TREND-BASED CORRELATION ANALYSIS OF PRECIPITATION AND DISCHARGE IN THE UPPER PADMA RIVER DURING THE DRY SEASON (1990-2019)

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ABSTRACT

Understanding the combined influence of climatic variability and human interventions on river systems is vital for sustainable water resource management, especially in transboundary basins. The Upper Padma River, a major distributary of the Ganges in Bangladesh, experiences significant dry-season (January-May) flow alteration due to both climate variability and upstream regulation. This study examines the long-term relationship between precipitation and discharge over a 30-year period (1990-2019) to assess how natural and human factors jointly shape dry-season hydrology. Satellite-based precipitation data from CHIRPS (v2.0) and observed discharge data from the Bangladesh Water Development Board (SW90 station, Hardinge Bridge) were analyzed. The Mann-Kendall test and Sen's slope estimator were applied to detect long-term trends, while Pearson's correlation analysis was used to quantify the strength and direction of the precipitation-discharge relationship. Results indicate a mixed hydrological response: 41.4% of years show proportional (direct) trends, whereas 58.6% exhibit inverse trends between precipitation and discharge, reflecting disrupted rainfall-runoff coherence. The correlation coefficient ($r = 0.303$, $p = 0.1035$) suggests a weak and statistically insignificant relationship. These findings reveal that discharge variability is not primarily driven by local rainfall but is strongly influenced by upstream flow regulation, irrigation abstraction, and channel morphological changes. The study highlights that the Upper Padma River's dry-season hydrology is governed by both climatic variability and anthropogenic control, with the latter playing a dominant role in modulating downstream discharge. Consequently, precipitation-based predictions alone are inadequate for managing dry-season flow in transboundary river systems. In conclusion, integrated hydroclimatic assessments that combine climatic, hydrological, and management data are essential for informed decision-making and cooperative water-sharing. Such an approach will enhance adaptive capacity and ensure sustainable water governance in the Ganges-Padma basin and similar transboundary contexts.

Keywords: *Climate variability, Dry season hydrology, Anthropogenic influence, CHIRPS precipitation data, Trend analysis.*

1. INTRODUCTION

River systems in South Asia are vital for maintaining agricultural productivity, navigation, and ecological sustainability. Among them, the Padma River, the distributary of the transboundary Ganges River, plays a pivotal role in supporting the livelihoods of millions in Bangladesh. However, in recent decades, its hydrological behavior has undergone profound changes, particularly during the dry season, due to both climatic variability and anthropogenic interventions (Gain, 2022; Rahman, 2023). The dry season, spanning from January to May, is characterized by minimal rainfall, high water demand, and increased dependency on upstream inflows. Any alteration in discharge during this period therefore has significant implications for agriculture, fisheries, domestic supply, and ecosystem services across southwestern Bangladesh. The Upper Padma River, stretching from the Ganges entry point at Chapai Nawabganj to the Hardinge Bridge region, represents a critical reach where upstream water diversion through the Farakka Barrage (commissioned in 1975) interacts with regional climatic variability. Numerous studies have documented that the operation of Farakka has significantly altered dry-season flows in the downstream Ganges-Padma system (Räsänen, 2013; Gain A. K., 2015). Controlled water releases, combined with expanding irrigation and sedimentation in distributary channels, have led to reduced discharge and modified flow timing. These anthropogenic changes often mask the natural hydrological response to precipitation, complicating the understanding of river climate linkages in this transboundary context (Das, 2023; Shrestha, 2022).

