Validation of TRMM 3B42 Rainfall Product at Lai Nullah Basin, Islamabad, Pakistan

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***Abstract*—In this study, the suitability of the research version Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) 3-hourly product has been evaluated at various time scales including the finest resolution possible at Lai Nullah basin (centroid: 33°40'19.94"N, 73° 1'27.70"E) in Islamabad, Pakistan. TMPA hourly rain rates (mm/h) are assessed by using most commonly used statistical measures such as correlation coefficients (CC), mean bias error (MBE), mean absolute error (MAE) and root mean square error (RMSE). Results reveal that the TMPA exhibited an overall underestimation. TMPA underestimated rainfall during monsoon and post-monsoon period while overestimated during pre-monsoon and winter seasons. During monsoon and post-monsoon seasons, greater MBE and RMSE are estimated. Overall, a weak correlation with high RMSE value is observed among TMPA and reference gauge hourly rain rates; at 3-hourly scale CC is 0.37 and RMSE is 5.12 and at daily scale CC is 0.50 and RMSE is 1.99. Significant correlation is noticed at decadal (CC = 0.75) and monthly (CC = 0.9) time scales having RMSE well within the tolerance threshold. Based on implementation of TMPA data in our study area, it is inferred that TMPA is more reliable at time scales of decadal and above than fine time scales of 3-hourly and daily.**

***Index Terms*— Rain rate, TMPA, Validation, Lai Nullah**

I. Introduction

Precipitation is a vital climate variable which has a direct effect on global climate processes. Variances in precipitation may cause natural hazards like water scarcities, torrents and landslides [1]. Conventionally, rainfall gauges have been used to detect rainfall. Currently these are the only devices to measure rainfall accretion directly. The number of rainfall gauges have been increased greatly over the recent past, but still their concentration does not meet scientific needs. Moreover, rainfall is a diverse phenomenon which contrasts at different spatiotemporal scales. Rain gauges only record local scale information which may induce possible errors when interpolation is applied at larger scales especially in hilly and semi-hilly regions. In addition, spatial spread of rain gauges is quite scarce in remote, undeveloped areas and regions with complicated terrain. Weather radar can be considered an alternative approach to estimate precipitation. Radar dependent measurements not only reveal the precipitation patterns and storm structure but also offer their real time monitoring at very high resolution. Limited availability of weather radars along with complex error source is additional challenge. Thus, measuring accurate precipitation at a high spatial and temporal resolution, from smaller to larger scale is still a challenge for researchers [1]–[3].

Advances in remote sensing technologies have enabled scientific community to make use of satellite-based precipitation products at various spatial and temporal resolutions [1]. Precipitation data from various satellites such as Tropical Rainfall Measuring Mission (TRMM), Climate Prediction Center MORPHing technique (CMORPH), and Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) is publicly available at no cost. These products are indeed valuable for hydrological modeling and predictions, flood forecasting, land surface derivation models, reservoir operations and risk analysis, resource management and monitoring, drought early warning and validation of numerical models for the regions lacking weather stations. Typically, these rainfall products have a high spatial and temporal resolution as well as coverage.

With multifarious advantages of satellite-based precipitation products, there are uncertainties and errors in the data induced by indirect measurements. These uncertainties include precipitation retrieval algorithm, cloud and ground surface type, thus generating errors in rainfall estimation which can further propagate into hydrological modelling. Therefore, rainfall retrieval capability of a satellite needs to be evaluated before its application. Such assessment can help users in applications of products and related impact of errors in those applications [1], [4], [5].

The scope of the current study is to validate research version 3-hourly TMPA product hourly intensities at various time scales during 2007 to 2010 in Lai Nullah basin Islamabad, Pakistan. Main objective of the study is to evaluate the research version TMPA rainfall rates (mm/h) at 3-hour time intervals by using 10-minutes temporal resolution telemetric rain gauge observations. TMPA hourly rain rates are also examined at daily, decadal and monthly time scales

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II. MATERIALS AND METHODS

A. Study Area

Study area is Lai Nullah basin which covers major portion of Islamabad and Rawalpindi (twin cities) in northern part of Pakistan. Lai Nullah basin is located at 33°45'36" to 33°33'01" North and 72°55'16" to 73°6'27" East (Fig. 1). Total area of the basin is approximately 230 km^2. Upper portion of basin covers Islamabad which is approximately 159.6 km^2 i.e. ~ 69% of total catchment area. Lower part of basin covers almost 70.5 km^2 of Rawalpindi city and its surroundings [6]–[8]. Lowest point of Lai Nullah is at the confluence of Soan River at an elevation of 420 m above mean sea level (AMSL), while highest point is at the top of Margalla hills with an elevation 1200 m AMSL.

