Analysis of Precipitation Characteristics of Alluvial Fans on the Northern and Southern Sides of the Kumtag Desert Based on Observational Data: Postprint

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Abstract

Based on field-measured precipitation data from June 2017 to May 2018 for the alluvial fans on the northern and southern sides of the Kumtag Desert, a detailed analysis of its precipitation characteristics was conducted. The results indicate: (1) Influenced by geographical location, topography, and other factors, the spatial distribution of precipitation in the Kumtag Desert shows considerable variation. The Sanlongsha area on the northern Beishan alluvial fan has the minimum annual precipitation of 21.6 mm; the Altun Mountain alluvial fan on the southern side exhibits a gradual increase in precipitation from west to east, with annual precipitation at Huyanggou upstream, Wushikate, Saimagou, and Duobagou being 73.0, 75.2, 176.0 mm, and 137.4 mm, respectively; the Altun Mountain alluvial fan on the southern side also shows a general increase in precipitation from north to south, with annual precipitation at Huyanggou downstream and midstream being 58.0 mm and 56.4 mm, respectively, which is less than that at Huyanggou upstream. (2) Precipitation on the alluvial fans on the northern and southern sides of the Kumtag Desert occurs mainly from May to August, with cumulative precipitation accounting for approximately 90% of the annual total. (3) The annual number of precipitation events on the alluvial fans on the northern and southern sides of the Kumtag Desert ranges from 11 to 26, with a small number of heavy precipitation events contributing significantly to the annual total precipitation.

Full Text

Analysis of Precipitation Characteristics in Alluvial Fans on the North and South Sides of the Kumtag Desert Based on Measured Data

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Abstract

This study analyzed precipitation characteristics in detail using field-measured precipitation data from alluvial fans on the north and south sides of the Kumtag Desert from June 2017 to May 2018. The results show: (1) Due to influences of geographical location and topography, the spatial distribution of precipitation in the Kumtag Desert varies significantly. The minimum annual precipitation occurs at Sanlongsha in the Beishan alluvial fan on the north side, at 21.6 mm. In the Altun Mountains alluvial fan on the south side, precipitation gradually increases from west to east, with annual precipitation at the upper reaches of Huyang Gully, Wushikate, Saimagou, and Duobagou being 73.0 mm, 75.2 mm, 176.0 mm, and 137.4 mm, respectively. Precipitation in the Altun Mountains alluvial fan also increases gradually from north to south, with annual precipitation at the lower and middle reaches of Huyang Gully being 58.0 mm and 56.4 mm, respectively—both lower than that at the upper reach. (2) Precipitation in the alluvial fans on both north and south sides occurs mainly from May to August, with cumulative precipitation accounting for more than 90% of the annual total. (3) The number of annual precipitation events ranges from 11 to 26, with a small number of large precipitation events contributing substantially to the total annual precipitation.

Keywords: Kumtag Desert; precipitation; alluvial fan

1. Introduction

Precipitation is a primary component of the water cycle and serves as a direct or indirect source of water replenishment for various water bodies on Earth, playing a crucial role in maintaining ecosystem structure and function [1]. Influenced by geographical location, atmospheric circulation, weather systems, and underlying surface conditions, spatial and temporal variations in precipitation lead to differentiation in land surface processes. Moreover, the spatial heterogeneity and temporal instability of precipitation are direct causes of floods, waterlogging, and drought disasters. In arid regions, water is the most limiting factor for ecosystem functioning, and many key ecological processes are strongly affected by water availability [2].

Surface and subsurface runoff in the Kumtag Desert originates from mountain precipitation and meltwater from snow and ice [3], with flow rates closely related to seasonal precipitation distribution, precipitation amount, and precipitation intensity [4]. The Kumtag Desert is one of China' s eight major deserts but has the weakest research foundation. Most areas are inaccessible and inconvenient for transportation, and systematic observations of meteorology and hydrology were very scarce before 2007 [5]. In recent years, as Chinese scholars have conducted increasingly comprehensive scientific expeditions to the Kumtag Desert, substantial investigations have been carried out on its formation and evolution, aeolian geomorphology development, regional water systems, soils, flora and fauna, laying a foundation for deeper understanding of the desert' s formation, environmental changes, and ecological processes [6].