In addition to human regulation, climate change has emerged as an increasingly dominant factor shaping the hydrological regimes of South Asian rivers. Studies have identified declining pre-monsoon rainfall trends, shifting monsoon onset, and altered evapotranspiration dynamics as key contributors to seasonal flow anomalies (Mishra, 2021; Pandey, 2021). For example, the increasing variability in the Indian summer monsoon and the growing frequency of regional droughts have reduced recharge and delayed runoff generation in upstream catchments. Consequently, dry-season discharge in the Padma River may no longer directly reflect rainfall variability, as the system now operates under dual stressors climatic uncertainty and anthropogenic modification (Islam, 2024). Understanding the interrelationship between precipitation and discharge is fundamental to quantifying how these stressors jointly influence the hydrological behavior of transboundary rivers. Traditionally, river discharge has been regarded as a direct response to catchment-scale precipitation; however, under regulated flow conditions, this relationship can weaken or even invert, depending on operational decisions and storage dynamics (Räsänen T. A., 2017; Gain A. K., 2022). Identifying whether precipitation and discharge move in the same or opposite directions across time therefore provides critical insight into the evolving dominance of natural versus human control within a river system. In the case of the Upper Padma River, such analyses remain limited, particularly for the dry season, when upstream regulation exerts maximum influence and local rainfall contributes minimally to runoff. Most previous research has either focused on the annual or monsoon-scale flow regimes (Rahman, 2023; Chowdhury, 2022) or employed basin-wide hydrological modeling without emphasizing intra-seasonal interactions. Consequently, there exists a knowledge gap in understanding how dry-season discharge dynamics respond to local precipitation variability under long-term (multi-decadal) hydroclimatic evolution.

This study addresses that gap by performing a trend-based correlation analysis between satellite-derived precipitation (CHIRPS) and observed discharge (SW90 station, Hardinge Bridge) for the 30-year period of 1990-2019. The approach combines long-term trend assessment and statistical correlation to evaluate whether rainfall and discharge behave proportionally or inversely during the dry season. Specifically, the objectives of this research are:

I. To detect and classify annual trend relationships (proportional or inverse) between precipitation and discharge.
II. To quantify the strength and statistical significance of the precipitation-discharge relationship using correlation analysis.
III. To interpret the relative dominance of climatic versus anthropogenic factors influencing dry-season hydrology in the Upper Padma River.

By integrating these analyses, the study provides empirical evidence of the evolving nature of the rainfall-runoff relationship in a highly regulated transboundary system. The findings contribute to broader discussions on hydro-political resilience, water-sharing treaties, and sustainable flow management in South Asia. More importantly, they underscore the need for integrated hydroclimatic assessment frameworks that account for both natural variability and upstream regulation to ensure equitable and adaptive management of shared river resources.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The study focuses on the Upper Padma River in Bangladesh, ocated between the Ganges entry point and the Hardinge Bridge hydrological station (SW90), covering the regions of Chapai Nawabganj, Rajshahi, and Pabna (up to Rajbari). The area is hydrologically influenced by both natural rainfall and regulated inflow from India through the Farakka Barrage.