B. Telemetric Rain Gauge (TRG) Data

In-situ rainfall datasets for a period of approximately four years (April 1, 2007 to December 31, 2010) at 10-minute temporal resolution were obtained from Pakistan Meteorological Department (PMD) – national weather forecasting agency of Pakistan. Surface rainfall observations have been recorded by telemetric rain gauges (TRGs); installed in Lai Nullah basin for flood prediction and early warning system by PMD with technical help of Japan International Cooperation Agency (JICA) [9]. Locations of TRGs are shown in Fig. 1, while characteristics of rain gauges can be seen in Table 1.

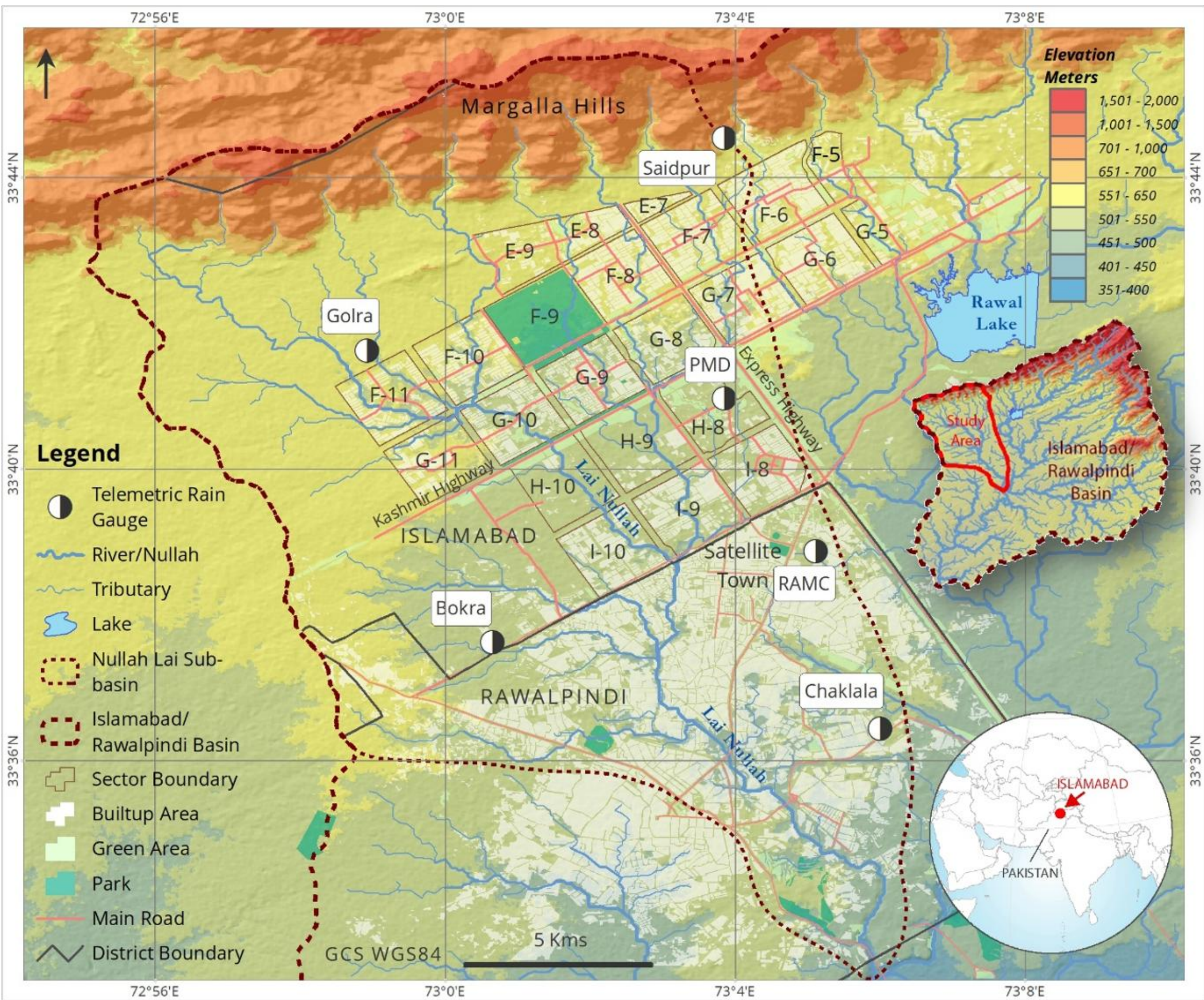

Fig. 1: Study area map showing Lai Nullah basin and its watershed; and location of telemetric rain gauges installed by PMD

TABLE I
PMD TELEMETRIC RAIN GAUGES' SPECIFICATIONS

Sr. No.	Name	Coordinates		Elevation (m)
		Longitude (E)	Latitude (N)	
1	Saidpur	73°03'51"	33°44'33"	668
2	Golra	72°58'55"	33°41'38"	556
3	PMD	73°03'51"	33°40'59"	531
4	Bokra	73°00'39"	33°37'38"	528
5	RAMC	73°05'07"	33°38'53"	508
6	Chaklala	73°05'60"	33°36'27"	506

Note: Temporal resolution of all stations is 10 minutes

A. *TRMM 3B42 (TMPA) Rainfall Product*

Tropical Rainfall Measuring Mission was launched in November 27, 1997 from the Tanegashima Space Center in Japan. Various weather related instruments like TRMM microwave imager (TMI), visible and infrared sensor (VIRS) are mounted on satellite [10]. TRMM has various products, and TMPA is one the those. TMPA is further categorized as real-time (3B42-RT) and post-real time (3B42research version) [11]. Both versions have same spatial and temporal coverages., Only difference between 3B42-RT and 3B42-research version is that the research version has been biased adjusted by using monthly rain gauge data. TMPA research version is used in the current research study which is a fine scale product having spatial resolution of 0.25° × 0.25° at 3-hour temporal scale [1], [12]. This research version of TMPA can be downloaded from STORM (https://storm.pps.eosdis.nasa.gov/storm).

B. *Methodology*

