Evaluation and Performance of SM2-Satellite Precipitation Product with Reference to Ground-Based Observations, in different cities of Pakistan

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Abstract

Rainfall is the fundamental component to drive globalized hydrological cycle. Satellite-based precipitation having great inherency over land with wider range of applications, but their validation is at risk due to lack of rain gauge observations in different regions of the world. All precipitation product community are used to monitor the substitute data of rainfall in water resources, climatology, hydrology, meteorology, and geography. This research paper calculated the performance of SM2 precipitation product on different region, climate, elevation, and rainfall rate. For investigation, the ten statistical metrics and three categorical statistic have been analyzed at 11 station over 12 years period from 2007 to 2018. The different statistical technique assessed the analysis of precipitation product at different temporal scales (monthly, seasonally, and yearly) to investigate performance score. On the monthly and yearly time scales, product was less reliable with low correlation (0.0057 to 0.67) vary with elevation but best correlation (0.81) and linear regression coefficient (1.02) was calculated at seasonal scale than rest scales. The rainfall captured rate at seasonal scale with (>80%) was more than another scale. The outcome of this product from satellite community is less at monthly scale with significantly under and overestimation and with BIAS (-34.08% to 132.45%) than seasonal and yearly scale. But slightly over and underestimation pattern exist at seasonal scale with BIAS score (5.13% to -19.61%). During winter, research product reduces its systematic bias, NMAE and NRMSE and maintains its potential at also another seasons. The impact of elevation and different rainfall events are also investigated to detect the performance of SM2 satellite. More intense precipitation was captured by SPPs SM2 with high score of POD (> 0.70 to 0.99) vary with respect to more elevation area. The elevation trend increasing gradually from south (near mean sea level) to the northwest (northern areas of Pakistan) that having complex topography with intense rainfall rate. Same interpolated pattern of precipitation were assessed from south to northern areas of Pakistan like elevation using Arc GIS software. The overall evaluated results shows that precipitation product can detect heavy precipitation events easily than less intense events at monthly and yearly scale but reliable to capture at seasonal scale. This SPP is not completely reliable for low precipitation event with high altitude.

Keywords: Rainfall, globalized hydrological cycle, water resources, geography.

Introduction

Pakistan economy is dependent upon agriculture sector that is direct connected with irrigation system network that contains larger canal network in the world (SIHP, 1990). whose source is rainfall, river, and groundwater. Hydrological cycle strengthen is dependent upon precipitation events and basic component rainfall also play important role in water cycle (Azmat et al., al., 2018; Wu et al., 2013; Azmat, et al., 2019 and Allen et al., 2012). Long-term assessment of precipitation record is crucial for climatology studies (Herold et al., 2016; Pendergrass and Knutti, 2018), water resources management (Hou, et al., 2014 and Lee et al., 2019), control drought conditions (Forootan et al., 2019) and used for the preparation and prevention of the disasters (Lee et al., 2014; Wang et al., 2017; Azmat et al., al., 2018; Brunetti et al., 2018; Camici et al., 2018; Kirschbaum and Stanley, 2018) such as (flood, rainstorms and land sliding). National Aeronautics and Space Administration (NASA) has been launched different precipitation products for different elevation, climatology, location and rainfall rate. Japanese Aerospace Exploration Agency (JAXA) and NASA launched Global Precipitation Measurement (GPM) Core Observatory Satellite on February 27th, 2014 to provide valid feedback to new generation about rain and snow around the world (Hou et al. 2014; Yong et al. 2015). Accurate measurement of rainfall is a mission of NASA to improve their product with more potential. Precipitation products are mostly used in ungauged region with their validity variations (Yong et al. 2012). The ground-based observations are independent on algorithmic product developers meteorological because rain gauge observation is more reliable than any precipitation products. Precipitation product error occurs due to different validity specifications and scarcity of rain gauge stations in different areas of the world. However, ground-based observed records have low spatiotemporal detection in south to northwest of Pakistan. The accomplishment of rainfall record varies with satellite sensors and used to build unfluctuating data records (Brocca, et al., 2019). High spatiotemporal variability at different region calculate accumulated precipitation mostly at longer temporal scale but this research evaluates the results at monthly, seasonal and yearly scale.

In previous studies different precipitation products were widely used for precipitation estimation from remotely sensed information using Artificial neutral network to assess rainfall rate with more accuracy (Sorooshian et al., 2000). In fast emerging era of remote sensing applications, uses and validity of SPPs have been increased to monitor precipitation pattern with different intensities rate (Guo, et al., 2015; Funk, et al., 2015; Mantas, et al 2015). It is concluded that performance of any SPPs (satellite precipitation products) is dependent upon complex topography, weather conditions and precipitation rate give feedback to algorithm developers researchers in previous studies. Specially elevation is the decisive factor disturbing the accuracy of any SPPs (Milewski et al., 2015; Yang, et al., 2020; Stisen, et al., 2010; Arias-Hidalgo, et al., 2013; Chen, et al., 2013; Mashingia, et al., 2014; Prakash, et al., 2015). Mostly all the SPPs have been evaluated by their performance in different region of the world in previous different studies. The aim of this study is to check the performance of SM2 SPP in Pakistan with different topographic region and precipitation rate at different

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spatiotemporal scale. The remaining part of this research is summarized as follows: Section 2 describes the study area with complex topography and datasets used methodology. Section 3 investigate the quantitative statistical error analysis and delineation pattern of average annual rainfall between SPP and rain gauge. In section 4, summary and conclusion finalized the paper with positive and negative impact of SPP over the region.

Study Region, Datasets and Methodology

Study Region

The total area of catchment of precipitation is km^2 and study area lies between the northeast to southwest of Pakistan with complex topography as shown in (Figure 1). The presence topography trend increasing from south (8 m) to northeast (214m) mountainous area hike up the error and affect the performance of the SPP (Dinku, et al., 2002; Xu, et al., 2017). Rivers flow from northern areas (more elevation with more precipitation rate) towards south Arabian sea from higher elevation to lower elevation in Pakistan that cause flood forecasting toward lower elevation areas that cause disasters due to less attention scarcity of water resources management. To measure accurately rainfall events are compulsory at different basins for water resources management in country to prevent disasters.

