierized areas, leading to a reduction of accumulation and the acceleration of ablation, especially during the summer (Chaulagai 2003). Due to that annual temperature significant increased between 1960 and 2007 and annual precipitation had stable trend, that not compensated rising temperature, led to intensive glacier melt.

The area changes of the glaciers investigated in the Karatal river basin confirmed an expected and widely published trend of glacier retreat (Unger-Shayesteh et al. 2013; Sorg et al. 2012). However, our results for this region indicated the highest shrinkage rate for the period of 1989–2012 compared to other glacierized areas of Central Asia, including all parts of

Table 4 Kendall test *Z* statistics for trends of monthly, annual, and seasonal runoff for the sub-basins of Karatal river

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Melt	Frozen
A.															
Kora	*4.28*	*4.11*	*4.50*	*2.60*	*2.73*	*3.12*	1.68	0.90	*2.89*	*3.06*	*3.49*	*4.21*	*3.32*	*2.97*	*4.96*
Koksu	*4.49*	*4.23*	*4.01*	*3.36*	*3.52*	1.15	1.45	1.92	*4.43*	*4.85*	*4.96*	*4.29*	*2.38*	*2.21*	*4.55*
Terisakkan	*4.9*	*5.07*	*5.27*	*3.64*	1.32	1.11	0.54	0.5	1.86	*2.83*	*3.14*	*4.17*	*2.31*	1.39	*5.38*
Chyzhyn	−1.91	−1.62	−0.72	*2.16*	0.52	−0.69	−1.08	−0.49	0.69	−0.7	0	−1.23	−0.43	−0.59	0.94
Tekeli	*2.33*	*2.12*	1.53	0.44	*−2.03*	−0.21	0.98	1.22	*2.88*	*2.26*	*2.5*	*2.8*	0.86	0.28	*2.94*
B.															
Kora	0.86	0.86	0.81	0.07	−0.72	0.07	−0.13	−1.56	−0.18	0.20	0.47	0.44	−0.33	−0.33	0.67
Koksu	−1.66	−0.82	0.56	0.39	0.17	−0.03	−0.37	−1.45	−1.59	−1.93	−1.16	*−2.22*	−0.58	−0.05	−0.85
Terisakkan	*4.51*	*3.92*	*3.6*	*2.71*	1.52	1.33	0.47	0.54	1.17	2.7	*4.08*	*4.31*	*2.03*	1.66	*4.73*
Chyzhyn	*−4.44*	*−4.31*	*−2.84*	0.08	−0.07	−0.44	−1.18	−1.6	−1.43	−2.32	−2.01	−2.68	−1.17	−1.28	−2.61
Tekeli	*−2.21*	*−2.03*	0.32	1.44	−0.23	−1.11	−1.19	−0.99	−1.28	−1.94	−1.7	−2.19	−0.7	−0.62	0.21
C.															
Kora	1.63	1.67	1.95	1.08	1.78	1.22	−0.63	−0.77	0.06	0.73	0.64	0.91	0.77	0.61	*2.08*
Koksu	*4.56*	*4.07*	*5.03*	*4.51*	*3.87*	*2.28*	*2.28*	*3.83*	*5.5*	*5.15*	*4.81*	*3.91*	*3.01*	*2.79*	*5.38*
Terisakkan	*2.82*	*3.66*	*3.92*	*2.81*	0.03	−0.79	−0.24	1.54	*2.39*	*2.37*	*2.27*	*2.51*	1.12	0.11	*3.92*
Chyzhyn	−0.33	0.45	1.78	0.39	−0.57	−1.17	−1.33	0	0.99	−0.79	0	−0.79	−0.51	−0.56	0.73
Tekeli	0.87	0.99	1.85	0.74	*−2.61*	−0.37	1.28	1.52	*2.24*	*1.98*	*2.34*	1.52	1	−0.02	*2.52*

(A) for entire period and (B) and (C) for the periods before and after the 1977 (step change) year, respectively. Statistically significant trends are indicated in italics. Significant at $P < 0.05$. Critical value of $Z < -1.96$ and $> +1.96$ (two-sided)

Table 5 The correlation coefficients between the annual temperature precipitation and the runoff

	Kora	Koksu	Koktal	Chizhin	Tekeli
Temp.	−0.05	0.15	−0.17	−0.06	−0.15
Prec.	0.00	0.12	*0.27*	*0.33*	*0.47*

Statistically significant trends are indicated in italics. Significant at $P < 0.05$

Tien Shan and Pamir (Vilesov and Morozova 2005; Bolch 2007; Aizen et al. 2007; Kutuzov and Shahgedanova 2009; Khromova et al. 2006; Kriegel et al. 2013).

Despite the detected glacier area loss, there was no significant positive trend in mean summer month discharge (JJA) observed for the all sub-basins that would be expected from the enhanced glacier melt. These results suggested that the increasing glacier melt and retreat do not positively affect the discharge in summer months (JJA). The absence of significant positive trends in these time discharges can be explained by the low glacierized catchments (less than 15 %). In addition, the evapotranspiration has negative effect on river runoff, but their roles are limited. Kriegel et al. (2013). who estimated changes in potential evaporation based on the empirical approach of Thornthwaite (1948). which solely relies on temperature, suggest that evaporation changes are insignificant during the ablation season, mainly due to small changes in air temperature. However, due to increasing trend in spring and autumn months, trend showed statistically significant positive increasing for the melting and annual cycle in glacierized catchments. The effect on runoff changes was different in glacierized sub-basins of Karatal river. Relatively highest glacierized Kora (14 % glaciation) showed highest positive trend, while smaller glacierized Koktal (5 %) demonstrated smaller trend, with the statistically significant magnitude of 3.32 and 2.31, respectively. In the catchment with only 2 % glaciation (Chizhin), trend was even negative with magnitude of −0.43. Apparently, the tipping point (peak water) for this catchment might be already passed (Sorg et al. 2014). The tipping point is a phenomenon when runoff during warming climate will, at first, increase owing to higher temperatures and more meltwater, while this effect is gradually reduced when the glacier area begins to decline as a result of continued glacier mass loss (Ye et al. 2003; Rango et al. 2007; Huss 2011). Tekeli sub-basin without glacier showed slight increasing trend, but absolute water volume of rising trend was very small. Based on runoff trend analysis, runoff in sub-catchments was controlled by temperature, provoking the glacier melting stored for previous decades and centuries.

Conclusions

Our results, with the shrinkage rate of about −0.8 to −1 % per year for the periods of 1956–1989 and 1989–2012 for this study area, showed a highest decreasing rate compared to other glacierized areas of Central Asian mountains, including Altai, Tien Shan, and Pamir. Climatic condition plays a basic role on glacier status. Two main climatic factors, statistically significant temperature increasing and precipitation slight decreasing, played the main cause in the glacierized area loss in the Karatal river basin.

River runoff demonstrated a significant increasing trend during the last half century at the expense of glaciers' melting intensification against a background of slight decreasing precipitation in the same time.

Even small glacierized areas (5–14 % of total basin) had significant impact on the river runoff fluctuations in condition of global temperature increasing.

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