Point-to-pixel comparison method has been considered for current study. TMPA is a grid- based product, therefore, location of each pixel with respect to rain gauge stations remains fixed for entire TMPA granules. To prepare datasets for comparison, spatial association of rain gauges with TMPA pixels has been checked, and it is revealed that rain gauges are quite closely distributed with five out of six rain gauges fall within a single pixel. Therefore, non-zero averaged rain rates (mm/h) of five rain gauges have been calculated for the comparison with satellite-based rainfall measurements. Remaining rain gauge are discarded from the analysis. Finally, temporal collocation using ±5–minute time window is performed to generate the satellite–gauge data pairs for comparison.

Continuous statistical measures are related with satellite rainfall amount evaluation which include mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE), and liner correlation coefficient (CC) between estimated and the observed rainfall values [3], [10], [13]–[15]. CC calculates the linear association between measured and observed rainfall. MBE computes the average difference between measured and observed rainfall. A positive MBE value implies an overestimation while negative value shows an underestimation of satellite measured rainfall with respect to the rainfall observed by rain gauges. MAE is the average absolute magnitude of error while RMSE also estimates average error magnitude but penalizes larger errors more. The perfect values for these measures are: 1 for correlation coefficient, and 0 for MBE, MAE, RMSE. CC value has been supposed weighty if it is equal or greater than 0.7 [16]. Table 2 shows further details of the continuous statistical measures.

Detection threshold for the telemetric rain gauge rain/no-rain is 0.1 mm/h. Hence, the data pairs having rain gauge value '0' and TMPA values less than 0.1 mm/h were excluded from the analysis. Moreover, to calculate continues statistics i.e. CC, MBE, MAE, RMSE and NMB, data pairs where both TMPA and rain gauge had zero values, were excluded from the calculations

Comparison of TMPA hourly rain intensities with the rain gauge observation were carried out at 3-hour time interval. Mean hourly rain rates were also computed for daily, decadal and monthly comparison.