Although previous studies have revealed precipitation characteristics of the Kumtag Desert to some extent, they were based either on peripheral meteorological stations or on fused datasets. The alluvial fan areas of the Altun Mountains and Beishan in the Kumtag Desert lack measured precipitation data, which substantially reduces the accuracy of precipitation analysis for these study areas. Precipitation is strongly affected by topography, and the alluvial fan areas of the Altun Mountains and Beishan are far from adjacent national meteorological stations with significantly different underlying surface characteristics, making their precipitation patterns unique. The southern Altun Mountains alluvial fan and northern Beishan alluvial fan are not only sources of material for desert formation, necessary pathways for mountain rivers flowing into the basin, and important habitats for regional flora and fauna, but also constitute significant land resources for regional economic development. Constrained by harsh natural conditions, these areas lack systematic measured precipitation data.

This study addresses this gap by presenting detailed analysis of precipitation characteristics based on one year of field measurements from the southern Altun Mountains alluvial fan and northern Beishan alluvial fan, providing important baseline data for research on climate change, ecological conservation, hydrological assessment, and geomorphological evolution in the Kumtag Desert region.

2. Methods

2.1 Study Area

The Kumtag Desert is located at the eastern end of the Tarim Basin, with geographical coordinates of 39°00 -40°47 N, 90°27 -94°48 E. It extends approximately 120 km from east to west and 90 km from north to south, covering an area of 2.28$×10^{4}$ km^2, making it China's sixth largest desert [Figure 1: see original paper]. The desert developed on extensive alluvial and proluvial fans between the Altun Mountains and Beishan, shaped like a "broom" or "feather fan." North-south oriented deeply incised gullies have developed from west to east, including Shashan Gully, Honggou, Shanshuigou, Donggou, and Xitugou, among which 7 have perennial flow while others are seasonal dry channels for flood discharge [7].

The northwestern part of the Kumtag Desert is Lop Nur, while the eastern part includes Xihu Wetland and dry downstream channels of the Shule and Dang rivers. Weathering products of exposed rock fragments on alluvial fans, fluvial (flood) deposits, and lacustrine deposits from Lop Nur have all provided abundant sand sources for desert development [8]. Situated deep inland far from oceans, the desert is difficult for moist air masses to reach, resulting in an extremely arid climate—one of China' s driest deserts, with some years receiving less than 20 mm of precipitation in surrounding areas.

2.2 Data Collection

Based on preliminary surveys of regional landforms and vegetation, we established that the Altun Mountains alluvial fan, Beishan alluvial fan, and interior of the Altun Mountains alluvial fan show significant differences, likely caused by precipitation variations. We therefore established field observation stations for precipitation measurement. Considering north-south precipitation gradients in the Altun Mountains alluvial fan, we established a north-south observation transect at the upper, middle, and lower reaches of Huyang Gully. Considering east-west precipitation gradients, we established an east-west observation transect at the upper reach of Huyang Gully, Wushikate, Saimagou, and Duobagou. Precipitation in the Beishan alluvial fan is extremely scarce, so we established only one observation point at Sanlongsha for comparison with the Altun Mountains alluvial fan.

Due to the remote nature of the study area, transportation difficulties, and protected area restrictions, station selection considered both scientific requirements and regulatory permissions, resulting in some suboptimal site placements. Precipitation observation equipment consisted of American HOBO Onset RG3-M tipping bucket rain gauges with integrated HOBO Pendant temperature loggers, powered by coin-cell lithium batteries capable of independent operation. The rain gauge collectors included memory capable of storing 16,000 data groups. A data interface on top of the instrument facilitated data download. The rain gauges were installed at a height of approximately 1.2 m.

A precipitation event was defined as precipitation $ $0.2 mm with an interval between events $ $60 minutes [9]. The observation period was June 2017 to May 2018, with automatic data collection at 10-minute intervals using Beijing time. (Note: The rain gauge has relatively limited capacity for monitoring snowfall.)

