Hydrochemical Characteristics and Controlling Factors of Glacier-Fed and Non-Glacier-Fed Runoff in the Kartamak Glacier, Muztagh Ata: A Postprint Study

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Abstract

From July to August 2016, sampling and analysis were conducted on glacier-fed and non-glacier-fed streams in the Kartamak Glacier region of Muztagh Ata. Hydrochemical characteristics and their controlling factors in glacier-fed and non-glacier-fed streams were analyzed using statistical analysis, principal component analysis, Piper diagrams, Gibbs diagrams, and forward modeling. The results indicate that both water types are alkaline with a hydrochemical classification of Ca2+ - SO42- - HCO3-. However, significant differences ($p<0.05$) were observed in pH, EC, and TDS between glacier-fed and non-glacier-fed streams, with extremely significant differences ($p<0.01$) among major ion concentrations. All ions in glacier-fed streams share a common origin, whereas NO3- in non-glacier-fed streams exhibits a distinct source compared to other ions. Forward modeling results demonstrate that the contribution rates of atmospheric input, silicate weathering, carbonate weathering, and evaporite dissolution to ion concentrations in glacier-fed and non-glacier-fed streams are 10.47%, 0.55%, 65.61%, 23.37% and 1.52%, 19.57%, 60.37%, 18.54%, respectively. In glacier-fed streams, carbonate weathering dominates the ionic contribution, with evaporite dissolution playing a secondary role; in non-glacier-fed streams, carbonate weathering also predominates, while silicate weathering assumes secondary importance. This difference arises because silicate weathering proceeds more slowly than evaporite dissolution, and the shorter water-rock interaction time in glacier-fed streams results in lower silicate weathering contributions; conversely, non-glacier-fed streams undergo more extensive water-rock interactions, leading to higher silicate weathering contributions. The findings of this study can provide references for water resource management applications in western regions.

Full Text

Hydrochemical Characteristics and Controlling Factors of Glacierized and Non-glacier Runoff in the Kaltamak Glacier Area, Muztagata Mountain

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Abstract

Water samples from both glacier runoff and non-glacier runoff in the Kaltamak Glacier area were collected during July to August 2016. Statistical analysis, principal component analysis, Piper diagrams, Gibbs diagrams, and forward modeling were subsequently conducted to analyze the hydrochemical characteristics and identify the major ion sources of the two runoff types. Results showed that both water types were alkaline, with hydrochemical types of Ca^{2}-HCO . However, pH, EC, TDS, and major ions showed significant differences, with non-glacier runoff consistently exhibiting higher values than glacier runoff. All ions showed similar sources in glacier runoff, while NO showed different sources in non-glacier runoff compared to other ions. Forward modeling results indicated that the contributions of atmospheric input, silicate weathering, carbonate weathering, and evaporite dissolution to ion concentrations were 10.47%, 0.55%, 65.61%, and 23.37% for glacier runoff, and 1.52%, 19.57%, 60.37%, and 18.54% for non-glacier runoff, respectively. The ion concentrations in glacier runoff were mainly affected by carbonate weathering, followed by evaporite dissolution; whereas non-glacier runoff was primarily influenced by carbonate weathering, followed by silicate weathering. The difference arises because silicate weathering proceeds more slowly than evaporite dissolution. The water-rock interaction time was shorter in glacier runoff, resulting in lower silicate weathering contributions, while the longer interaction time in non-glacier runoff led to higher silicate weathering contributions. This study provides guidelines for water resource management in western China.

Keywords: Glacierized catchment; non-glacier catchment; hydrochemical characteristics; controlling factors; Muztagata

1. Introduction

Glaciers are important components of the cryosphere and serve as crucial water resources in arid regions [?]. Under global warming, accelerated glacier melting has significantly altered the hydrological processes and water chemistry in glacierized catchments [?]. Previous studies have shown that glacier meltwater chemistry is influenced by multiple factors, including weathering processes, atmospheric deposition, and water-rock interaction time [?]. The hydrochemical characteristics of glacier runoff differ markedly from those of non-glacier runoff due to differences in flow paths and contact time with bedrock [?].

Research on glacier hydrochemistry has primarily focused on the Himalayas, Tianshan, and other high mountain regions [?]. For example, studies on the Urumqi Glacier No. 1 in the Tianshan Mountains revealed that carbonate weathering dominates the hydrochemical composition of meltwater [?]. However, comparative studies between glacierized and non-glacier runoff in the Muztagata region remain limited. Understanding these differences is essential for water resource management in western China, where glacier meltwater constitutes a significant portion of river discharge [?].

2. Materials and Methods

2.1 Study Area The Kaltamak Glacier (38°17’ N, 75°03’ E) is located on the northern slope of Muztagata Mountain in the western Kunlun Range. The glacier covers an area of approximately 12 km^2, with an elevation range from 4,200 to 5,500 m a.s.l. The region experiences a continental climate, with mean annual precipitation of 149.0 mm, mean annual temperature of 0.4°C, and mean wind speed of 3.6 $m \cdot s^{1}$ during the study period (2010-2015).