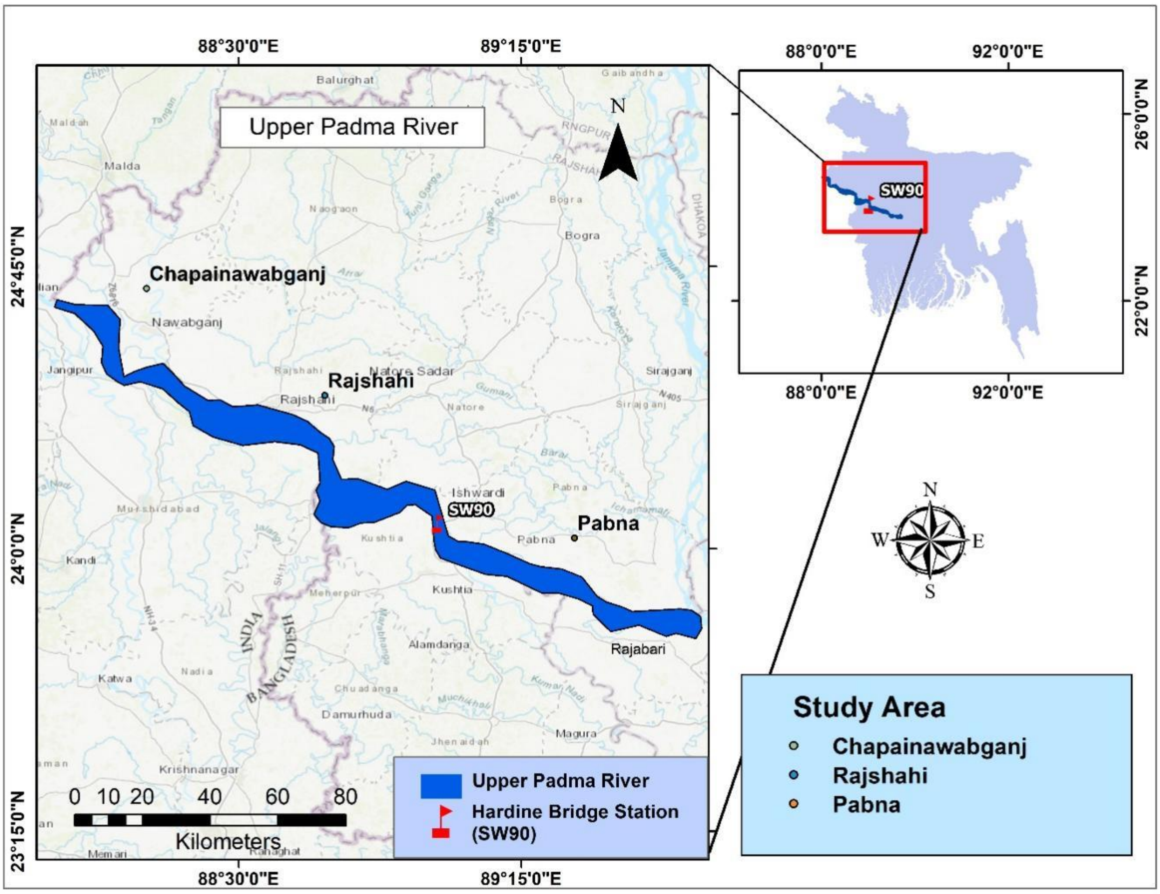

Figure 1: Study Area Map

2.2 Data Collection

Two key datasets were utilized:

I. Precipitation Data:

Monthly precipitation data for January-May (1990-2019) were extracted from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS v2.0) at 0.05° resolution.

II. Discharge Data:

Corresponding discharge data for the same period were collected from the Bangladesh Water Development Board (BWDB) at Hardinge Bridge (SW90 station).

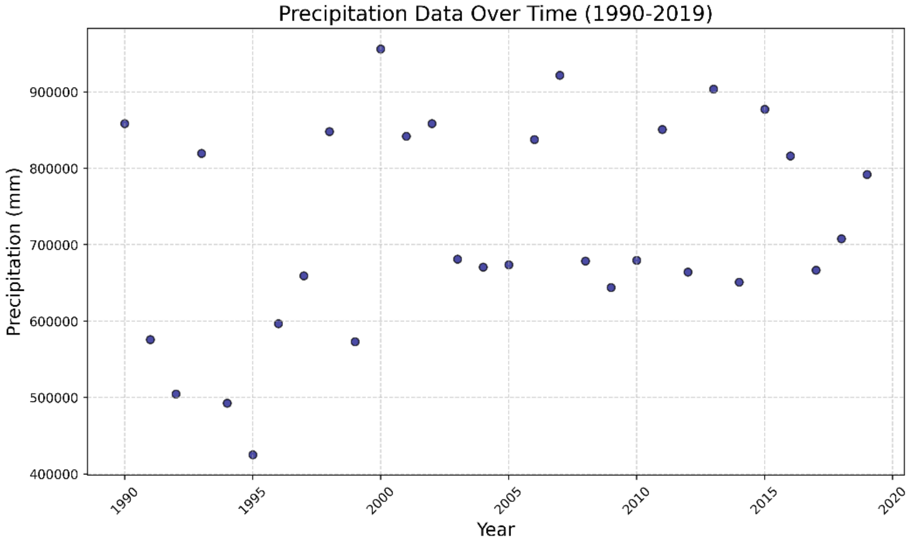

Figure 2: Dry-season precipitation data (CHIRPS, 1990–2019).