Datasets and Methodology

All rain gauge stations are maintained and controlled by the Pakistan Meteorological Department (PMD). The monthly based observed precipitation records of data of eleven rain gauge stations were obtained from PMD and Water & Power Development Authority of Pakistan (WAPDA). The ground-based observed stations data was selected as true reference for evaluation and performance of SPP. Then monthly data records were converted into seasonal and yearly analysis of precipitation. Performance errors of SPP were calibrated with PMD ground-based monthly, seasonal and yearly observed data. The tropical rainfall covers the two-third part of global precipitation in mostly summer monsoon season (Reddy et al., 2019). World Meteorological Organization (WMO) standard code WMO-N (WMO-No. 168) was used for the collection and analysis of data of observed rain gauge stations. The basin characteristics of the rain gauge stations are represented in Table 1. Abbreviation for the symbols used in different formulas (Table 2) are discussed as where n represent the total number of rain gauge observation data and SPP data; Si and Gi are the satellite product and rain gauge observed data respectively; and S and G represent average values of satellite and ground-based observed data respectively. Where a, b and c describe the detected rate (event detected correctly and observed to occur), False alarm (event detected falsely but there is no actual precipitation to occur) and missing (event not detected by satellite but observed to occur) respectively. The performance of SPP was evaluated in large catchment area at three temporal scale i.e., monthly, seasonal and yearly with the help of statistical metrics and categorical statistic. In case of seasonal analysis, we assessed and compared the performance of SPP at all season (winter, spring, summer and autumn) that exist in Pakistan. The maximum alteration pattern was observed in summer monsoon season at complex topography from south (Karachi) to North (Fort Monroe). Delineation pattern was adopted to difference between the elevation and rainfall observed through rain gauges and SPP, using geostatistical technique of Kriging Interpolation using GIS applications (Burrough, 1986; Adhikary, et al., 2017; Lam, et al., 1983). Statistical metrics index used in Table 02. such as error (E), relative error (RE), mean error (ME), mean absolute error (MAE), normalized mean absolute error (NMAE), root mean square error (RMSE), normalized root mean square error (NRMSE), Probability of Detection (POD), False Alarm Ratio (FAR) and Critical Success Index (CSI) are crucial to assess the performance of SPP at different temporal scale in different region with different critical situations. Statistical metrics used to detect the potential of SPP in evaluation rain or no rain events. More detailed of these statistics are discussed in previous studies (Ali, et al., 2017; Chen, et al., 2013; Dinku, et al.,2008; Mashingia, et al., 2014).

Results

Annual Accumulated Rainfall Assessment

Figure 2 illustrates the delineation and spatial pattern of average annual precipitation between the rain gauge (Figure 2a) and SPP SM2 (Figure 2b). Pattern of rain gauge observed indicate the low rainfall at the central region (Rohri) but around this area rainfall precipitation rate increases gradually. At low elevation near about Karachi region, alternative slightly intense precipitation pattern observed every year due to cool breeze occurrence in the Arabian sea but towards northern areas of Pakistan always remain cold due to presence of cloud and intense precipitation. The SPP was completely failed to capture low precipitation events (151 to 200) in low elevation (<100 m) at yearly scale. Interpolated pattern showed increasing trend from southwest to northwest of the region. This product was also unsuitable in northern area (more precipitation & elevation) to capture rainfall correctly. Interpolated patterns evaluation showed that SPP unreliable to detect rainfall rate at annual rate.

Evaluation of Precipitation Product at different Spatiotemporal Scales

Figure 3 (a-c) shows the scatterplots of SM2 satellite product precipitation verses observed rain gauge data at monthly, seasonally and annual based respectively from 2007 to 2018. SPP displays low accuracy with rain gauge data at monthly scale by low values of correlation-R squared (0.0057 to 0.67). The linear regression coefficient scores (a = 0.05 to 0.85) also confirm less accuracy of SM2 satellite with rain gauge data at monthly scale than seasonal and yearly. SM2 product showed underestimations of precipitation at monthly scale (BIAS= -5.15). The values of statistical error are -0.85 mm/month, 2.96 mm/month, 18.81%, 4.09 mm/month and 24.58% respectively. More statistical error values indicate that SM2 precipitation product is less reliable to observe the monthly scale data along the region.

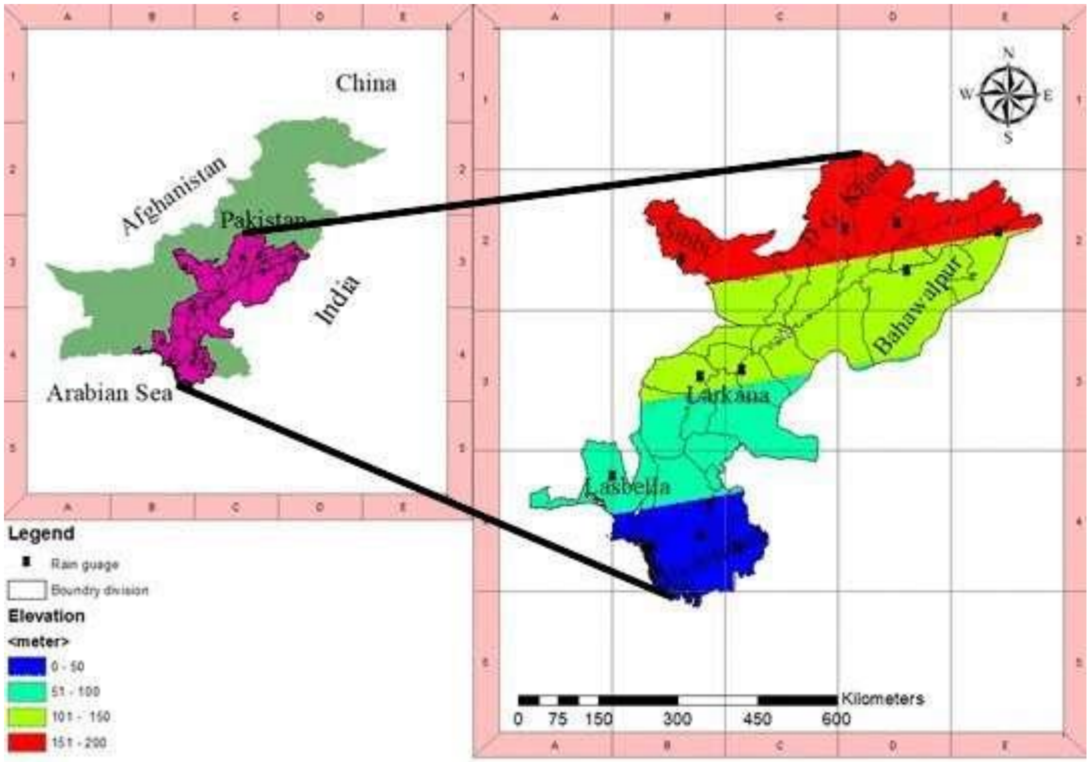

Figure 1. Study region mapping with different elevation catchment with rain gauges stations in Pakistan.

Table 1 The basic characteristics of the rain gauge stations in study region.

Sr No.	Station	Elevation (m)	Latitude	Longitude	Average Annual precipitation (mm) (SM2 Satellite)	Average Annual precipitation (mm) (Rain gauge)
1	Badin	10	24° 39' 20" N	68° 50' 14" E	229	227
2	Bahawalnagar	163	30°33'2"N	73°23'26" E	275	286
3	Bahawalpur	214	29° 25' 5" N	71° 40' 14" E	206	192
4	Deraa Ghazi Khan	129	30°3'22"N	70°38'5"E	269	252
5	Hyderabad	13	25°23'32" N	68°22'25" E	147	165
6	Karachi	8	24° 55' 34" N	67° 1' 19" E	141	196
7	Larkana	147	27° 33' 50" N	68° 12' 54" E	147	162
8	Lasbella	149	25°50'15"N	66°31'20" E	136	172
9	Multan	122	30° 10' 53" N	71° 29' 31" E	291	219
10	Rohri	62	27°40'30"N	68°54'1"E	133	110
11	Sibbi	130	33° 44' 16" N	73° 5' 4" E	219	208

Table 2. Contents of statistical indexes used to evaluate the performance of satellite precipitation product.