The distribution of the 7 precipitation observation points and their surrounding underlying surface conditions is shown in [Figure 1: see original paper].

3. Results

3.1 Monthly Variation Characteristics

As shown in [Figure 3: see original paper], the seven observation points—Sanlongsha, lower Huyang Gully, middle Huyang Gully, upper Huyang Gully, Wushikate, Saimagou, and Duobagou—exhibited clear monthly variation throughout the observation period, with precipitation concentrated from May to August. Cumulative precipitation during these four months accounted for 90.56% of the annual total. Sanlongsha received the most precipitation in July, approximately 16.67% of its annual total, while the other six observation points received the most precipitation in June, accounting for 41.67%-61.35% of their annual totals. The main precipitation periods varied significantly among observation points.

3.2 Diurnal Variation Characteristics

As shown in [Figure 4: see original paper], daytime precipitation (08:00-20:00) exceeded nighttime precipitation (20:00-08:00) at Sanlongsha, upper Huyang Gully, middle Huyang Gully, lower Huyang Gully, Wushikate, and Saimagou, with daytime precipitation proportions reaching 78.70%, 63.84%, 73.76%, 76.55%, 65.43%, and 58.52%, respectively. Only at Duobagou did daytime precipitation proportion (43.23%) fall slightly below nighttime.

In the northern margin of the Kumtag Desert, Sanlongsha precipitation occurred mainly at 14:00-20:00 and 08:00-14:00, accounting for 41.67% and 25.00%, respectively. Upper Huyang Gully precipitation occurred mainly at 14:00-20:00 and 20:00-02:00, accounting for 50.00% and 20.27%, respectively. Middle Huyang Gully precipitation occurred mainly at 14:00-20:00, accounting for 39.72%. Lower Huyang Gully precipitation occurred mainly at 14:00-20:00 and 08:00-14:00, accounting for 33.24% and 19.86%, respectively. Wushikate precipitation occurred mainly at 14:00-20:00, accounting for 50.00%. Saimagou precipitation occurred mainly at 14:00-20:00, accounting for 57.95%. Duobagou precipitation occurred mainly at 20:00-02:00 and 02:00-08:00, accounting for 30.28% and 18.62%, respectively.

3.3 Precipitation Event Characteristics

As shown in [Figure 5: see original paper], during the observation period, Sanlongsha experienced the fewest precipitation events at only 11, while Duobagou experienced the most at 26. Wushikate and upper Huyang Gully had 19 and 18 events, respectively, while middle Huyang Gully, lower Huyang Gully, and Saimagou each had 16 events.

Among the seven observation sites, single precipitation events showed considerable variation in duration, with the shortest lasting only about 10 minutes. The maximum single-event duration at Sanlongsha was 470 minutes, while at the other sites maximum durations ranged between 1,450–1,770 minutes. In terms of average event duration, Sanlongsha had the shortest at 148 minutes, Saimagou the longest at 463 minutes, and the remaining sites fell between 278–352 minutes.

The minimum cumulative precipitation for single events was identical across all seven sites at 0.2 mm. However, maximum cumulative precipitation for single events varied considerably, reaching 42.6 mm at Saimagou, 30.6 mm at Duobagou, and 22.4–26.4 mm at the other sites. Average precipitation per event was lowest at Sanlongsha (1.96 $\text{mm} \cdot \text{event}^{-1}$) and highest at Saimagou (9.78 $\text{mm} \cdot \text{event}^{-1}$), followed by Duobagou (6.15 $\text{mm} \cdot \text{event}^{-1}$), with remaining sites ranging from 3.13–3.40 $\text{mm} \cdot \text{event}^{-1}$.

Minimum precipitation intensity for single events ranged from 0.08–0.38 $\text{mm} \cdot \text{h}^{-1}$ across sites. Maximum intensity varied significantly, reaching 9.60 $\text{mm} \cdot \text{h}^{-1}$ at Wushikate, 6.80 $\text{mm} \cdot \text{h}^{-1}$ at Saimagou, and 2.49–5.60 $\text{mm} \cdot \text{h}^{-1}$ at other sites. Average precipitation intensity was highest at Wushikate (1.58 $\text{mm} \cdot \text{h}^{-1}$), followed by Sanlongsha (1.53 $\text{mm} \cdot \text{h}^{-1}$), with other sites ranging from 0.93-1.49 $\text{mm} \cdot \text{h}^{-1}$.

