Characteristics and Meteorological Causes of Medium and Small Floods at Xiagou Reservoir, Hami City: Postprint

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Abstract

Using water regime data from the Xiakou Reservoir and Yiwu Hydrological Station in Yiwu County, Hami City, Xinjiang, hourly precipitation observations from five automatic weather stations in the reservoir' s upstream watershed, as well as conventional upper-air observations and NCEP reanalysis data, this study analyzed the hydrological characteristics and watershed precipitation features of eight medium-small flood events at Xiakou Reservoir from 2015 to 2022. The results indicate: (1) Upstream-type flood processes have flood peak durations within 10 hours, concentrated flood volumes, and stable rise and fall; downstream-type flood processes exhibit rapid rise, with flood peak durations exceeding 10 hours. Although the average precipitation and maximum hourly rainfall intensity of flood-causing heavy precipitation for upstream-type floods are not as large as those for downstream-type floods, the average rainfall duration is longer. The duration of flood peaks exceeding the blue warning threshold is relatively shorter, and the resulting maximum peak discharge, highest water level, and reservoir storage increase are not as large as those for downstream-type floods. (2) The peak discharge at Yiwu Hydrological Station shows a positive correlation with the maximum precipitation over different time periods within the watershed above the reservoir, with the closest relationships being with the maximum 3-hour precipitation from upstream-area weather stations and the maximum 6-hour precipitation from downstream-area weather stations. (3) During flood-causing heavy precipitation events for downstream-type floods, the 100 hPa South Asian High exhibits a dipole pattern, with both the Central Asian long-wave trough and 500 hPa low trough positioned further south than in upstream-type events, while the Western Pacific subtropical high is positioned further north. During flood-causing heavy precipitation events for downstream-type floods, the 700-500 hPa specific humidity, 700 hPa water vapor flux and vorticity, and 700-500 hPa pseudo-equivalent potential temperature

are all larger than the corresponding values for upstream-type events, providing favorable indicators for forecasting flood-causing heavy precipitation.

Full Text

Characteristics and Meteorological Causes of Medium and Small Floods in Xiagou Reservoir, Hami City

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Abstract: Using water regime data from Xiagou Reservoir and Yiwu Hydrological Station in Yiwu County, Hami City, Xinjiang, together with hourly precipitation observations from five automatic weather stations in the reservoir' s upstream basin, routine upper-air observations, and NCEP reanalysis data, this study analyzed the hydrological characteristics and precipitation features of eight medium and small flood events at Xiagou Reservoir during 2015–2022. The results show that: (1) Upstream-type floods exhibit peak durations within 10 hours, with concentrated flood volumes and stable rising and falling stages. In contrast, downstream-type floods rise rapidly with peak durations exceeding 10 hours. While the average rainfall and maximum hourly intensity of upstream-type flood-inducing heavy precipitation are lower than those of downstream-type events, the average rainfall duration is longer. The flood peak durations exceeding the blue warning threshold are shorter for upstream-type floods, and their corresponding maximum peak discharge, highest water level, and reservoir storage increase are significantly smaller than those of downstream-type floods. (2) A positive correlation exists between the peak discharge at Yiwu Hydrological Station and maximum rainfall across different time periods within the basin above the reservoir. The peak discharge shows the strongest correlation with maximum 3-hour precipitation at upstream meteorological stations and maximum 6-hour precipitation at downstream stations. (3) During downstream-type flood-inducing heavy precipitation, the 100 hPa South Asian High exhibits a double-centered structure, with the Central Asian long-wave trough and 500 hPa low trough positioned further south compared to upstream-type floods, while the subtropical high is located further north. Specific humidity between 700–500 hPa, 700 hPa moisture flux and vorticity, and 700–500 hPa pseudo-equivalent potential temperature are all higher during downstream-type flood-inducing heavy precipitation, providing favorable indicators for forecasting such events. This study provides insights into the distinct characteristics of upstream- and downstream-type floods and offers valuable indicators for forecasting flood-inducing heavy precipitation.

Key words: Xiagou Reservoir; flood characteristics; circulation features; peak discharge

1.1 Study Area Overview

Xiagou Reservoir is located in Yiwu County, Hami City, eastern Xinjiang. As a river-blocking reservoir on the Yiwu River, it serves as a key control and regulation project with multiple objectives including agricultural irrigation, ecological protection, industrial water supply, and flood control. The reservoir is classified as a small (type 2) water conservancy project. The Yiwu River, which feeds the reservoir, originates from the Qilake glacier group at approximately 4,200 m elevation. The river basin is formed by the confluence of various tributaries including the Big and Small Baiyanggou, Ketougou, Tashekeqike, and Nayitake gullies. The terrain slopes from south to north, with permanent glaciers in the southern high mountains, gullies crisscrossing the mid-low mountain areas, and runoff loss zones in the northern plains. The reservoir' s watershed features partial forests and alpine meadows along its banks.