TABLE 2
LIST OF THE STATISTICAL INDICES USED IN THE VALIDATION OF TMPA

Statistical Index	**Equation**	**Perfect Value**	**Description**
MBE	$\mathrm{MBE} = \frac{1}{n}\sum_1^n (\mathbf{M} - \mathbf{O})$	0	n = number of samples, M = measured value (TMPA) O = observed value (TRGs), Bar on variable shows mean value
MAE	$\mathrm{MAE} = \frac{1}{n}\sum_1^n \lvert \mathbf{M} - \mathbf{O} \rvert$	0	
RMSE	$\mathrm{RMSE} = \sqrt{\frac{\sum_1^n (M-O)^2}{n}}$	0	
CC	$\mathrm{CC} = \frac{\sum_1^n (M-\bar{M})(O-\bar{O})}{\sqrt{\sum_1^n (M-\bar{M})^2}\sqrt{\sum_1^n (O-\bar{O})^2}}$	1	

III. RESULTS AND DISCUSSION

TMPA rainfall rates (mm/h) have been validated at various time intervals i.e. 3-hourly, daily, decadal, and monthly. Validation at mentioned time intervals has also been undertaken in different seasons.

Validation statistics has been given in Table 3. On average at 3-hourly time scale, TMPA gives a rain rate of 1.79 mm/h while TRG rain rate is 2.53 mm/h, thus, MBE is -0.74 mm/h negative sign shows an overall underestimation of rainfall by TMPA), and MAE is 2.57 mm/h with a maximum absolute error of 37.9 mm/h. RMSE; which gives more weightage to larger errors, has a value of 5.12 mm/h. Fig. 2 shows the scatter plot of TRG and TMPA measurements at different time scales. Value of the correlation coefficient at 3-hourly scale is 0.37. These scatterplots show that the value of correlation coefficient gets increased when hourly rain rates are averaged at daily, decadal and monthly time intervals. CC has a value of 0.90 at monthly time interval, which is highest among all time scales. Table 3 exhibits that the error statistics gets improved when moving from smaller time interval to larger time interval. At monthly time interval, values of MBE, MAE and RMSE are: -0.06, 0.13, 0.25 respectively, which are least among all time intervals.

TABLE 3
CONTINUOUS STATISTICS FOR HOURLY RAIN RATES (MM/H)

Time Scale	TMPA Average	TRG Average	MBE	MAE	RMSE	CC
3-Hour Interval	1.79	2.53	-0.74	2.57	5.12	0.37
Mean Daily	1.21	1.39	-0.18	1.18	1.99	0.50
Mean Decadal	0.48	0.55	-0.07	0.25	0.45	0.75
Mean Monthly	0.39	0.45	-0.06	0.13	0.25	0.90

Fig. 3 illustrates monthly averaged rain rate (mm/h) over 2007-2010. TMPA slightly overestimated in the months of February, April, May, October and December and underestimates rainfall in rest of the months. TMPA rainfall underestimation is most during monsoon and post-monsoon seasons i.e. during June, July, August and September. Fig. 4 also confirms that the TMPA underestimates rainfall in monsoon and post-monsoon seasons and slightly overestimates in pre-monsoon season.

Diurnal analysis (in UTC time zones) is performed for rainfall rate at 3-hours' time interval averaged over the entire time span i.e. 2007-2010. Fig. 5 demonstrates that TMPA underestimated rainfall at different time slots of the day except 12:00 hours (17:00 hours locally). TMPA performed well at 21:00 hours (02:00 hour local) and it is the time slot where maximum rain rate has been found for entire time span and thus consequently, a relatively high correlation coefficient value (0.47) has been found at 21:00. Overall, there are dispersed rain rate patterns between TMPA and TRG over day and night.