3.4 Spatial Variation Characteristics

Precipitation characteristics show significant spatial heterogeneity between the north and south alluvial fans of the Kumtag Desert. Despite similar monthly variation patterns, precipitation in the southern Altun Mountains alluvial fan is substantially greater than in the northern Beishan alluvial fan. Within the southern alluvial fan, precipitation also shows a pattern of southern areas exceeding northern areas—for example, precipitation at the southern upper Huyang Gully exceeds that at the northern middle and lower reaches.

The southern alluvial fan experiences more precipitation events than the northern fan, with longer average event durations. The eastern part of the southern alluvial fan has more events than the western part (except Saimagou) and longer average event durations. The proportion of nighttime precipitation in the southern alluvial fan exceeds that in the northern fan, with the proportion gradually increasing from west to east across the southern fan.

Affected by geographical location and topography, precipitation also varies around the Kumtag Desert. Dunhuang, located in the basin center, had an average annual precipitation of 39.52 mm during 1971-2015, with cumulative May–August precipitation of 31.75 mm. Our observations show that the southern alluvial fan of the Kumtag Desert receives more precipitation than Dunhuang, which in turn receives slightly more than the northern alluvial fan. Data from the China Meteorological Administration show that during 1971–2015, the average annual precipitation at surrounding stations (Ruoqiang, Tieganklik, Turpan, Qijiaojing, Hami, Hongliuhe, Anxi, Lenghu) ranged from 14–44.9 mm.

Hu et al. [10], using a merged hourly precipitation grid dataset from Chinese automatic stations and CMORPH products (version 1.0), identified an east-west oriented high-precipitation belt along the Altun Mountains on the southern margin of the Kumtag Desert—our measured results corroborate this finding. From north to south across the Kumtag Desert, elevation gradually increases, and topographic thermal and dynamic effects on airflow lead to increased precipitation—a pattern consistent with precipitation gradients in the Qilian Mountains [20] and Tianshan Mountains [21].

4. Discussion

The spatial heterogeneity of precipitation in north-south and east-west directions across the Kumtag Desert region is a key factor causing differences in soil, vegetation, and gully distributions. Influenced by regional climate, moisture, and topography, vegetation on the southern Altun Mountains margin shows decreasing species richness and simpler community structure from east to west, transitioning from pre-mountain steppe-desert vegetation to desert vegetation [22]. From south to north, decreasing elevation leads to increasingly arid climate, reduced surface runoff, and sparser vegetation distribution. The southern pre-mountain alluvial fan zone at higher elevations supports cold-resistant desert steppe vegetation dominated by *Stipa* and *Ajania* communities, while lower alluvial plains are dominated by shrub desert species such as *Sympegma regelii*, and the lowest desert margins support *Haloxylon ammodendron* communities; the northern desert interior, being extremely arid, has no vegetation or only typical desert vegetation like *Salsola* spp. [23].

Soil types in the Kumtag Desert also show clear north-south patterns: from south to north, they progress from alpine cold desert soil, frigid calcic soil, cold calcic soil, chestnut soil, brown calcic soil, and gray-brown desert soil, with alluvial fans having brown desert soil, transition zones between alluvial fans and desert having aeolian sandy soil, desert interior having sandy soil, transitional areas between desert margins and Aqik Valley having brown desert soil and semi-fixed aeolian sandy soil, Aqik Valley margins to center having meadow soil and saline soil, and Beishan areas having brown desert soil [24].

Numerous gullies have developed on the northern Altun Mountains alluvial fan in the southern Kumtag Desert. The eastern region has large mountains with glaciers, more precipitation, and substantial snowmelt and precipitation recharge, resulting in many perennial-flow gullies. The western region has lower mountains without glaciers and scarce precipitation, so gullies are mostly seasonal or intermittent with shallow channels and short courses [7].

