Vol.4, No.8, Page 2403- 2406, 2026 https://doi.org/10.59628/jast.v4i8.3668 ISSN 2958-9568 JAST

SUN PUBLISHER
مجلة جامعة صنعاء للعلوم التطبيقية والتكنولوجيا
Sana'a University Journal of Applied Sciences and Technology
https://journals.su.edu.ye/index.php/jast/

Reply To Comments On The Spatiotemporal Analysis of Rainfall Variability in the Sana'a Basin, Yemen: An Integrated Remote Sensing and GIS Approach

Hadi A. Quriaa[1*], Bassim S. Al Khirbash[2], Hisham M. Nagi[2] and Amer M. Al-Sabri[3]

[1]National Water Resource Authority (NWRA), Sana'a, Yemen,
[2]Department of Environmental Sciences, Faculty of Petroleum and Natural Resources Sana'a University, Sana'a, Yemen,
[3]Department of Geology and Environment, Faculty of Applied Sciences Thamar University, Dhamar, Yemen.

*Corresponding author: hadi.quriaa@su.edu.ye

We sincerely thank the commentator for reading our article and recognizing the importance of studying rainfall variability in the Sana'a Basin, a region where water resources are critical for domestic supply, agriculture, and sustainable development. While the comment raises a reasonable question regarding the use of TRMM after 2015 and suggests alternative gap-filling approaches, the comment appears to overstate their impact on the study conclusions. This article is fundamentally a descriptive spatiotemporal assessment based primarily on rain-gauge observations rather than a predictive or trend-modeling exercise. The recommendation to re-run Mann-Kendall and Sen's slope analyses is not applicable because these analyses were not conducted in the published paper.

Comment 1: Introduction

I read with great interest the recently published paper by Quriaa et al. (2026) regarding a spatiotemporal analysis of rainfall variability in the Sana'a Basin. While the authors tackle a critically important topic for Yemen's water security, a rigorous methodological review reveals foundational errors that compromise the reliability of the study's results. This comment focuses on two primary fatal flaws: (1) a severe physical and temporal impossibility regarding the utilization of the Tropical Rainfall Measuring Mission (TRMM) dataset and (2) an inadequate statistical approach to handling missing data through mean imputation. As established by Little and Rubin (2019), mean imputation artificially underestimates variance, distorts the probability distribution of the dataset, and erases the natural statistical covariance [1]. In hydrological modeling, this bias is particularly severe because it dampens extreme events such as hyper-arid spells and localized flash floods [2]. In a basin characterized by high spatial heterogeneity, where orographic lifting dictates precipitation, these flaws systematically misrepresent the true spatiotemporal rainfall patterns. This comment outlines these limitations and provides explicit technical recommendations for their correction.

Reply:

Thank you. We respectfully disagree with the characterization of the identified issues as "foundational errors" or "fatal flaws." The principal analyses and conclusions presented in our study are based primarily on observed rainfall records from 26 ground-based rain-gauge stations distributed across the Sana'a Basin for the period 2010–2024. Satellite-derived precipitation data were incorporated only as supplementary information to support the spatial interpretation of rainfall distribution and were not the primary source of the analyses or conclusions drawn. Likewise, the treatment of missing observations affected only a limited number of records and was implemented solely to maintain continuity in the descriptive statistical analyses.

The methodological procedures adopted in this study were selected in accordance with established hydrological and climatological practices and considering the constraints associated with data availability in arid and conflict-affected regions [1–3]. Although alternative approaches may be employed in similar studies, methodological preference alone does not invalidate scientific conclusions when the primary findings are supported by extensive ground-based observations.

Comment 2: The Physical and Temporal Impossibility of TRMM Data (2015–2024)

The authors explicitly state in their methodology that they utilized TRMM satellite precipitation products to drive or validate their spatial mapping for the continuous period spanning 2010 to 2024. This assertion introduces a direct physical impossibility. According to official technical documentation from the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), the TRMM spacecraft ceased data collection in April 2015 and re-entered the Earth's atmosphere on June 15, 2015 [3]. Therefore, no physical TRMM data were available for 2015–2024. Mapping a continuous spatiotemporal rainfall trend up to 2024 using a decommissioned satellite platform represents a severe data provenance error. Blending disparate satellite grids without formal cross-calibration alters spatial rainfall gradients and artificially shifts the apparent wet/dry boundaries across sub-basins. Page 1 of 4 *Recommendation for Correction:* To correct the satellite timeline while preserving a continuous, high-resolution temporal scope from 2010 to 2024, the spatial analysis should transition entirely to the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) dataset. CHIRPS features a high spatial resolution (0.05 ° × 0.05 °), making it exceptionally well-suited for capturing the complex orographic rainfall patterns of the Sana'a Basin. Local empirical evidence confirms this adjustment, as demonstrated by Al-Falahi et al. (2020) in regional hydroclimatic evaluations across the highland regions of Yemen; CHIRPS exhibits a superior ability to capture local convective mechanisms and offers gridded rainfall estimates that align closest with actual ground station observations [4].