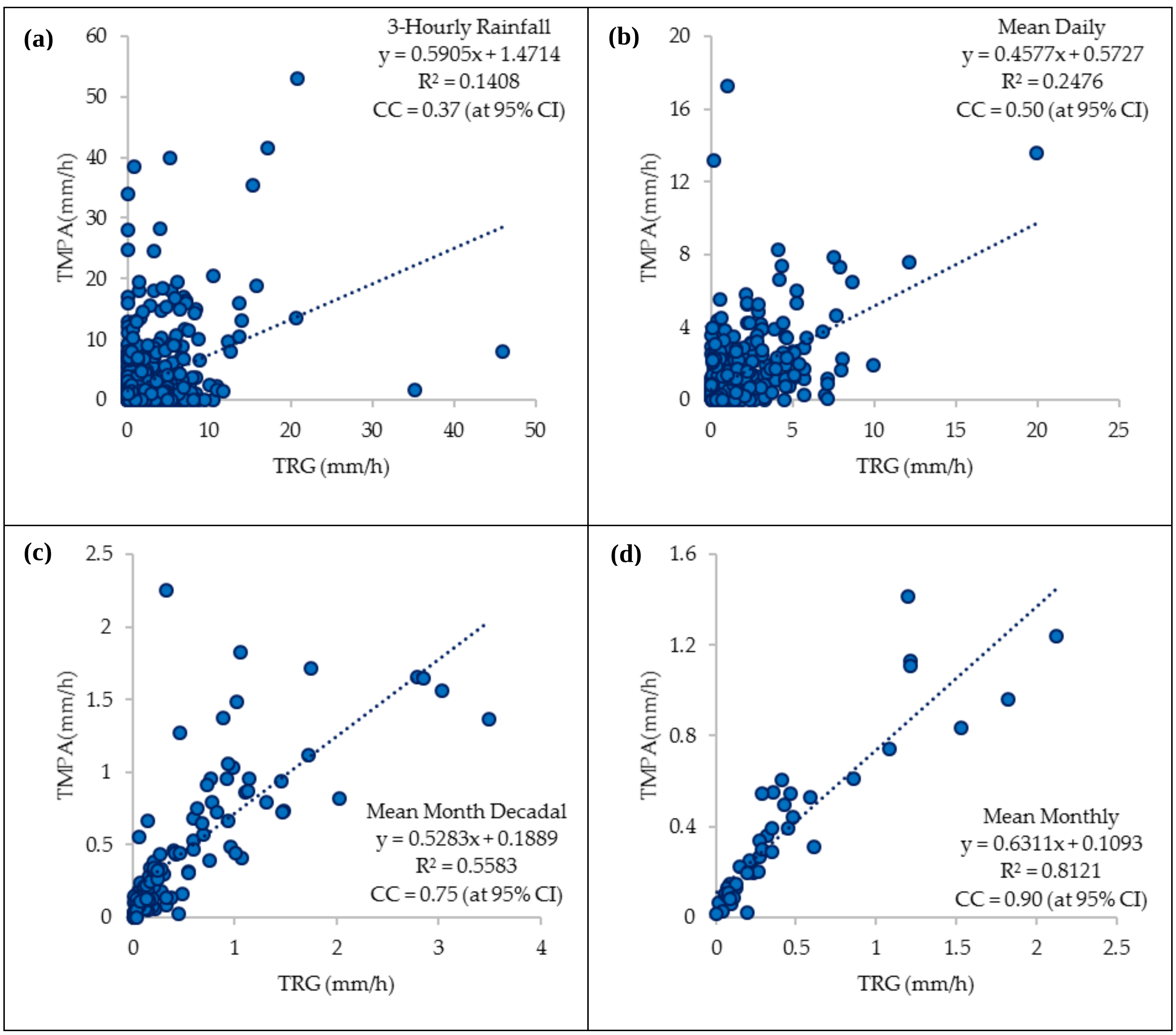

Fig. 2: Scatterplots of TMPA rain rate versus TRGs rain rate at (a) 3-hour interval, (b) mean daily, (c) mean decadal, (d) mean monthly

Validation results show an overall underestimation of TMPA in measuring actual rainfall. By considering the standard definition of acceptable accuracy to ±10% of observed precipitation, overall TMPA exhibits an underestimation of 17% of observed rainfall. Seasonally, TMPA overestimates in winter and pre-monsoon seasons while, underestimates in monsoon and post-monsoon; supported by a recent study conducted in Pakistan [2]. In comparison, post-monsoon period has highest value of underestimation i.e. 37% less than that of actual rainfall. Difference in rainfall estimation by TMPA and reference rain gauge data is lower in relatively dry periods, while rainfall estimates difference (underestimation) is more significant during wet periods. This finding is in backed by many other studies [10], [17], [18].