[Figure 1: see original paper]

1.2 Data Sources

The study utilized four main data sources: (1) Hydrological data including water level, storage capacity, and discharge from Xiagou Reservoir and Yiwu Hydrological Station for the period 2015-2022; (2) Hourly precipitation observations from five regional automatic weather stations in the Xiagou Reservoir upstream basin, obtained from the Meteorological Big Data Cloud Platform (Tianqing) with strict quality control; (3) Routine upper-air observation data; and (4) NCEP reanalysis data with $1° \times 1°$ spatial resolution.

1.3 Flood Case Selection

Following the criteria proposed by Wang et al. and Chen et al., this study analyzed indicators including peak discharge, flow increase, water level rise, flood rise rate, and time difference between rainfall and flood peaks. The water level warning system uses four escalating levels: blue, yellow, orange, and red. Based on historical flood return period calculations at Yiwu Hydrological Station, the warning thresholds are: blue warning at $45 m^{3}$/s, yellow warning at $80 m^{3}$/s, and red warning at $85 m^{3}$/s. Flood events reaching or exceeding the blue warning level were selected as medium and small flood cases for this study.

2 Flood Hydrological Characteristics

During 2015-2022, Xiagou Reservoir experienced eight medium and small flood events caused by heavy precipitation. The maximum peak discharges reached blue, yellow, and red warning levels in 4, 2, and 2 events respectively, with no orange warning events. According to the location of heavy precipitation in the upstream basin before each flood event, these processes were classified into upstream-type (3 events) and downstream-type (5 events).

2.1 Upstream-Type Floods

During upstream-type flood events, precipitation at meteorological stations in the reservoir's upstream area was mainly moderate to heavy rain, with durations within 10 hours. The precipitation was relatively uniform with smaller average rainfall amounts and hourly intensities. Hydrological characteristics show that upstream-type floods had maximum peak discharges of 45.5–74.0 m^3/s (blue to yellow warnings), peak durations of 1–9 hours, water level rises of 0.3–3.0 m, and storage capacity increases of 16.7\$$\times 10^{\{4\}-138.5\times 10}$\{4\}\$ m^3. The longest duration reaching blue warning standard was 7–9 hours.

2.2 Downstream-Type Floods

During downstream-type flood events, precipitation at meteorological stations in the reservoir' s upstream area was all heavy rain (storm level), with relatively long durations, large average rainfall amounts, and strong hourly intensities, sometimes accompanied by short-duration heavy precipitation. Hydrological characteristics show that downstream-type floods had maximum peak discharges of 120.0–210.0 m^3/s (red warnings), peak durations exceeding 10 hours, water level rises of 5.8–9.6 m, and storage capacity increases of 283.7\$$\times 10^{\{4\}-335.0\times 10}$\{4\}\$ m^3. The longest duration reaching blue warning standard was 12–16 hours, and the longest duration reaching red warning standard was 4–6 hours.

3 Response Relationship Between Flood Processes and Precipitation

3.1 Relationship Between Precipitation and Peak Discharge

A positive correlation exists between peak discharge at Yiwu Hydrological Station and maximum precipitation across different time periods in the basin above the reservoir. The correlation is strongest with maximum 3-hour precipitation at upstream meteorological stations and maximum 6-hour precipitation at downstream stations. Statistical analysis shows that when the average 3-hour precipitation at upstream stations reaches 4.0 mm, the maximum peak discharge occurs within 7–9 hours. When the average 6-hour precipitation at downstream stations reaches 4.0 mm, the maximum peak discharge occurs within 4 hours. During short-duration heavy precipitation events, the time to peak discharge is even shorter.

[Figure 2: see original paper]

3.2 Comparison of Typical Flood Processes

To further compare the differences and similarities between the two flood types, two events with relatively long peak discharges, large flood rises, and extended blue warning durations were selected as representative cases.

3.2.1 Comparison of Precipitation Conditions For the upstream-type flood event (July 28, 2020), precipitation occurred from 00:00–11:00, with average precipitation of 12.0 mm in the upstream area and 16.5 mm in the downstream area. The maximum cumulative precipitation was 21.2 mm at station Y6359 (downstream). The average precipitation duration was 9.6 hours, with maximum hourly intensity appearing at 06:00. This event featured low intensity, short duration, and small spatial differences in precipitation.

For the downstream-type flood event (July 2, 2020), precipitation occurred from 02:00–14:00, with average precipitation of 40.0 mm in the upstream area and 41.3 mm in the downstream area. The maximum cumulative precipitation was 147.0 mm at station Y6333 (downstream). The maximum hourly intensity was 12.0 mm/h, also at station Y6333. Precipitation duration was 8–13 hours, with maximum hourly intensity in the downstream area appearing at 06:00 and in the upstream area at 09:00. This event featured high intensity, wide coverage, long duration, large cumulative rainfall, and significant spatial differences.

3.2.2 Comparison of Flood Processes Analysis of the relationship between precipitation at meteorological stations and discharge at Yiwu Hydrological Station shows that the upstream-type flood event had a rainfall-flood time difference of about 3 hours. The downstream-type flood event had a rainfall-flood time difference of about 1 hour. For the upstream-type event, when the 3-hour precipitation at upstream stations reached 4.0 mm, the discharge began to increase, reaching blue warning standard 3 hours later and peaking 6 hours after the maximum hourly precipitation appeared. For the downstream-type event, when the 6-hour precipitation at downstream stations reached 4.0 mm, the discharge began to increase, reaching orange warning standard 1 hour later and peaking 3 hours after the maximum precipitation appeared.