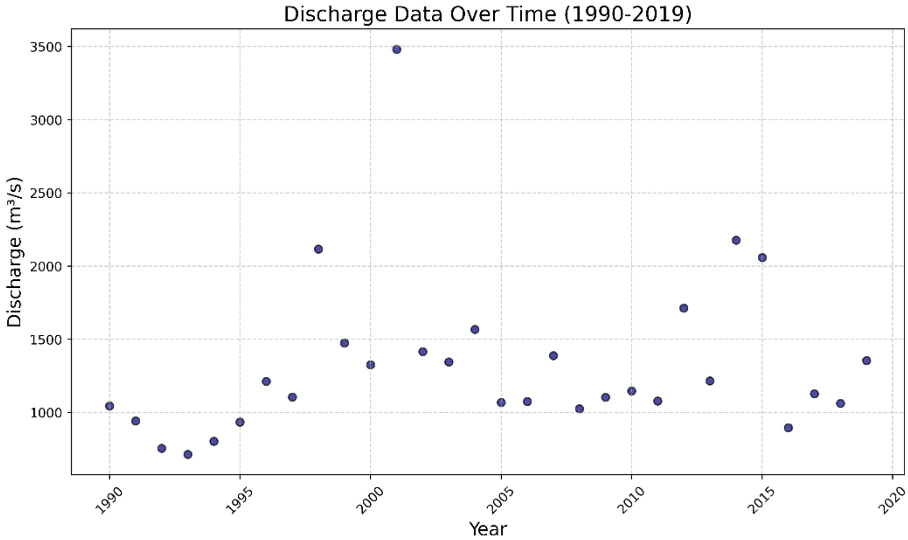

Figure 3: Dry-season discharge at Hardinge Bridge (SW90, 1990–2019), m^3/s

2.3 Data Preprocessing

Following the procedure illustrated in the flowchart, preprocessing steps included:

i. Extraction of dry-season data (January-May) for each year.
ii. Temporal alignment between precipitation and discharge time series to ensure identical sampling periods.
iii. Data cleaning, addressing missing or inconsistent values through interpolation and validation against long-term averages.
iv. Unit standardization, converting both datasets into comparable formats (mm/month for precipitation; m^3/s for discharge).