Statistical validation results show a CC of 0.37 at 3-hourly time scale for entire period. This CC value is lesser than calculated by [19]; which has an average CC value of 0.45. Calculated MBE is -1,11 which indicates an underestimation of TMPA in rainfall measurements. At daily, decadal and monthly time scales, correlation values between TMPA and TRG rain rates get increased to 0.50, 0.75 and 0.90 respectively which are in agreement with [2], [20].

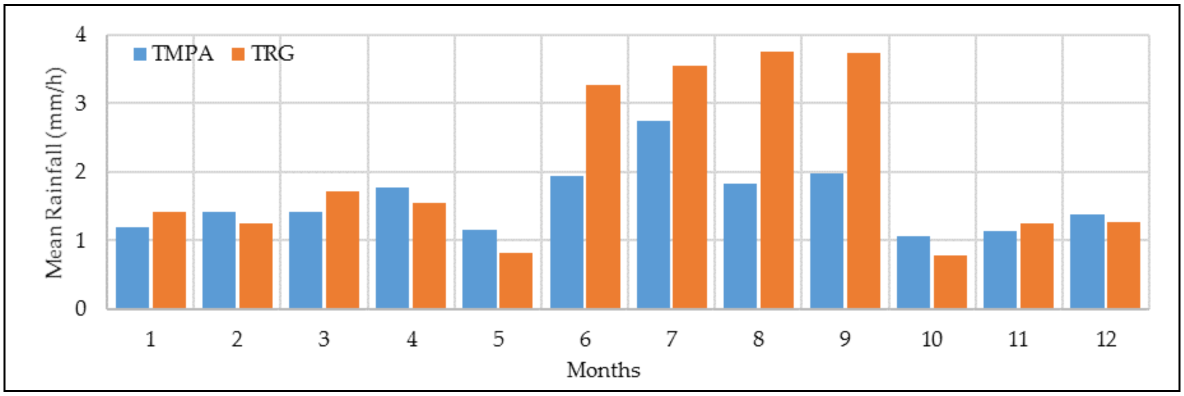

Fig. 3: Mean monthly rainfall rate (mm/h) averaged over 2007-2010

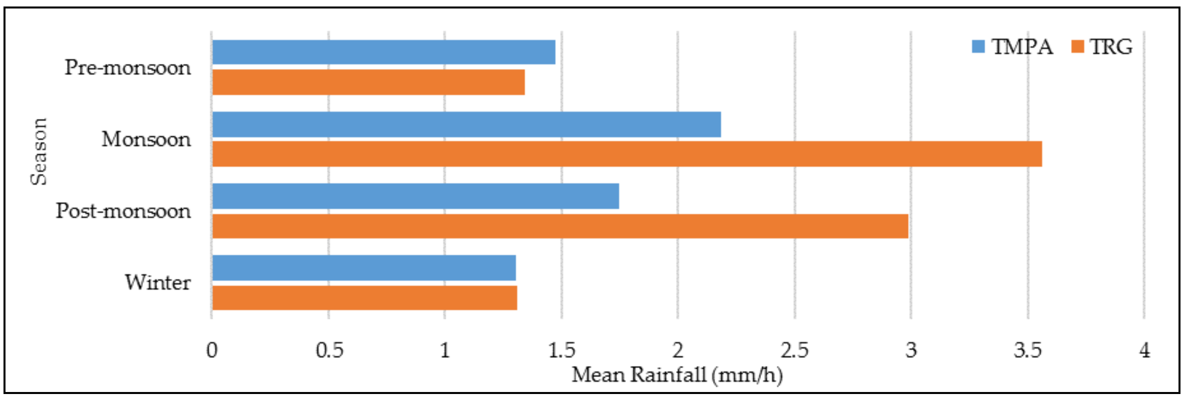

Fig. 4: Mean seasonal rainfall rate (mm/h) averaged over 2007-2010

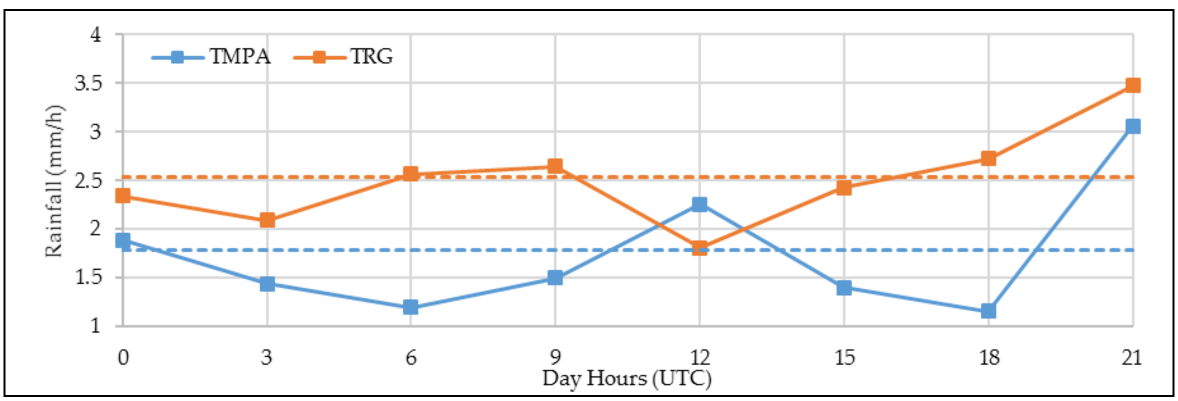

Fig. 5: Diurnal analysis of avg. rain rates (mm/h) at 3-hourly time interval. Dotted lines show average value for entire time span (2007-2010)

I. CONCLUSION

Current study reveals that the correlation coefficient between TMPA estimates and telemetric rain gauge observations ranges from a modest value of 0.37 at 3-hourly time interval to a strong value of 0.9 at monthly averages. Higher MAE and RMSE are associated with TMPA at 3-hourly and mean daily rain rate measurements. MAE and RMSE are declined at decadal and monthly rain rate averages. In seasonal perspective, TMPA underestimates rainfall in monsoon (wet period) and post-monsoon (relatively less wet period), while overestimates rainfall in winter and pre-monsoon (relatively dry seasons). Values of CC and RMSE show that TMPA estimates