Equation	Statistical Index	Symbol	Unit	Formulas	Perfect value
01	Error	E	mm	$E = Si - Gi$	0
02	Relative Error	RE	mm	$RE = \frac{Si - Gi}{Gi} \times 100$	0
03	Mean Error	ME	mm	$ME = \frac{1}{n} \sum_{i-1}^{n} (Si - Gi)$	0
04	Mean Absolute Error	MAE	mm	$MAE = \frac{1}{n} \sum_{i-1}^{n} \mid Si - Gi \mid$	0
05	Normalized Mean Absolute Error	NMAE (%)	mm	$NMAE = \frac{MAE}{G} \times 100$	0
06	Root Mean Square Error	RMSE	mm	$RMSE = \sqrt{\frac{1}{n} \sum_{i-1}^{n} (\mathrm{Si} - \mathrm{Gi})2}$	0
07	Normalized Root Mean Square Error	NRMSE (%)	mm	$NRMSE = \frac{RMSE}{G} \times 100$	0
08	Probability of Detection	POD	-	$POD = \frac{a}{a + c}$	1
09	False Alarm Ratio	FAR	-	$FAR = \frac{b}{a + b}$	0
10	Critical Success Index	CSI	-	$CSI = \frac{a}{a + b + c}$	1
11	Relative bias	BIAS	-	$Bias = \frac{\sum_{i=1}^{n} (Si - Gi)}{\sum_{i=1}^{n} Gi}$	0
12	Pearson's Correlation Coefficient (CC)	r	-	$r = \frac{\sum_{i=1}^{n}(Gi - G)(Si - S)}{\sqrt{\sum_{i=1}^{n}(Gi - G)2} \times \sqrt{\sum_{i=1}^{n}(Si - S)2}}$	+1 to -1

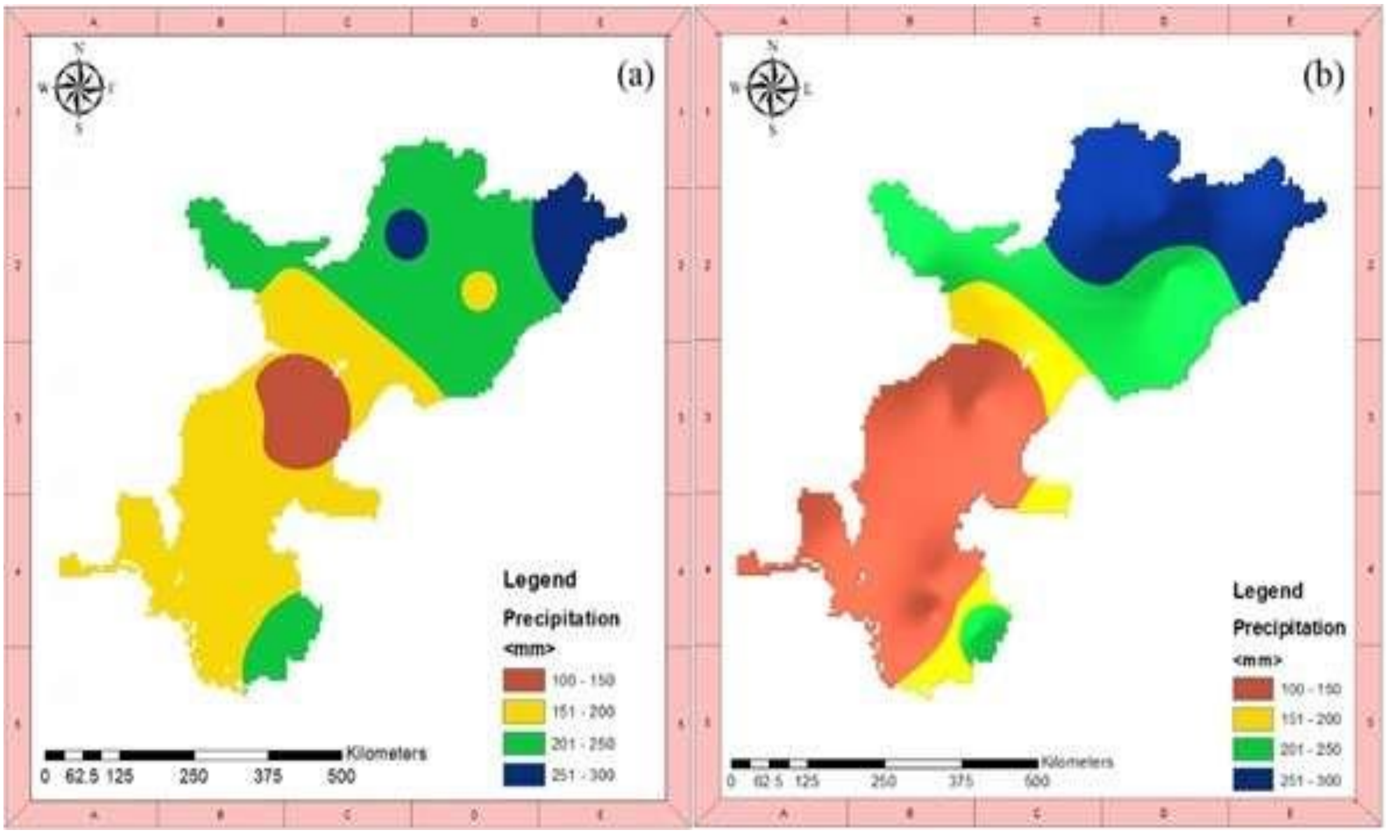

Figure 2. Spatial pattern of average annual precipitation: (a) Rain gauge; (b) SPP-SM

While the relationships between the SM2 satellite and rain gauge at seasonal scale are shown in Figure 3 (b). The product justifies the best agreement at seasonal scale. The R squared values (0.2 to 0.81) are also significantly increased from monthly scale to seasonal scale and the linear regression coefficient scores of seasonal scale varies (0.42 to 1.02) and also justify the best display between precipitation product and observed rain gauges data. Precipitation product showed overestimations of precipitation at seasonal scale (BIAS= 4.26). The respective statistical errors (ME, MAE, NMAE, NMAE, RMSE and NRMSE) for the seasonal (2.04 mm/month, 8.23 mm/month, 10.46%, 9.97 mm/month and 20.80%) and annual scale (0.29 mm/month, 25.02 mm/month, 12.52 %, 30.92 mm/month and 15.50 %) are slightly increasing than monthly scale. But annual scale of precipitation product is justifies slightly overestimated along Badin, Bahawalpur, Dera Ghazi Khan, Multan, Rohri and Sibbi.