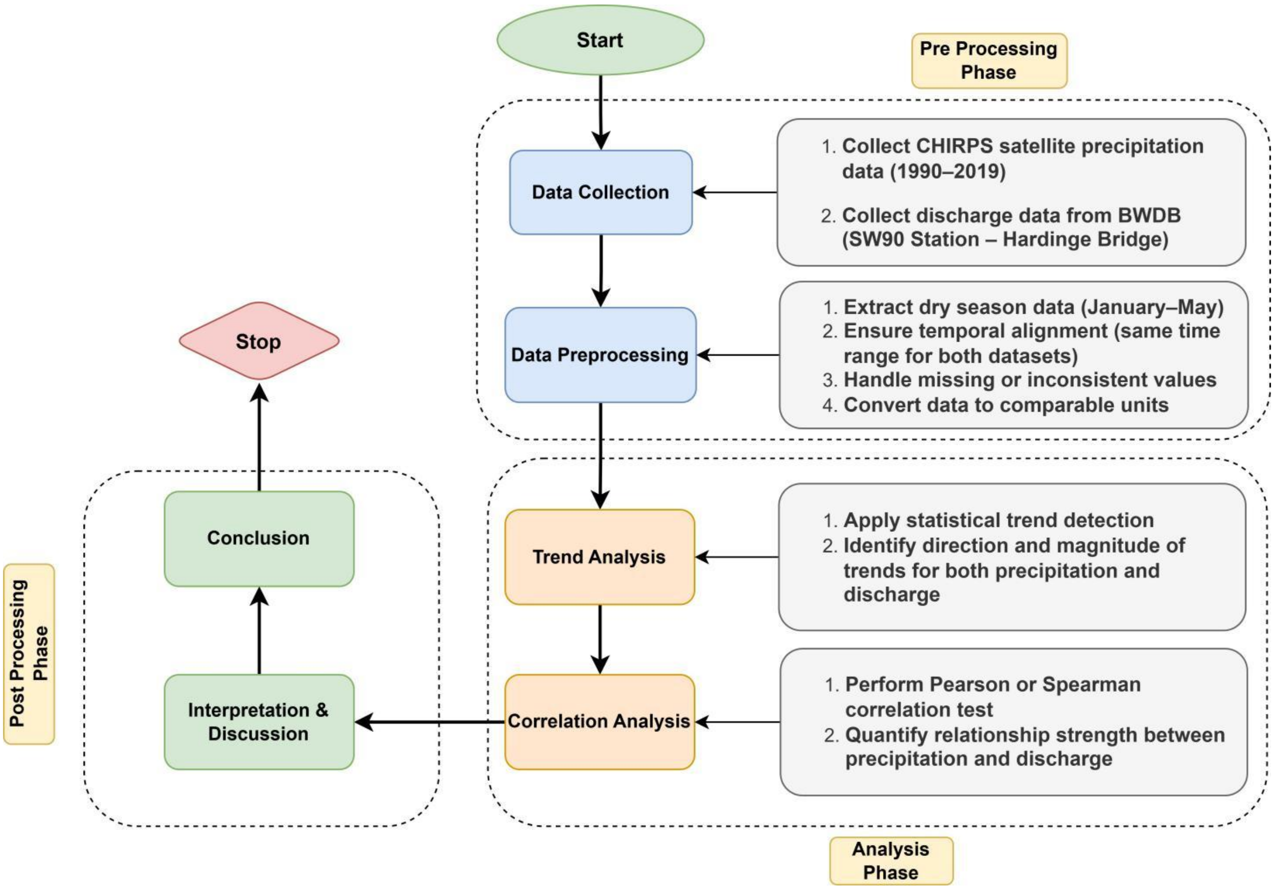

Figure 4: Methodology Flowchart

The methodology combines data processing, trend detection, and correlation analysis to evaluate how precipitation and discharge interact during the dry season, distinguishing climatic effects from upstream human influences.

2.4 Trend Analysis

Statistical trend detection was performed using the Mann-Kendall (MK) test and Sen's slope estimator, both of which are robust non-parametric methods widely used in hydroclimatic studies. These techniques are effective for identifying monotonic trends in time series data that may contain outliers or non-normal distributions. The MK test was applied to detect whether precipitation and discharge exhibited statistically significant increasing or decreasing trends, while Sen's slope estimator quantified the rate and direction of those trends. A significance level of $p < 0.05$ was adopted to determine the statistical validity of the observed trends. The analysis also quantified the proportion of years exhibiting proportional (similar) versus inverse (opposite) trends between precipitation and discharge, providing insights into their temporal relationship and potential influencing factors.

2.5 Correlation Analysis

The Pearson correlation coefficient (r) was calculated to quantify the linear relationship between mean monthly precipitation and discharge during the dry season. This statistical measure helped evaluate how closely variations in precipitation were reflected in corresponding changes in discharge. To determine the significance of this relationship, hypothesis testing was conducted, where the null hypothesis (H_0) stated that no significant correlation exists between precipitation and discharge, while the alternative hypothesis (H_1) indicated the presence of a significant relationship. The correlation strength was interpreted based on the value of r: values below 0.3 denoted a weak relationship, values between 0.3 and 0.6 represented a moderate correlation, and values of 0.6 or above indicated a strong correlation. A p-value threshold of 0.05 was adopted to test the statistical significance of the observed correlations.

This analysis provided a quantitative basis for understanding the extent to which rainfall variability influences discharge behavior in the Upper Padma River during the dry season.
Pearson correlation was selected because the analysis focuses on identifying the linear association between seasonally aggregated precipitation and discharge over a multi-decadal period, which allows for direct interpretation of rainfall-runoff coherence under regulated flow conditions.Both CHIRPS precipitation and BWDB discharge data are continuous, temporally aligned variables, making Pearson correlation statistically suitable for evaluating systematic rainfall-runoff co-variation.
Although hydrological processes may involve time-lag effects between rainfall and discharge, such effects are expected to be limited during the dry season when precipitation magnitude is low and river discharge is predominantly controlled by upstream regulation and irrigation abstraction rather than immediate runoff response.Therefore, the absence of a strong contemporaneous correlation is interpreted as an indicator of precipitation-discharge decoupling rather than a limitation of the correlation method itself.