cannot be used as alternate of rain gauge data at 3-hour and daily time scales; can only be used as supplementary information. TMPA rainfall data is more reliable at decadal and above decadal time scales; where TMPA shows a significant value of CC >0.7 with in-situ reference data and exhibits error within tolerance threshold.

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REFERENCES

[1] W. Wang, H. Lu, T. Zhao, L. Jiang, and J. Shi, "Evaluation and Comparison of Daily Rainfall From Latest GPM and TRMM Products Over the Mekong River Basin," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 10, no. 6, pp. 2540–2549, 2017.

[2] M. F. Iqbal and A. Hussain, "Validation of satellite based precipitation over diverse topography of Pakistan," *Atmos. Res.*, vol. 201, no. March 2018, pp. 247–260, 2018.

[3] E. E. Ebert, "Methods for Verifying Satellite Precipitation Estimates," in *Measuring precipitation from space: EURAINSAT and the future*, Vol. 28., V. Levizzani, P. Bauer, and F. J. Turk, Eds. Springer, Netherlands, 2007, pp. 345–356.

[4] S. Khodadoust Siuki, B. Saghafian, and S. Moazami, "Comprehensive evaluation of 3-hourly TRMM and half-hourly GPM-IMERG satellite precipitation products," *Int. J. Remote Sens.*, vol. 38, no. 2, pp. 558–571, 2017.

[5] S. Moazami, S. Golian, M. R. Kavianpour, and Y. Hong, "Comparison of PERSIANN and V7 TRMM Multi-satellite Precipitation Analysis (TMPA) products with rain gauge data over Iran," *Int. J. Remote Sens.*, vol. 34, no. 22, pp. 8156–8171, 2013.