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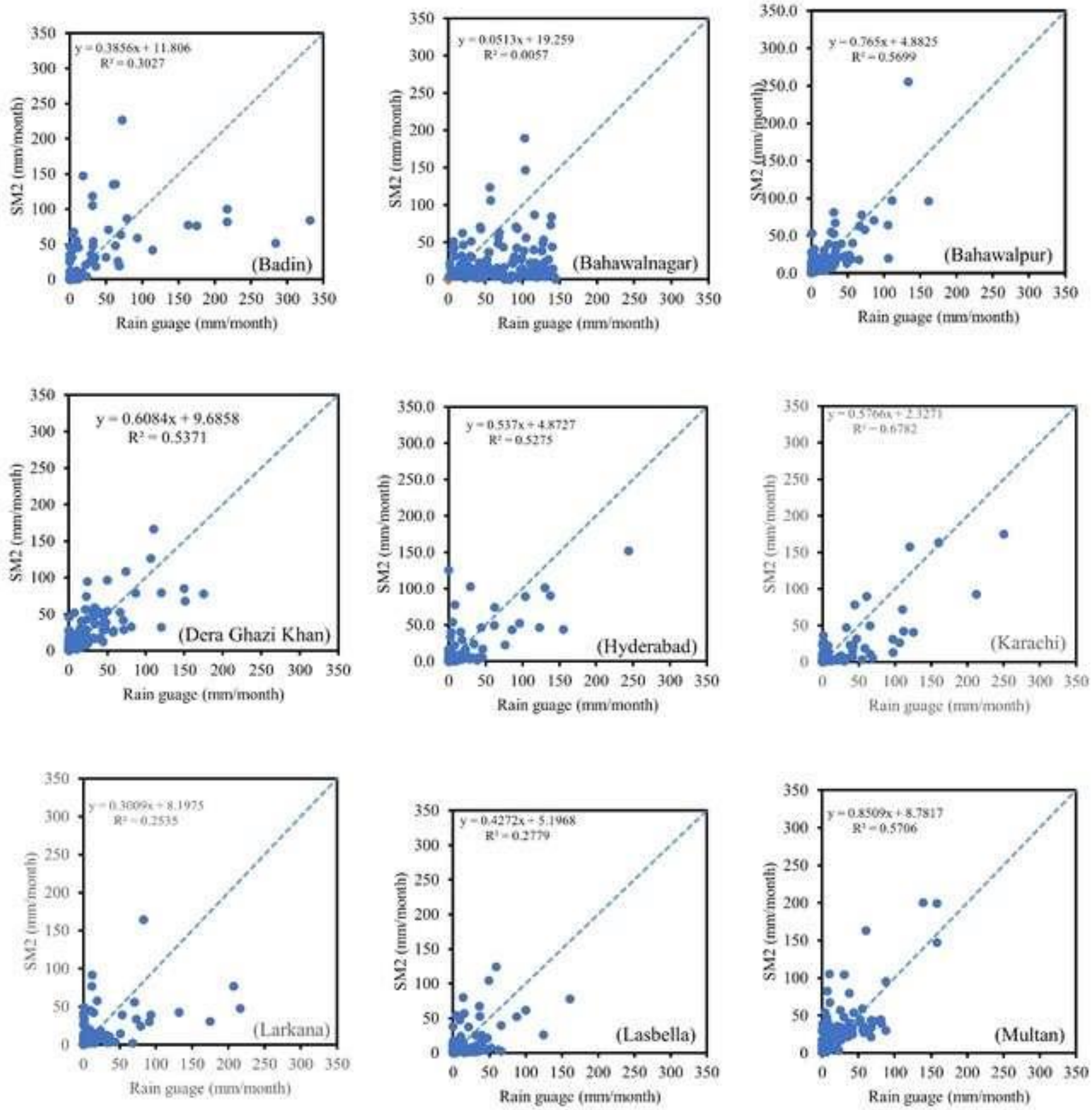
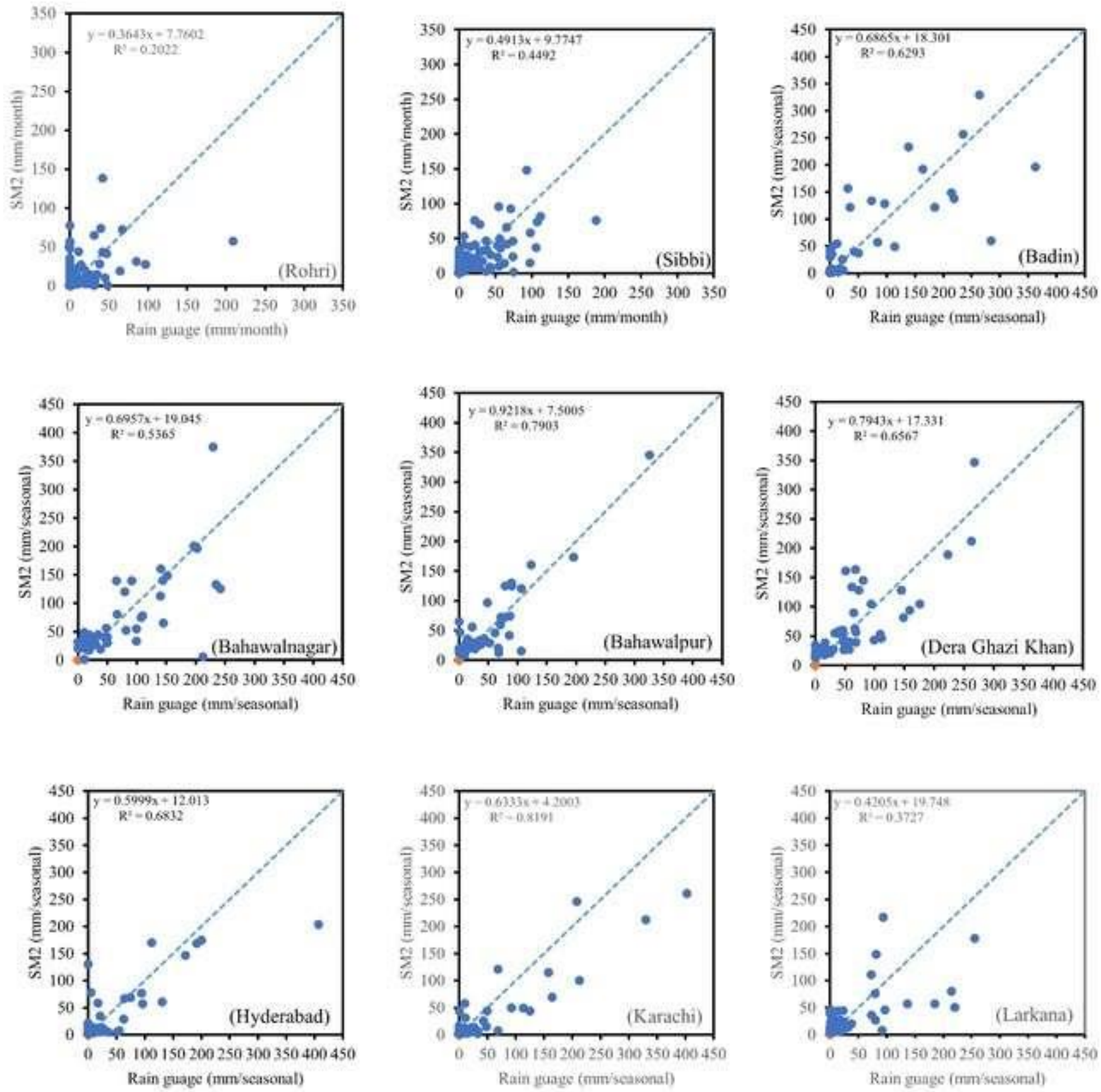
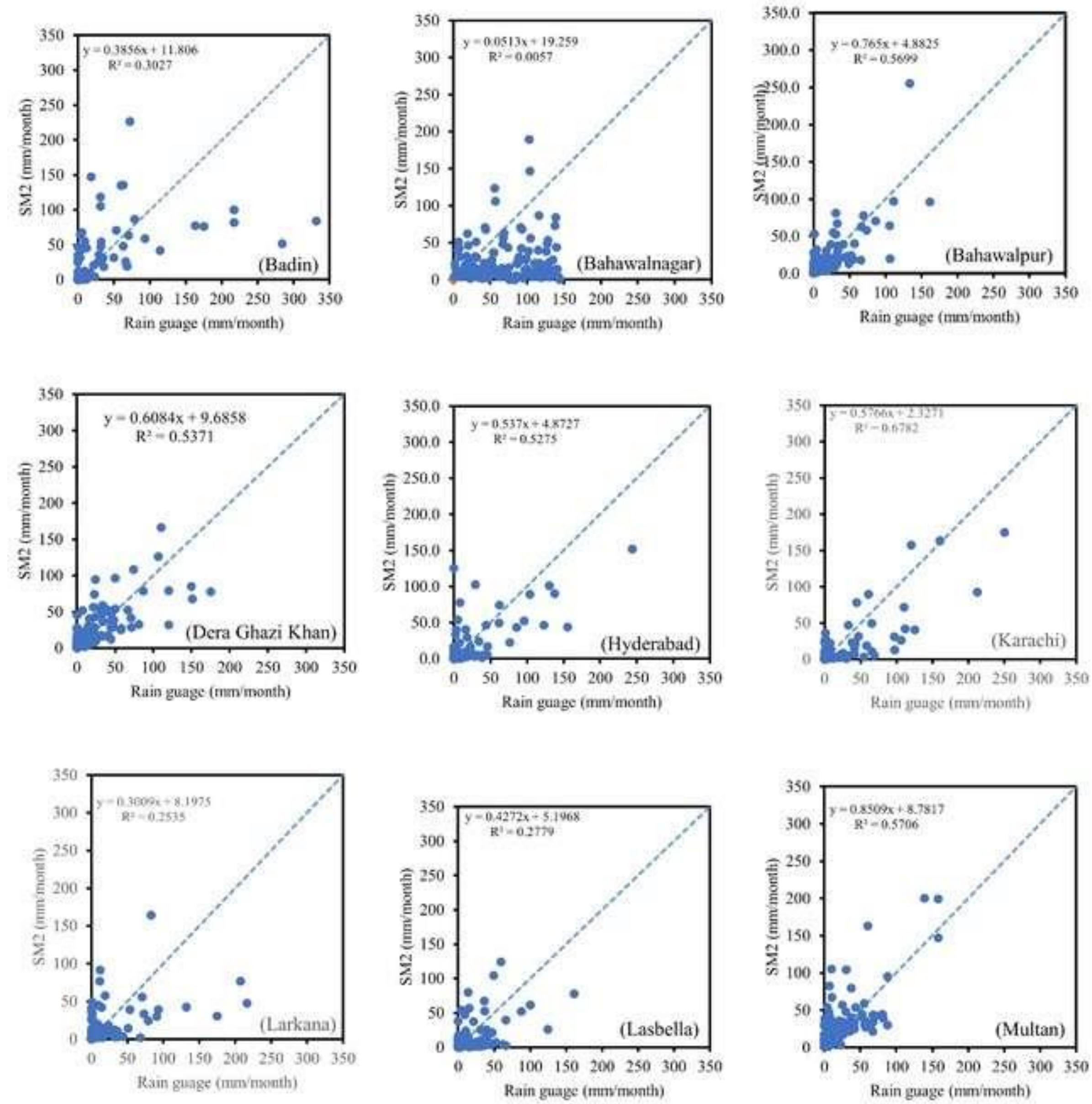
Statistical error MAE and RMSE were more at monthly, seasonally, and annually scale respectively, while the NMAE and NRMSE are vice versa. It was found that seasonal scale exists at intermediate conditions with best agreement, with average high R squared value (0.56) and low Pearson Correlation Coefficient (CC = 0.72) at seasonal scale. Table 02, shows monthly, seasonal, and annual evaluation results with the help of Table 4 evaluation indices that were used to compare the SM2 satellite precipitation against observed rain gauge data. The precipitation product can capture better in all season than summer season on seasonal scale with accuracy (R^2=0.09) and statistical errors scores were more in summer. While this precipitation product is most suitable for winter, spring and autumn by high value of R^2=0.98, 0.98, 0.99, respectively are shown in Table 2. Other discrepancies of error were less detected in winter season with best accuracy like previous studies (Yang et al. 2015)