3. RESULTS ANALYSIS & DISCUSSION

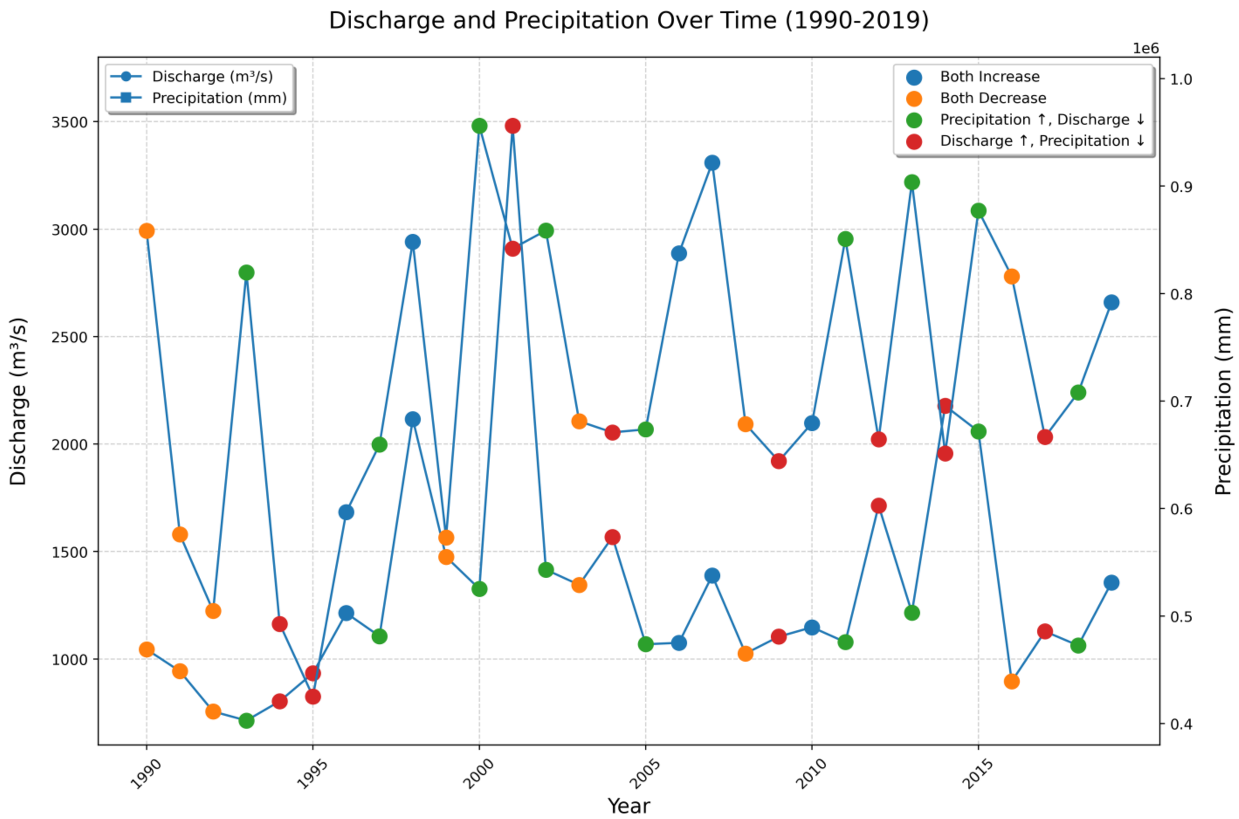

Figure 5: Dry-season precipitation and discharge trends (1990–2019).