[6] M. Butt, "A view from Pakistan : Recurrent flash floods in areas surrounding Nullah Lai , Rawalpindi , Pakistan," *Middle East J. Bus.*, vol. 9, no. 4, pp. 29–32, 2014.

[7] B. Ahmad, M. S. Kaleem, M. J. Butt, and Z. H. Dahri, "Hydrological Modelling and Flood Hazard Mapping of Nullah Lai," *Proc. Pakistan Acad. Sci.*, vol. 47, no. 4, pp. 215–226, 2010.

[8] M. Ali, S. J. Khan, I. Aslam, and Z. Khan, "Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan," *Landsc. Urban Plan.*, vol. 102, no. 4, pp. 271–279, 2011.

[9] JICA, "Basic Design Study Report on the Lai Nullah Flood Forecasting and Warning System Project in the Islamic Republic of Pakistan," 2005.

[10] M. Almazroui, "Calibration of TRMM rainfall climatology over Saudi Arabia during 1998-2009," *Atmos. Res.*, vol. 99, no. 3, pp. 400–414, 2010.

[11] Z. Liu, "Comparison of versions 6 and 7 3-hourly TRMM multi-satellite precipitation analysis (TMPA) research products," *Atmos. Res.*, vol. 163, pp. 91–101, 2015.

[12] G. J. Huffman, R. F. Adler, D. T. Bolvin, G. Gu, E. J. Nelkin, K. P. Bowman, Y. Hong, E. F. Stocker, and D. B. Wolff, "The TRMM Multisatellite Precipitation Analysis (TMPA): Quasi-Global, Multiyear, Combined-Sensor Precipitation Estimates at Fine Scales," *J. Hydrometeorol.*, vol. 8, no. 1, pp. 38–55, 2007.

[13] M. N. Islam, S. Das, and H. Uyeda, "Calibration of TRMM Derived Rainfall Over Nepal During 1998-2007," *Open Atmos. Sci. J.*, vol. 4, no. 1, pp. 12–23, 2010.

[14] M. N. Anjum, Y. Ding, D. Shangguan, M. W. Ijaz, and S. Zhang, "Evaluation of High-Resolution Satellite-Based Real-Time and Post-Real-Time Precipitation Estimates during 2010 Extreme Flood Event in Swat River Basin, Hindukush Region," *Adv. Meteorol.*, vol. 2016, 2016.

[15] S. Yu, B. Eder, R. Dennis, S.-H. Chu, and S. E. Schwartz, "New unbiased symmetric metrics for evaluation of air quality models," *Atmos. Sci. Lett.*, vol. 7, no. 1, pp. 26–34, 2006.

[16] Y. Hussain, F. Satgé, M. B. Hussain, H. Martinez-Carvajal, M. P. Bonnet, M. Cárdenas-Soto, H. L. Roig, and G. Akhter, "Performance of CMORPH, TMPA, and PERSIANN rainfall datasets over plain, mountainous, and glacial regions of Pakistan," *Theor. Appl. Climatol.*, pp. 1–14, 2017.

[17] M. N. Islam and H. Uyeda, "Use of TRMM in determining the climatic characteristics of rainfall over Bangladesh," *Remote Sens. Environ.*, vol. 108, no. 3, pp. 264–276, Jun. 2007.

[18] D. Kumar, A. K. Gautam, S. S. Palmate, A. Pandey, S. Suryavanshi, N. Rathore, and N. Sharma, "Evaluation of TRMM multi-satellite precipitation analysis (TMPA) against terrestrial measurement over a humid sub-tropical basin, India," *Theor. Appl. Climatol.*, pp. 1–17, 2016.

[19] M. R. P. Sapiano and P. A. Arkin, "An Intercomparison and Validation of High-Resolution Satellite Precipitation Estimates with 3-Hourly Gauge Data," *J. Hydrometeorol.*, vol. 10, no. 1, pp. 149–166, 2009.

[20] M. L. M. Scheel, M. Rohrer, C. Huggel, D. Santos Villar, E. Silvestre, and G. J. Huffman, "Evaluation of TRMM Multi-satellite Precipitation Analysis (TMPA) performance in the Central Andes region and its dependency on spatial and temporal resolution," *Hydrol. Earth Syst. Sci.*, vol. 15, no. 8, pp. 2649–2663, 2011.