ORIGINAL ARTICLE

INTERNATIONAL JOURNAL OF ARTIFICIAL INTELLIGENCE

ISSN: 2692-515-x, Impact Factor: 9.23
American Academic publishers, volume 6, issue 02,2026

Journal: https://www.academicpublishers.org/journals/index.php/ijai

SPATIAL DISTRIBUTION PATTERNS OF WATER RESOURCES IN RIVER BASINS AND THEIR RELATIONSHIP WITH NATURAL FACTORS: EVIDENCE FROM MAJOR RIVERS OF UZBEKISTAN

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Abstract: Water availability in Uzbekistan exhibits strong spatial heterogeneity because runoff is generated mainly in high-elevation water-tower zones (Tien Shan and Gissar-Alay mountains and their foothills) and then transported into arid lowlands where climatic losses and water demand intensify scarcity. This article synthesizes basin-scale evidence on the spatial distribution of water resources across major river systems influencing Uzbekistan (Amu Darya, Syr Darya, Zarafshan, Chirchiq, and selected internal basins) and explains how natural factors (orography, precipitation and temperature gradients, cryosphere dynamics, basin hypsometry, and geomorphology) control runoff formation, seasonality, and downstream attenuation.

Keywords: Amu Darya; Syr Darya; cryosphere; orographic precipitation; runoff formation; spatial distribution; Uzbekistan; water resources.

Introduction

Uzbekistan's water resources are distributed unevenly in space and time. The country's lowland plains are arid, while the main runoff-forming zones lie in surrounding mountain systems. Orographic controls generate strong precipitation gradients and produce a spatial "upstream water-tower vs downstream demand" configuration. This natural template is intensified by longitudinal increases in potential evapotranspiration and infiltration losses across alluvial corridors.

At the national scale, renewable water resources reflect this geography. FAO AQUASTAT summary statistics report internal renewable water resources (IRWR) of about 16.34 km³/year and total renewable water resources (TRWR) of about 48.87 km³/year, while the dependency ratio is around 80% (FAO AQUASTAT, 2022). In practical hydrology terms, upstream climate variability (snow accumulation, melt timing, and mountain precipitation) strongly conditions downstream water availability.

This paper focuses on the natural drivers that shape baseline spatial distribution patterns in the river basins relevant to Uzbekistan, emphasizing: (I) relief-controlled precipitation and temperature gradients, (II) snow and glacier storage–release processes, (III) basin hypsometry and geomorphological transmission characteristics, and (IV) aridity-driven losses in lowland reaches.

Methodology

The study uses a secondary-data synthesis and basin-comparative framework grounded in physical hydrology and regional geography. Evidence is compiled from: (a) national renewable water resource statistics (FAO AQUASTAT), (b) basin-scale annual flow reporting for the Aral Sea basin (SIC ICWC yearbook), (c) climate diagnostics described in Uzbekistan's UNFCCC Third National Communication, and (d) peer-reviewed and institutional literature on cryosphere–runoff relationships in Central Asia. The analysis follows a three-scale logic:

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-national scale: internal vs external renewable water resources and dependency.

-basin scale: comparison of basin types (transboundary mountain-fed vs internal/foothill basins).

-river-corridor scale: longitudinal pattern from headwaters to arid plains.

Natural controls are interpreted through established process linkages: orographic precipitation determines runoff-production belts; snow and glacier storage regulate the seasonal hydrograph; increasing temperatures and aridity amplify potential evapotranspiration and channel/floodplain losses; and geomorphology (alluvial fans, porous sediments) governs infiltration and surface–groundwater exchange.

Uzbekistan lies in the interior of Central Asia at the interface between high-elevation mountain belts (runoff formation) and arid lowlands (runoff consumption and climatic loss). The principal river systems relevant to the country's water balance are transboundary and originate in the Pamir-Alay and Tien Shan regions.

For comparative analysis, this article considers:

-transboundary, mountain-fed systems: Amu Darya and Syr Darya.

-mountain-to-foothill systems with high importance for national supply: Zarafshan and Chirchiq.

-primarily internal basins: Kashkadarya and Surkhandarya.

These basins span pronounced gradients in altitude, precipitation phase (snow vs rain), temperature regime, and geomorphic transmission properties, making them suitable for diagnosing natural controls on spatial water-resource patterns.

Results are presented as spatial patterns (national and basin comparisons) and linked directly to governing natural factors.

Orographic precipitation and basin hypsometry define runoff-production belts. Orographic lifting and elevation-dependent cooling create steep precipitation gradients toward mountain belts, while western and central lowlands remain strongly moisture-limited. This establishes geographically concentrated runoff-production zones in upstream headwaters and foothills. Basin hypsometry further conditions total runoff: basins with a larger fraction of high-elevation area typically experience greater snow storage, later melt, and a more pronounced spring–summer hydrograph.

For example, precipitation gradients in the Zarafshan basin show a clear elevation dependence, with high-altitude locations receiving several times the precipitation of lowland stations (Juraev et al., 2023). Such gradients are a primary reason why local runoff generation is concentrated near mountain belts even when downstream plains remain dry.

Results

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High external dependence reflects transboundary hydrologic geography. At national scale, the IRWR–TRWR contrast indicates that Uzbekistan's renewable supply is dominated by inflows formed outside its territory (FAO AQUASTAT, 2022). This "externalization" of runoff production means that natural-factor variability in upstream mountain climates propagates into Uzbekistan's downstream reaches, influencing seasonal reliability and interannual anomalies.