3.1 Trend Analysis of Precipitation and Discharge (1990-2019)

The temporal analysis of dry-season precipitation and river discharge revealed distinct and variable trends over the 30-year period. CHIRPS satellite-derived precipitation data exhibited high interannual variability, with no consistent increasing or decreasing pattern across the study duration. Similarly, the observed discharge data from the Hardinge Bridge (SW90 station) indicated noticeable fluctuations, reflecting both natural hydrologic variability and potential human-induced flow alterations.
Out of the 29 annual intervals examined, 12 years (41.4%) demonstrated proportional trends meaning both precipitation and discharge either increased or decreased simultaneously. In contrast, 17 years

(58.6%) showed inverse trends, where discharge decreased despite precipitation increases or vice versa. This predominance of inverse behavior implies that the direct rainfall-runoff linkage is disrupted, particularly during the dry season when anthropogenic regulation becomes dominant.

No year showed complete stability (no change), indicating continuous variability in the hydroclimatic regime of the Upper Padma River.

The observed dominance of inverse trends aligns with hydrological expectations for regulated transboundary rivers, where upstream interventions, such as barrage operations, irrigation withdrawals, and dry-season flow diversions, influence downstream hydrology more strongly than local precipitation variability.

3.2 Correlation Analysis between Precipitation and Discharge

Pearson's correlation analysis was applied to quantify the statistical relationship between CHIRPS precipitation and observed discharge for the dry-season months (January-May). The correlation coefficient ($r = 0.303$) indicates a weak positive relationship, while the p-value ($p = 0.1035$) exceeds the 0.05 significance threshold, signifying that the correlation is not statistically significant.

This weak and statistically insignificant relationship suggests that, although higher rainfall is generally associated with higher discharge, the linkage is neither strong nor consistent. Discharge variations during the dry season are influenced by additional factors such as upstream flow control, irrigation practices, and channel morphological adjustments. Therefore, precipitation alone does not adequately explain the downstream discharge behavior in the Upper Padma River.

3.3 Integrated Interpretation

The integrated interpretation of the trend and correlation analyses provides valuable insight into the dry-season hydrology of the Upper Padma River. The following patterns emerge:

Table 1: Combined Interpretation

Aspect	Observation	Interpretation
Trend consistency	41.4% proportional; 58.6% inverse	Mixed hydrological behavior; precipitation-discharge decoupling
Correlation strength	Weak positive ($r = 0.303$)	Limited influence of rainfall on discharge
Statistical significance	$p = 0.1035$	Relationship not significant
Possible drivers	Upstream regulation, irrigation abstraction, climatic variability	Human-climate co-influence on discharge

These findings reinforce the conceptual understanding that the Upper Padma River's dry-season flow regime is governed by both climatic and anthropogenic controls. While local precipitation variability contributes to runoff generation, upstream hydrological regulation exerts a stronger influence on discharge availability downstream.

3.4 Climatic Variability and Its Role in Hydrological Trends

The CHIRPS dataset reflects considerable spatial and temporal variability in precipitation across the basin. Dry-season rainfall is generally low in magnitude and irregularly distributed, which inherently limits its contribution to downstream discharge. The presence of short-term wet anomalies (e.g., El Niño-Southern Oscillation years) occasionally enhances rainfall but does not translate proportionally into discharge increases, likely due to upstream storage and regulated release patterns.

These findings are consistent with studies on South Asian transboundary rivers, which emphasize the reduced rainfall-runoff responsiveness in heavily regulated systems. Therefore, climatic variability serves as a secondary driver, modulated by human regulation that dictates flow distribution and timing.

3.5 Anthropogenic Influence on Dry-Season Flow

The predominance of inverse trends and the weak correlation coefficient clearly signify human interference in natural river dynamics. The Upper Padma River receives a significant portion of its dry-season flow from upstream releases. Regulation structures, coupled with irrigation withdrawals, alter both the magnitude and timing of flow reaching the downstream reaches. Consequently, discharge may decline even during periods of above-average rainfall.

Furthermore, sedimentation and channel morphology changes could amplify the effects of regulation, causing localized water storage and altered hydraulic conveyance. These anthropogenic effects obscure the natural hydrological response to rainfall variability, leading to the decoupled precipitation-discharge relationship observed in this study.