Reply:

We thank the commentators for raising this point. We clarify that TRMM was used for the earlier period, while GPM was used for the later period following the end of the TRMM mission; TRMM was not used continuously until 2024. The Global Precipitation Measurement (GPM) mission is an advanced extension of the Tropical Rainfall Measurement (TRMM) mission, which was launched to develop and improve global precipitation monitoring after the end of the TRMM mission [4–6]. We appreciate the suggestion of using CHIRPS as an alternative precipitation product. However, the primary objective of this study was to analyze rainfall variability using observations from 26 ground-based stations across the Sana'a Basin. Satellite data were employed only as a comparative source to support the spatial interpretation of the rainfall patterns. Therefore, the principal findings and conclusions were derived from gauge observations rather than satellite estimates. Although CHIRPS may represent a useful alternative dataset for future investigations, replacing TRMM with CHIRPS would not alter the central conclusions regarding the spatial rainfall gradients and temporal variability identified from the station network.

Comment 3: Methodological Flaws in Missing Data Handling: The Failure of Mean Imputation

To address the data scarcity common in conflict-affected regions, the study under review resorted to the "mean imputation" method, replacing missing gauge records with the average rainfall from the same station or from nearby locations. Although simple, applying mean imputation to spatiotemporal climate data introduces catastrophic statistical bias. As established by modern statistical missing-data theory (Little & Rubin, 2020), mean imputation artificially reduces the natural variance of the dataset, truncates the frequency of extreme events, and destroys spatial covariance [1]. In the arid and semi-arid terrain of the Sana'a Basin, precipitation is heavily driven by isolated, convective, and high-intensity episodic storms. By smoothing these convective peaks into a historical average, spatial interpolation models (e.g., IDW or Kriging) generate highly distorted maps that over-stabilize the spatial water balance. Recommendation for Correction: To preserve the true variance and extreme variation characteristics of the region, mean imputation must be discarded in favor of modern stochastic or model-based gap-filling frameworks using the following: - - Multiple Imputation by Chained Equations (MICE), which models missing values by capturing the joint spatial distribution of neighboring stations, drawing simulated values from a predictive distribution that preserves the natural variance and spatial covariance matrix of the rainfall field. Alternatively, data gaps can be filled using highly localized gridded products such as Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data, which are specifically built for complex terrains and blend station observations with satellite imagery to maintain accurate daily and monthly spatiotemporal rainfall patterns.

Reply:

We agree that advanced imputation techniques, such as MICE, can be advantageous in studies focused on predictive modeling, uncertainty quantification, or climate reconstruction. However, the present study was primarily descriptive and exploratory, focusing on broad spatiotemporal rainfall patterns based on observed station records.

The proportion of missing data was less than 2% in certain years at only three stations, with missing values occurring as limited isolated gaps rather than prolonged or systematic periods of missing data. Mean imputation was therefore applied only to these isolated gaps [1, 7, 8] and was not used for predictive modeling or trend estimation. Under these circumstances, we do not believe that the use of more sophisticated imputation methods would materially affect the principal conclusions regarding rainfall distribution and variability across the basin.

Comment 4: Summary of Methodological Discrepancies and Reconstructive Fixes

Reply:

We respectfully note that this article does not report Mann-Kendall trend analyses or Sen's slope estimators. These methods were mentioned in the introduction only as examples of commonly used approaches in rainfall-runoff studies. The analyses presented in this article are based primarily on descriptive statistics, temporal rainfall comparisons, and GIS-based spatial interpretation, and are cited according to published international references included in the published article [9]. Consequently, there are no Mann-Kendall or Sen's slope results whose statistical significance would be affected by the imputation procedure, and re-running such analyses is therefore not applicable to the study as published.

Comment 5:

In conclusion, while the structural intentions of Quriaa et al. (2026) are commendable for filling regional data gaps, the baseline inputs of their model suffer from a critical physical anomaly and an oversimplified data-reconstruction strategy. In a highly sensitive, water stressed basin like Sana'a, relying on smoothed variances and misaligned satellite timelines can lead to fundamentally flawed water management policies and incorrect engineering designs for flood protection and artificial recharge structures. We urge the authors to clarify their data sources, apply the recommended cross-calibration and stochastic imputation techniques, and re-evaluate their spatiotemporal rainfall dynamics to ensure a scientifically defensible foundation for basin water resource planning.