y = 0.3856x + 11.806
R² = 0.3027
(Badin)
y = 0.0513x + 19.259
R² = 0.0057
(Bahawalnagar)
y = 0.765x + 4.8825
R² = 0.5699
(Bahawalpur)
y = 0.6084x + 9.6858
R² = 0.5371
(Dera Ghazi Khan)
y = 0.537x + 4.8727
R² = 0.5275
(Hyderabad)
(Karachi)
(Larkana)
y = 0.4272x + 5.1968
R² = 0.2779
(Lasbella)
y = 0.8509x + 8.7817
R² = 0.5706
(Multan)
SM2 (mm/month)
Rain guage (mm/month)


y = 0.3643x + 7.7602
R² = 0.2022
(Rohri)
SM2 (mm/month)
Rain guage (mm/month)
y = 0.4913x + 9.7747
R² = 0.4492
(Sibbi)
SM2 (mm/month)
Rain guage (mm/month)
y = 0.6865x + 18.301
R² = 0.6293
(Badin)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.6957x + 19.045
R² = 0.5365
(Bahawalnagar)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.9218x + 7.5005
R² = 0.7903
(Bahawalpur)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.7943x + 17.331
R² = 0.6567
(Dera Ghazi Khan)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.5999x + 12.013
R² = 0.6832
(Hyderabad)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.6333x + 4.2003
R² = 0.8191
(Karachi)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)
y = 0.4205x + 19.748
R² = 0.3727
(Larkana)
SM2 (mm/seasonal)
Rain guage (mm/seasonal)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R² = 0.3027
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R² = 0.0057
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R² = 0.5699
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R² = 0.5371
(Dera Ghazi Khan)
y = 0.537x + 4.8727
R² = 0.5275
(Hyderabad)
y = 0.5766x + 2.3271
R² = 0.6782
(Karachi)
y = 0.3009x + 8.1975
R² = 0.2535
(Larkana)
y = 0.4272x + 5.1968
R² = 0.2779
(Lasbella)
y = 0.8509x + 8.7817
R² = 0.5706
(Multan)
SM2 (mm/month)
Rain guage (mm/month)