2.2 Sample Collection and Analysis Water samples were collected from both glacier runoff and non-glacier runoff during July-August 2016. Sampling was conducted daily from 13:00 to 21:00 local time. A total of 24-hour continuous sampling was performed from August 3, 11:00 to August 4, 10:00 to capture diurnal variations.

Physical parameters including pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured in situ using a portable multi-parameter meter. Major ion concentrations (Ca^{2} , Mg^{2} , Na , K , HCO , SO^{2} , Cl , NO) were determined in the laboratory using ion chromatography. Statistical significance was tested at $p < 0.05$ and $p < 0.01$ levels.

3. Results

3.1 Comparison of Basic Hydrochemical Parameters The mean pH values of glacier runoff and non-glacier runoff were 9.10 ± 0.34 and 9.30 ± 0.11, respectively, indicating alkaline conditions for both water types. EC and TDS values showed significant differences ($p < 0.05$), with non-glacier runoff exhibiting higher values (334 ± 55 S · cm ^{1} and 169 ± 27 mg · L ^{1}) compared to glacier runoff (64 ± 21 S · cm ^{1} and 32 ± 10 mg · L ^{1}) .

3.2 Major Ion Composition The major ion composition differed significantly between the two runoff types . Non-glacier runoff showed substantially higher concentrations of all major ions compared to glacier runoff. The dominant cations in both water types were Ca^{2} and Mg^{2} , while HCO and SO^{2} were the dominant anions. The mean Ca^{2} concentration in non-glacier runoff (58.47 mg · L ^{1}) was nearly five times that in glacier runoff (12.41 mg · L ^{1}). Similarly, SO^{2} concentration in non-glacier runoff (153.22 mg · L ^{1}) was significantly higher than in glacier runoff (34.17 mg · L ^{1}).

3.3 Hydrochemical Facies Piper diagram analysis revealed that both water types fell in the Ca^{2}-HCO hydrochemical facies [Figure 2: see original paper]. However, non-glacier runoff samples plotted closer to the Mg^{2} and SO^{2} apexes, indicating greater influence from these ions. The distribution pattern suggests that carbonate weathering dominates the hydrochemistry of both runoff types, with additional contributions from sulfate sources in non-glacier runoff.

3.4 Gibbs Diagram Analysis Gibbs diagrams showed that both runoff types were primarily controlled by rock weathering processes rather than atmospheric precipitation or evaporation [Figure 6: see original paper]. Glacier runoff plotted closer to the atmospheric precipitation domain, suggesting a relatively higher contribution from atmospheric input compared to non-glacier runoff.

3.5 Relationship Between Ions and Discharge The relationship between major ion concentrations and discharge showed dilution effects during high flow periods for both runoff types [FIGURE:4, FIGURE:5]. In glacier runoff, ion concentrations decreased with increasing discharge, indicating flushing of weathering products during melt events. Non-glacier runoff showed a similar but less pronounced pattern, suggesting more stable baseflow contributions.

4. Discussion

4.1 Controlling Factors of Hydrochemistry Forward modeling results indicated that carbonate weathering was the dominant process controlling ion concentrations in both runoff types, contributing 65.61% to glacier runoff and 60.37% to non-glacier runoff . However, the relative importance of other processes differed significantly between the two runoff types.

For glacier runoff, evaporite dissolution contributed 23.37%, atmospheric input contributed 10.47%, and silicate weathering contributed only 0.55%. The low silicate weathering contribution reflects the short water-rock interaction time in glacier runoff, which typically flows through channels with limited contact with silicate minerals.

In contrast, non-glacier runoff showed a substantially higher silicate weathering contribution (19.57%) and lower evaporite dissolution (18.54%) and atmospheric input (1.52%). The longer residence time and slower flow paths in non-glacier runoff allow for more extensive silicate weathering.

4.2 Nitrate Sources NO showed different source characteristics compared to other ions. In glacier runoff, NO concentrations were low and primarily derived from atmospheric deposition. In non-glacier runoff, higher NO concentrations suggest additional sources such as soil organic matter decomposition and anthropogenic inputs, though the remote location minimizes direct human impact.

4.3 Water-Rock Interaction Time The fundamental difference between the two runoff types lies in water-rock interaction time. Glacier runoff has rapid flow paths with short contact time, favoring rapid dissolution of more soluble minerals (carbonates and evaporites) while limiting silicate weathering. Non-glacier runoff, with longer residence times and subsurface flow components, allows for more complete weathering of silicate minerals.

5. Conclusions

This study demonstrates significant hydrochemical differences between glacier and non-glacier runoff in the Kaltamak Glacier area. While both are alkaline Ca^{2}-HCO type waters, non-glacier runoff shows higher ion concentrations across all parameters. Carbonate weathering dominates both systems, but silicate weathering plays a more important role in non-glacier runoff due to longer water-rock interaction times. These findings highlight the importance of considering runoff sources when assessing water quality and managing water resources in glacierized regions of western China.

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