[Figure 3: see original paper]

4 Circulation and Physical Quantity Characteristics

4.1 Circulation Background

The occurrence of flood-inducing heavy precipitation results from interactions among multiple-scale weather systems, with large-scale circulation exerting significant constraints. Research shows that during Xinjiang summer rainstorms, the 100 hPa South Asian High typically exhibits a double-centered structure over the Iranian Plateau and the Tibetan Plateau. Analysis reveals that upstream-type floods occur when the South Asian High shows a single-centered pattern, with the Central Asian long-wave trough located near the Balkhash Lake region and the trough base north of 45°N. Downstream-type floods occur when the South Asian High shows a double-centered pattern (over the Iranian Plateau and eastern Tibetan Plateau) with a stronger eastern center, and the Central Asian long-wave trough positioned further south, creating more vigorous southwesterly flow ahead of the trough that favors moisture replenishment.

At 500 hPa, both flood types feature a two-ridge-one-trough pattern, with ridges over Europe and near Lake Baikal. The upstream-type trough is located in West Siberia with its center north of the Balkhash Lake, while the subtropical high remains stable over the southeast coast. The downstream-type trough is located in Central Asia with its center south of the Balkhash Lake, while the subtropical high is positioned over the Hetao region, placing Xiagou Reservoir under the southwesterly flow on its western side. A common feature is that the Iranian subtropical high develops northward, superimposing on the European ridge with large circulation meridionality, placing the reservoir area under the control of southwesterly flow ahead of the trough.

4.2 Physical Quantity Field Characteristics

As Xinjiang is an arid and semi-arid region, water vapor is crucial for heavy precipitation. Analysis of specific humidity and moisture flux shows that both flood types have easterly flow from the Hexi Corridor to Hami at 700 hPa. This easterly flow is blocked by the northwest-southeast oriented Tianshan Mountains, causing rapid moisture convergence favorable for heavy precipitation formation. The downstream-type trough's more southerly position facilitates moisture transport from lower latitudes, while the subtropical high' s northward extension and blocking effect on system eastward movement are significant.

Both flood types show upward motion between 700–500 hPa with similar vertical velocity values. However, vorticity differs: upstream-type floods show 500 hPa vorticity of 0-10$\times10^{-5}$ s^{-1} and 700 hPa vorticity of ~20$\times10^{-5}$ s^{-1}, while downstream-type floods show 500 hPa vorticity of 10$\times10^{-5}$ s^{-1} and 700 hPa vorticity of 20$\times10^{-5}$ s^{-1}. The stronger rotation in downstream-type events favors system intensification.

Pseudo-equivalent potential temperature, which comprehensively represents atmospheric temperature, pressure, and humidity characteristics, shows significant differences between the two types. Upstream-type events exhibit 500 hPa pseudo-equivalent potential temperature of 328–340 K and 700 hPa values of 328–336 K, while downstream-type events show 500 hPa values of 342–352 K and 700 hPa values of 340–348 K, indicating greater unstable energy in downstream-type events that can produce stronger vertical motion.

5 Conclusions

This study analyzed eight medium and small flood events at Xiagou Reservoir during 2015–2022, reaching the following conclusions:

(1) The eight flood events were concentrated in mid-July to mid-August, with the most occurring in late July. Based on the location of heavy precipitation in the upstream basin, floods were classified as upstream-type (3 events) or downstream-type (5 events). Upstream-type floods featured moderate to heavy rain, short peak durations, concentrated flood volumes, and stable rising and falling stages. Downstream-type floods featured storm-level precipitation, rapid rise, long peak durations, and larger average rainfall amounts, maximum hourly intensities, peak discharges, water level rises, and storage increases.

(2) Peak discharge at Yiwu Hydrological Station showed positive correlation with maximum precipitation across different time periods in both upstream and downstream areas. The strongest correlations were with maximum 3-hour precipitation at upstream stations and maximum 6-hour precipitation at downstream stations. When the average 3-hour precipitation at upstream stations reached 4.0 mm, the peak discharge occurred within 7–9 hours. When the average 6-hour precipitation at downstream stations reached 4.0 mm, the peak discharge occurred within 4 hours.

(3) The circulation patterns of both flood types featured a two-ridge-one-trough pattern at middle-high latitudes, with the Iranian subtropical high superimposed on the European ridge. During downstream-type flood-inducing heavy precipitation, the 100 hPa South Asian High exhibited a double-centered structure, with the Central Asian long-wave trough and 500 hPa low trough positioned further south than in upstream-type events, and the subtropical high located further north. Specific humidity between 700–500 hPa, 700 hPa moisture flux and vorticity, and 700–500 hPa pseudo-equivalent potential temperature were all larger in downstream-type events, providing favorable indicators for forecasting flood-inducing heavy precipitation.

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