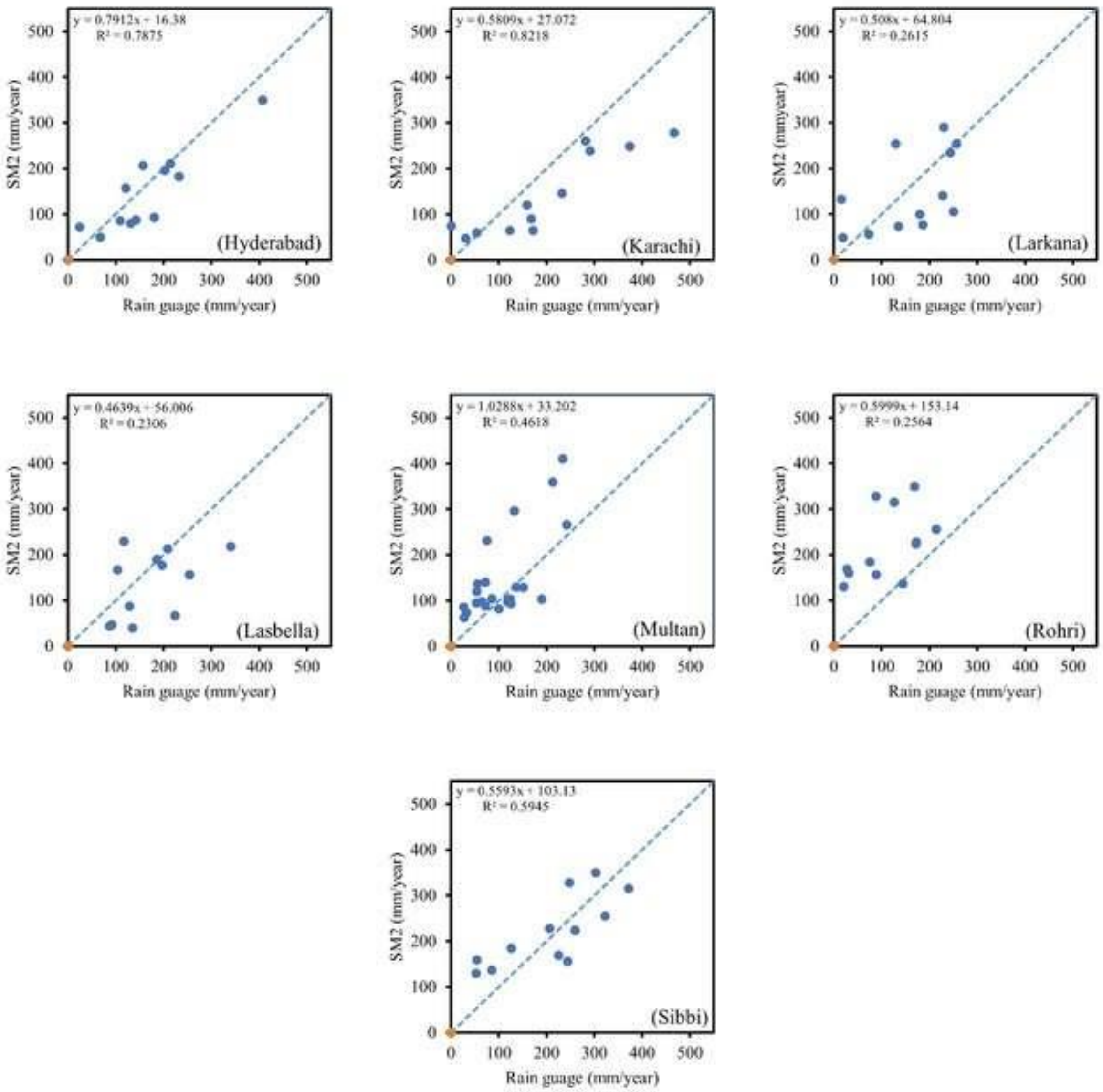

Figure 3. Scatter plots of SM2 SPP vs rain gauge precipitation data at different temporal scale. (a) monthly (b) seasonal (c) yearly scale, from Baddin to Sibbi station.

Accuracy of Precipitation Product at different intensities against Categorical Statistics

Figure 4, demonstrate the performance of precipitation product against different spatiotemporal scales. The high values of R (0.72 to 0.83) justify the best agreement. According to low statistical error of seasonal scale, best score of winter season recorded against other seasons. The score of NRMSE decreased significantly with increase of spatial temporal scale from monthly to annually (Ali, A.F. et al. 2017). Same results were existing for NMAE on all scale.

Figure 05, demonstrates the spatiotemporal scale at monthly as well as seasonally. In startup of the year coefficient of correlation was maximum with low scores of NRMSE and NMAE due to low rainfall intensity then decreasing gradually. Errors were also evaluated at seasonal and monthly scale. This result shows the comparison of precipitation product with gauge observation during all season. During pre-monsoon season (winter) SM2 product slightly overestimated (+5.13%) the precipitation but significantly overestimated (+14.58%) in summer season. Spring and autumn seasons also underestimate (-19.61% and -10.5%) the precipitation, respectively. Similar fluctuated results of have been observed in different region of the world at seasonal scale (Derin et al. 2016, Anjum et al. 2016, Chen et al. 2013). During pre- and post-monsoon season, the values of r were 0.78, 0.94, 0.90, 0.82 and 0.90 with best agreement, in January, February, march, April and October respectively. The score of NRMSE and NMAE were low during pre-monsoon season with moderate rainfall intensity. But pattern revealed opposite during summer season with more rainfall. NRMSE and NMAE showed a similar pattern with higher values of monsoon season due to more rainfall and in month of October with too much low rainfall (Ali, A.F. et al. 2017). It was concluded rainfall Intensity increases gradually in winter, autumn, spring and summer season respectively (Yang, X. et al. 2015). that precipitation product performs better in winter season with low BIAS and higher correlation coefficient (CC) than remaining season.

In South Asia summer monsoon rainfall frequently occurs in June, July and early August. Cyclones and storms usually occur during late July to September that cause more rainfall. Precipitation product SM2 completely fails to capture during summer season. (Svensson and Rakhecha 1998). The reliable agreement between observed gauge and SM2 product was found in summer monsoon and spring season. But the agreements with more accuracy were observed during autumn and winter.

Table 3. Statistical error characteristics of TMPA products at seasonal and annual scale

Statistical Error	**Seasonal**				**Annual**
-	Winter	Spring	Summer	Autumn	-
CC	0.96	0.91	0.88	0.89	0.83
ME	1.1	-5.5	15.97	-3.39	0.29
MAE	5.87	6.74	28.96	8.28	25.02
NMAE	25.62	29.86	23.08	28.6	12.52
RMSE	7.89	11.1	37.96	9.32	30.92
NRMSE	36.17	39.57	37.66	28.82	15.50
BIAS	5.13	-19.61	14.58	-10.5	0.14

The monthly results of categorical statistic (POD, FAR and CSI) variations of satellite-based rainfall data against observed rain gauge data for different rainfall threshold were assessed in Figure 6. POD and CSI higher range values (0.16 to 0.80) at rate of rainfall (< 80 mm/month) indicate the better performance of SM2 precipitation product but at high rate of rainfall intense (> 85 mm/month), POD and CSI were decreased. However, FAR score (0.38 to 0.77) was increased with increase of rainfall intensities up to (> 80 mm/month). Especially SM2 product at high values of monthly threshold record the higher risk of unreliable detection of monthly rainfall (< 10 mm/month) events. Evaluation results shows that worse score of all statistics with higher score of FAR and lower values of POD and CSI due to increase of monthly rainfall threshold values and SM2 satellite product having limited capabilities to detect high rainfall events.

Figure 7. represented that SM2 precipitation product in winter season over and underestimate the light precipitation intensities (< 30 mm/month) in . In spring season, slightly increased in precipitation intensities (< 67 mm/month) also represent underestimated moderate precipitation with reliable error and BIAS (20%). SM2 precipitation product is also reliable in summer monsoon season to detect the higher precipitation intensities (190 to 582 mm/month) with more BIAS (15%) and high score of FAR (0.51, 0.52 and 0.78) and low values of CSI (0.41,0.40 and 0.16) in June and July and August respectively. Due to current scenario of climate changes, more deflection were observed during low rainfall events in low elevation areas. Autumn season with rainfall events also indicated the under and overestimation of precipitation intensities (80 to 127 mm/month). Mostly satellite products in heavy precipitation intensities better detect in lower elevation with low statistical errors, while in low and moderate precipitation events vice versa. The SPP efficiency vary from area to area (Xu, R. et al. 2015). Precipitation product was not completely reliable in Badin and Hyderabad in the month of May and October due to low elevation from mean sea level and more precipitation intensity within study area while in other area, better agreements were detected in low elevation with intense precipitation.