3.6 Implications for Transboundary Water Management

Understanding these mixed hydroclimatic signals is crucial for the sustainable and equitable management of shared river systems. The findings indicate that downstream water availability during the dry season cannot be effectively managed based solely on precipitation forecasts, given the weak rainfall-runoff linkage. Instead, coordinated flow management, real-time monitoring of upstream releases, and improved water-sharing mechanisms are essential to ensure ecological and socio-economic balance. This study's integrated analytical framework demonstrates that combining satellite-based climatic datasets with observed discharge records offers a robust approach for diagnosing the complex interactions between natural and human drivers in transboundary basins. Similar recommendations have been highlighted in recent basin-scale studies across the Ganges-Brahmaputra-Meghna region (Gain A. K., 2021; Mukherjee, 2023), emphasizing the need for cooperative data monitoring and joint water allocation strategies for sustainable river basin management.

3.7 Implications for Sustainable Water Management and SDG-6

The findings of this study have direct implications for sustainable water resources management in transboundary river systems and align closely with the objectives of Sustainable Development Goal 6 (SDG-6), particularly targets related to water availability, integrated water resources management, and transboundary cooperation. The weak precipitation–discharge linkage observed during the dry season indicates that engineering and policy interventions must extend beyond climate-based forecasting approaches.

From an engineering perspective, adaptive flow regulation strategies, enhanced dry-season storage optimization, and sediment-aware channel management could help mitigate downstream water scarcity. Policy mechanisms such as coordinated real-time data sharing, joint flow monitoring, and treaty-based minimum environmental flow provisions are essential to ensure equitable downstream water access. Integrating hydroclimatic evidence into basin-scale decision frameworks can strengthen resilience against both climatic variability and anthropogenic pressures, supporting long-term sustainability of the Ganges-Padma river system.

3.8 Comparison with Regional Studies

The weak precipitation-discharge correlation identified in this study ($r = 0.303$) is consistent with findings from other regulated South Asian river systems. For example, weak rainfall-flow relationships ($r < 0.35$) in the Upper Ganges under regulated conditions (Räsänen T. A., 2017), while reduced dry-season runoff responsiveness despite localized rainfall variability (Mukherjee, 2023). In contrast, unregulated or monsoon-dominated river reaches often exhibit moderate to strong rainfall-discharge correlations ($r > 0.6$), highlighting the role of human control in altering natural hydrological responses. Compared to these studies, the Upper Padma River demonstrates a comparable degree of precipitation-discharge decoupling, reinforcing the conclusion that upstream regulation dominates dry-season flow dynamics.

4. CONCLUSIONS

This study presents a 30-year (1990-2019) analysis of precipitation and discharge trends in the Upper Padma River during the dry season, using CHIRPS satellite precipitation and BWDB discharge data. The findings reveal:

i. Trend variability: 41.4% of years exhibit proportional rainfall-discharge trends, while 58.6% show inverse patterns, indicating disrupted hydrological coherence.
ii. Weak correlation: The relationship between precipitation and discharge is weak ($r = 0.303$) and statistically insignificant ($p = 0.1035$).
iii. Dominant influence: Discharge variations are primarily shaped by upstream regulation and water abstraction rather than precipitation variability.

These results confirm that discharge variability during the dry season cannot be solely explained by precipitation, but rather by a combination of climatic and human influences. Future studies should integrate additional variables such as evapotranspiration, land-use changes, and temperature anomalies into predictive frameworks for more robust hydroclimatic assessments.

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DECLARATION OF USE OF AI

The authors used artificial intelligence (AI) tools only to assist with language refinement, grammar correction, and improving the clarity of the manuscript. The conceptualization, study design, data analysis, interpretation of results, preparation of figures, and all scientific conclusions were entirely performed and verified by the authors. The AI tools were not used for generating research content, conducting analysis, or drawing conclusions. All outputs from AI assistance were carefully reviewed, edited, and validated by the authors to ensure accuracy and academic integrity.

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