Reply:

We sincerely thank the commentator for the constructive remarks and for emphasizing the importance of methodological rigor in rainfall studies conducted in water-stressed regions, such as the Sana'a Basin. We agree that transparency in data sources, careful treatment of missing observations, and appropriate selection of satellite precipitation products are essential components of high-quality hydrological research. However, we respectfully disagree with the conclusion that the methodological issues identified necessarily invalidate the study or could lead to fundamentally flawed water management decisions. The principal analyses and conclusions of the study are based on observed rainfall records collected from 26 ground-based rain-gauge stations distributed across the Sana'a Basin over the period 2010–2024, as detailed in a previous study [9]. These observations constitute the primary source of information used to characterize rainfall variability, whereas satellite-derived precipitation data serve only as supplementary information for comparison of the spatial rainfall distribution. Likewise, the limited number of missing observations was addressed to preserve the continuity of the descriptive analyses [1–3] and did not materially alter the observed rainfall patterns or the principal conclusions of the study.

Conclusion

In conclusion, the methodological concerns raised by the commentator are acknowledged, particularly regarding satellite data selection, missing data treatment, and methodological transparency. However, these concerns do not constitute foundational or fatal flaws because the study is fundamentally a descriptive and exploratory assessment based primarily on rainfall observations from 26 ground-based stations covering 2010–2024. The methodological approaches were selected considering established hydrological practices and data limitations in arid and conflict-affected regions.

Regarding the precipitation datasets, TRMM was used for the earlier period and GPM for the later period, rather than using TRMM continuously through 2024. We appreciate the suggestion of using CHIRPS as an alternative precipitation product. Satellite products were used only as supplementary and comparative information to support the spatial interpretation of rainfall, whereas the principal findings were derived from ground station observations. Similarly, although more advanced gap-filling techniques, such as MICE, may be preferable for predictive modeling, reconstruction, or uncertainty analysis, mean imputation was applied only to a very limited number of isolated missing observations, representing less than 2% in certain years at three stations; therefore, it is not considered to materially affect the study's principal findings.

The recommendation to rerun Mann–Kendall and Sen's slope analyses is not applicable because these methods were not used in the published analysis; they were mentioned only as examples of approaches commonly used in rainfall studies.

Finally, this study relies primarily on descriptive statistics, temporal comparisons, and GIS-based spatial interpretations. Accordingly, the methodological issues identified in the commentary do not invalidate the principal conclusions concerning the spatiotemporal rainfall variability and spatial rainfall patterns in the Sana'a Basin.

REFERENCES

[1] L. E. Alejo-Sanchez et al., "Missing data imputation of climate time series: A review," *MethodsX*, vol. 15, p. 103 455, 2025. DOI: 10.1016/j.mex.2025.103455 [Online]. Available: https://doi.org/10.1016/j.mex.2025.103455

[2] C. T. Haan, *Statistical Methods in Hydrology*, 2nd. Iowa State Press, 2002. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=823041

[3] D. R. Helsel, R. M. Hirsch, K. R. Ryberg, S. A. Archfield, and E. J. Gilroy, *Statistical Methods in Water Resources* (Techniques and Methods). U.S. Geological Survey, 2020, vol. Book 4, Chapter A3, p. 458. DOI: 10.3133/tm4a3 [Online]. Available: https://doi.org/10.3133/tm4a3

[4] NASA, *The global precipitation measurement mission (gpm)*, NASA Global Precipitation Measurement Mission, 2026. [Online]. Available: https://gpm.nasa.gov/missions/GPM

[5] G. Skofronick-Jackson et al., "The global precipitation measurement (gpm) mission for science and society," *Bull. Am. Meteorol. Soc.*, vol. 98, no. 8, pp. 1679–1695, 2017. DOI: 10.1175/BAMS-D-15-00306.1 [Online]. Available: https://doi.org/10.1175/BAMS-D-15-00306.1

[6] NASA, *Trmm comes to an end after 17 years*, NASA Global Precipitation Measurement Mission, 2015. [Online]. Available: https://gpm.nasa.gov/missions/trmm/mission-end

[7] R. J. A. Little and D. B. Rubin, *Statistical Analysis with Missing Data*, 3rd. Wiley, 2019. [Online]. Available: https://www.wiley.com/en-us/shop/general-introductory-statistics/statistical-analysis-with-missing-data-3rd-edition-p-9780470526798

[8] M. T. Sattari, A. R. Joudi, and A. Kusiak, "Assessment of different methods for estimation of missing data in precipitation studies," *Hydrol. Res.*, vol. 48, no. 4, pp. 1032–1044, 2017. DOI: 10.2166/nh.2016.364 [Online]. Available: https://doi.org/10.2166/nh.2016.364

[9] H. A. Quriaa, B. S. Al Khirbash, H. M. Nagi, and A. M. Al-Sabri, "Spatiotemporal analysis of rainfall variability in the sana'a basin, yemen: An integrated remote sensing and gis approach," *Sana'a Univ. J. Appl. Sci. Technol.*, vol. 4, no. 5, pp. 2122–2129, 2026. DOI: 10.59628/jast.v4i5.2859 [Online]. Available: https://doi.org/10.59628/jast.v4i5.2859