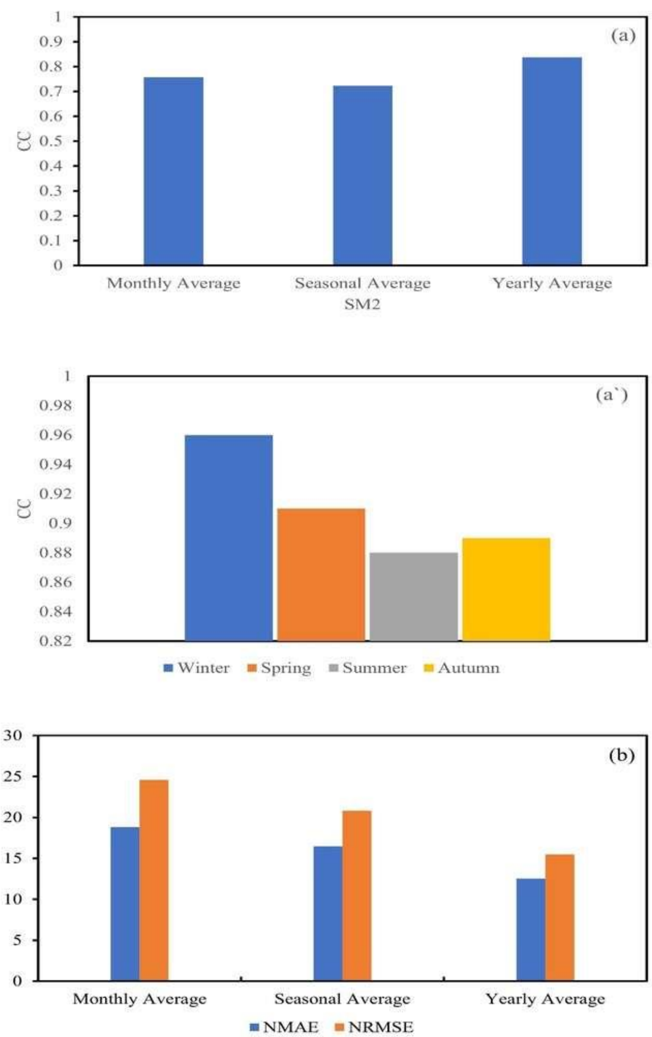

Figure 4. Comparison of validation indices for spatial temporal scales for monthly, seasonal and annual; (a,a`) correlation coefficient (CC), (b)normalized root mean square error (NRMSE) and normalized mean absolute error (NMAE).

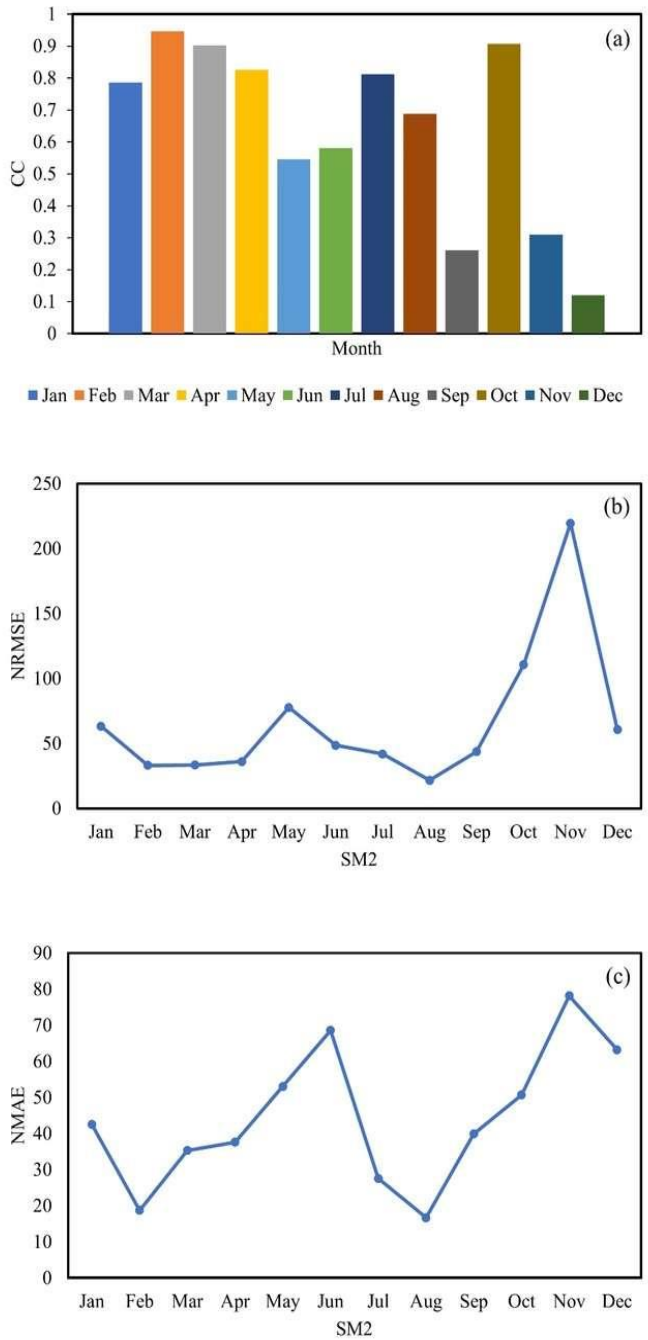

Figure 5. Mean monthly statistical indices (CC, NRMSE and NMSE)

Violent weather conditions (high speed wind, thunder and lightning) cause more rainfall and flood forecasting after September. Finding evaluation shows that SM2 satellite completely failed in capturing precipitation events in late October and November.

Table 3. Categorical statistics of SM2 for probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI).

Months	POD	FAR	CSI	Rainfall intensity (mm/month)
Jan	0.615	0.550	0.348	30.18
Feb	0.776	0.527	0.413	21.43
Mar	0.738	0.417	0.461	67.86
Apr	0.728	0.407	0.464	67.30
May	0.535	0.590	0.306	57.60
Jun	0.647	0.386	0.448	187.25
Jul	0.679	0.582	0.346	582.69
Aug	0.804	0.515	0.429	265.29
Sep	0.699	0.484	0.418	80.77
Oct	0.327	0.775	0.169	99.59
Nov	0.420	0.619	0.250	127.36
Dec	0.609	0.455	0.408	127.36