In hydrological terms, the spatial distribution of renewable water is not congruent with the spatial distribution of demand: generation occurs upstream, whereas the largest consumptive use and climatic losses occur downstream. Consequently, downstream water security depends on both upstream climate (natural control) and conveyance conditions along the river corridor (geomorphology and aridity).

Interannual variability: Aral Sea basin 2020 as an illustrative case. SIC ICWC reporting for 2020 indicates total annual flow in the Amu Darya and Syr Darya basins of 96.44 km^3, which is about 82% of the long-term average. The Amu Darya basin accounted for 64.2 km^3 (including tributaries plus Zarafshan), and the Syr Darya basin accounted for 32.24 km^3 (SIC ICWC, 2020). Such departures are consistent with year-to-year variability in mountain precipitation, snow accumulation, and temperature-driven melt timing.

This interannual signal is amplified downstream because lowland reaches have high evaporative demand and limited local runoff formation; thus, any upstream deficit is transmitted into larger proportional shortages at points of use.

Cryosphere control of seasonality: snowmelt dominance with basin-dependent glacier signals. Mountain hydrology in Central Asia is shaped by the mismatch between winter precipitation maxima and summer water demand. Seasonal snowpack acts as the primary storage, releasing water during spring and early summer. In the highest headwaters, glacier ice provides additional buffering and can contribute substantially in selected sub-basins.

A World Bank assessment for the Aral Sea basin headwaters reports that in an upper Amu Darya headwater aggregation, snowmelt is the dominant modeled component with a substantial glacier-melt fraction, while in upper Syr Darya headwaters precipitation and snowmelt dominate at basin scale and the glacier component, though locally important, is smaller (World Bank, 2015). A synthesis of glacierized catchments in Central Asia emphasizes uncertainty in component attribution and highlights data and model limitations in quantifying glacier and snowmelt contributions (Chen et al., 2017).

Longitudinal pattern: the generation–transfer–depletion corridor. Across Uzbekistan-relevant river basins, spatial distribution can be conceptualized as a three-zone corridor:

-generation zone (high mountains): high precipitation and snow accumulation; low evapotranspiration; rapid runoff response.

-transfer zone (foothills/valleys): mixed rain–snowmelt contributions; strong sediment transport; infiltration increases on alluvial fans.

-depletion zone (arid plains/deltas): minimal local runoff formation; high potential evapotranspiration; channel and floodplain losses; high sensitivity to warming.

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This corridor framework clarifies why hydrological abundance in upstream zones can coexist with scarcity and instability in downstream plains.

1-Table

Comparative natural controls and spatial distribution attributes of selected river basins affecting Uzbekistan

Basin / River system	Runoff-production setting	Dominant natural controls	Typical seasonality (natural regime)	Primary natural vulnerabilities
Amudarya (headwaters to Uzbekistan)	Pamir-Alay high mountains; snow and glacier zones	Orographic precipitation; snowpack storage; glacier melt in high-altitude sub-basins; basin hypsometry	Spring–summer peak from snowmelt; glacier contribution supports warm-season flow in some sub-basins	Warming shifts melt timing; long-run glacier retreat reduces buffering; high downstream evaporative loss
Sirdarya (Naryn–Kara Darya system to Fergana)	Tien Shan mountains; snow-dominated headwaters	Snow cover duration/extent; temperature-driven melt timing; orographic precipitation variability	Pronounced spring/early-summer peak; sensitivity to earlier snowmelt	Earlier runoff and reduced snow duration; growing aridity raises depletion in lowland corridors
Zarafshan	Mountain - fed river terminating in arid plains; strong foothill gradients	Altitude-dependent precipitation; snowmelt inputs; geomorphic transmission along valley/alluvial plains	Spring peak; substantial summer use and depletion; limited downstream persistence	High sensitivity to precipitation variability; summer low-flow risk increases with warming
Chirchiq	Western Tien Shan tributary system feeding Tashkent region	Orographic precipitation; snowmelt timing; catchment relief controls runoff response	Spring–summer high flows; lower winter flows	Temperature increase elevates ET and shifts seasonality; rainfall/snow partition shifts

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Kashkadarya / Surkhandarya (internal basins)	Foothill to lowland basins with limited external inflow	Local precipitation variability; high potential evapotranspiration; infiltration to alluvial sediments	Short spring peak; intermittent or reduced summer flow in lower reaches	High drought sensitivity; strong losses in arid reaches; dependence on local snow/rain anomalies

The spatial distribution of water resources in Uzbekistan is structurally asymmetric: runoff is produced in upstream mountain belts but depleted across downstream arid plains.

Orographic precipitation gradients and basin hypsometry determine the location and intensity of runoff-production corridors.

Snow storage controls seasonal timing across most headwaters; glacier melt provides additional buffering in the highest sub-basins, especially within the Amu Darya system.

National renewable water statistics show high external dependence (around 80%), making upstream natural variability a key determinant of downstream availability.

Warming trends are expected to shift runoff timing earlier and increase evaporative losses, raising low-flow risk in arid reaches.

Conclusion

Uzbekistan's river-basin water resources exhibit a consistent spatial logic: runoff is generated in mountain "water-tower" zones under orographic precipitation and cryospheric storage, transferred through foothill valleys, and progressively depleted across arid plains where potential evapotranspiration and infiltration losses are high.

National renewable water statistics confirm that internal renewable resources are modest compared with total renewable resources and that the country is heavily dependent on transboundary inflows (FAO AQUASTAT, 2022). Consequently, natural variability in upstream climate and cryosphere conditions is a first-order control on downstream reliability.

The proposed generation–transfer–depletion model provides an operational conceptual tool for diagnosing basin vulnerability and for designing monitoring programs that target the most influential natural drivers (snowpack, melt timing, and aridity-driven losses).

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