Precipitation diurnal variation results from comprehensive influences of atmospheric thermal and dynamic processes on the water cycle in Earth' s climate system, involving interactions across different scales, water vapor phase changes and cloud-rain evolution, and mutual influences between atmospheric aerosols and cloud-rain formation [25]. In southeastern and northeastern China, precipitation peaks occur mainly in the afternoon; in southwestern China at midnight; in the Yangtze River basin in early morning; and on the Tibetan Plateau, afternoon and midnight peaks coexist [26]. The Qilian Mountains show greater nighttime than daytime precipitation [27]. The China automatic station and CMORPH merged hourly precipitation grid dataset (version 1.0) shows that the Altun Mountains' diurnal precipitation evolution is primarily "early morning type," while the Kumtag Desert' s is mainly "afternoon-dusk type" [12]. Our study shows that the Kumtag Desert' s southern and northern alluvial fans have greater daytime than nighttime precipitation (except Duobagou), with both afternoon and early morning peaks.

Precipitation in northwest China concentrates in summer, with the least in winter. Adjacent to the Kumtag Desert, the Shule River mainstream shows extremely uneven intra-annual precipitation distribution, with 87.5% of annual precipitation concentrated in May–September [28]. The southwestern Tibetan Plateau not only blocks southwestern warm-moist airflow but also acts as a "cold source" in winter. The westerly circulation splits into two branches that circumvent the plateau, forming a north-ridge-south-trough pattern, with the Kumtag Desert located under the high-pressure ridge controlled by subsidence, resulting in scarce precipitation. In summer, moist southwestern airflow from the Bay of Bengal can bypass the Tibetan Plateau and converge with southeast airflow from the South China Sea and western Pacific, bringing precipitation to the desert. Meanwhile, moist airflow originating from the Atlantic or Mediterranean that gathers in Central Asia, though greatly diminished after crossing mountains, also enhances summer precipitation in the Kumtag Desert region [29].

In this study, during winter (December–February), reduced temperatures cause snow collected by the precipitation gauges to require time to melt, creating some lag in observed precipitation events. However, precipitation observations at national meteorological stations around the Kumtag Desert show that winter precipitation accounts for a very small proportion of annual totals [11], so this error has minimal impact on regional precipitation characteristic analysis.

Spring and summer constitute the plant growing season, and precipitation is also concentrated during this period, with synchronized water and heat conditions that benefit plant growth. Despite the extremely arid conditions, the Altun Mountains region on the southern side of the Kumtag Desert experiences a considerable number of precipitation events in terms of event count, duration, and cumulative amount. For the largest precipitation events at Sanlongsha, upper Huyang Gully, middle Huyang Gully, lower Huyang Gully, Wushikate, Saimagou, and Duobagou, precipitation amounts accounted for 30.68%, 40.43%, 39.31%, 35.11%, 24.20%, 40.74%, and 22.27% of respective annual totals. Thus, precipitation on both sides of the Kumtag Desert depends primarily on a small number of large precipitation events. Hu et al. [10] found that extreme precipitation contributed approximately 40% to annual totals in areas around the Kumtag Desert, consistent with our results.

5. Conclusions

Based on one year of field precipitation data from the southern Altun Mountains alluvial fan and northern Beishan alluvial fan, this study fills a gap in measured precipitation data for these areas and provides important baseline data for regional hydrology, geomorphology, and flora/fauna research. The main findings are:

1) Precipitation shows strong spatial heterogeneity in the Kumtag Desert. The southern Altun Mountains alluvial fan receives more precipitation than the northern Beishan alluvial fan (Sanlongsha). Within the Altun Mountains alluvial fan, precipitation gradually increases from west to east and from north to south.
2) Precipitation in the alluvial fans on both sides occurs mainly from May to August, with cumulative precipitation accounting for over 90% of the annual total. This concentration during the plant growing season is crucial for regional vegetation.
3) Annual precipitation events number 11–26, with a small number of large precipitation events contributing substantially to annual totals.
4) Daytime precipitation exceeds nighttime precipitation on both sides (except at Duobagou), with both afternoon and early morning peaks.

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