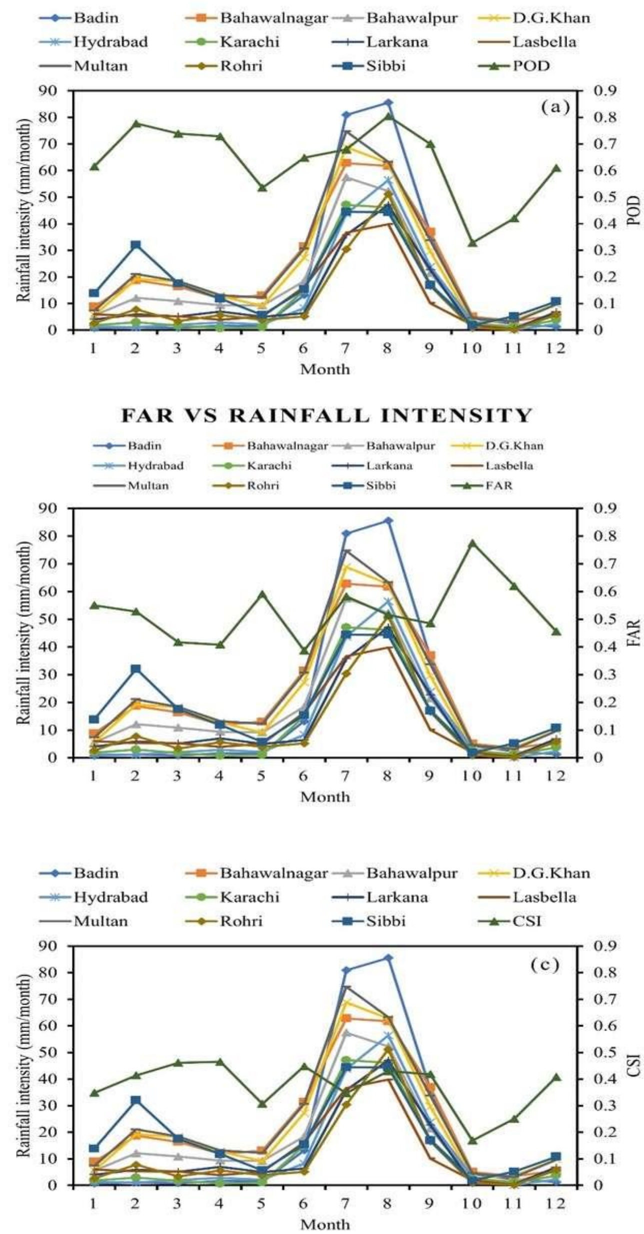

Figure 6. Categorical statistics of (SM2) for probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI).

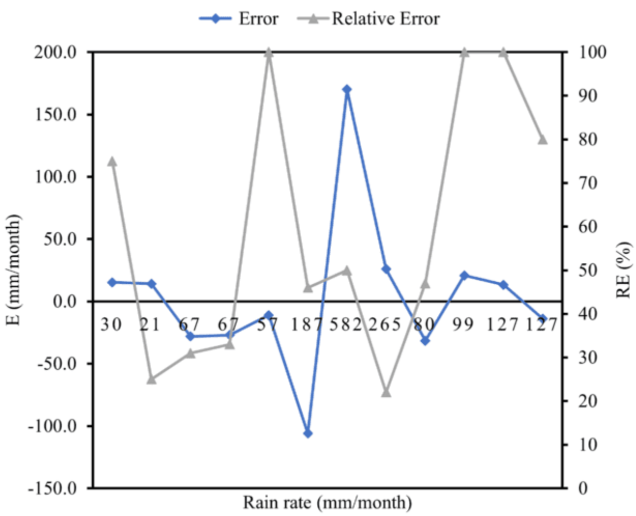

Figure 7. The precipitation differences and relative errors at different precipitation intensities for SM2 product.

Summary and Conclusions

This study was conducted to evaluate a challenging task of how much accurate a satellite precipitation product measure rainfall against ground-based measurement. The evaluated results performance of satellite product conducted at monthly seasonally and yearly scale. The product is further evaluated to capture different intensities of rainfall events at three different calibration periods for performance of satellite product over Pakistan. The average annual precipitation patterns show the fluctuating trends in north and south direction to check the performance of precipitation product by significantly observed changes. The assessment of scattering plots, statistical metrics and categorical statistics including R, ME, MAE, NMAE, RMSE, NRMSE, BIAS, CC, E, RE, POD, FAR and CSI are implemented at different spatiotemporal scale. In this study, the comparison and evaluation of satellite-based product data against rain gauge for utilization of SM2 precipitation product in Pakistan. The following results were concluded:

(1) The scattering plots result indicate the best agreement with high score (1.02) at seasonal scale between precipitation product and ground-based observed data than daily and yearly scale with minimum score (0.0057).

(2) Over the entire area best rainfall captured estimate with low error score and BIAS (5 to 19 %) and high correlation at seasonal scale but low accuracy was at monthly scale BIAS (4 to 132%) with more statistical errors. The precipitation events with low or high intensities indicate slightly over or underestimated precipitation while these precipitation events significantly overestimated against monthly scale and showed low performance than other scales.

(3) The satellite precipitation product showed moderate performance with less accuracy in spring, summer and autumn season. After cyclone period better performance was captured in winter season with better accuracy.

(4) The categorical statistics (POD, FAR and CSI) were used to detect the accuracy rate and agreement between satellite and gauge-based observations. Best score of probability of detection (>0.73) and CSI were observed with low value of FAR (0.41) in months of winter season and vice versa in other seasons. Satellite product is reliable to detect intense precipitation rate of seasonal scale than monthly and yearly. The statistical score of POD and CSI decreases with intense precipitation rate but FAR score increases with intense precipitation.

(5) SM2 precipitation product can capture low rainfall intensity with less accuracy at lower elevation (Badin and Hyderabad) while heavy rainfall events were captured with better agreement. It was found that precipitation product could captured the better precipitation event with good score of POD in the districts having more elevation in the study area at seasonal scale than monthly and yearly scale. POD score increased with increase of elevation in all season.

(6) SM2 satellite product is completely reliable on monthly scale but can capture precipitation intensities at monthly and yearly scale with low accuracy. This precipitation product was suitable at seasonally scale and calibrated with respect to pre-monsoon and post-monsoon seasons.

(7) High elevation areas with low altitude capture mostly overestimated precipitation at all scale discussed except in summer season due to more intense average precipitation rate (> 109.5 mm). At low elevation, underestimated precipitation is capture and vice versa in northern areas.

(8) Figure 8, illustrate that overestimated precipitation is captured at all scale in southern Punjab areas (Multan, Dera Ghazi Khan and Bahawalpur) having higher elevation and less altitude from SPP. Bahawalnagar and Cholistan desert area have slightly underestimated with different elevation.

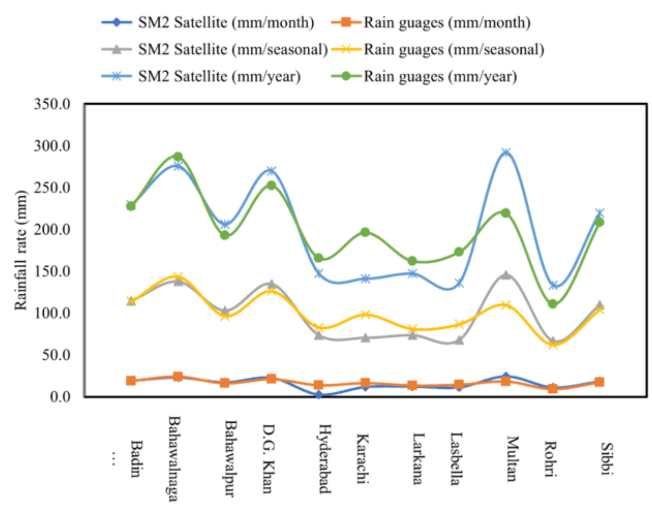

Figure 8. Comparison of average Rainfall rate at monthly, seasonally and yearly scale over the study area having different elevation.

This study shows that it remains always a challenging task for researchers to assess the performance of all new launched precipitation products at different region of the world for better use permanently. Low performance evaluation may be due to imperfectly insufficient number of gauges in region. More number of gauges also used to capture accurately and all precipitation events as well as bias correction reduced error. This report can help the Pakistan Meteorological Department to use this product at better scale. The question arises that whether this study assessment is feasible at different spatiotemporal scales will be identified and labeled in future analysis. Finding evaluations from this study, will give feedback to researchers and water resources managers during their research, practical work and algorithm developers to improve more this useful product.

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