Satellite Rainfall Products for analysis of Rainfall trends for Mahaweli River Basin

Helani Perera[a,*], Miyuru B. Gunathilake[b] & Upaka Rathnayake[a]
[a] Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka.
[b] Hydrology and Aquatic Environment, Natural Resources and Environment, Norwegian Institute of Bioeconomy Research,
1433, As, Norway.
helaniperera1@gmail.com , miyurubandaragunathilake@gmail.com , upaka.r@sliit.lk

ABSTRACT

The presence of accurate and spatiotemporal data is of utmost importance in hydrological studies for river basins. However, limited ground-measured rainfall data restrict the accuracy of these analyses. Data scarcities can often be seen not only in many developing countries but also in the developed world. Therefore, much attention is given to alternative techniques to accomplish the data requirement. Precipitation data extraction from satellite precipitation products is one of the frequently used techniques in the absence of ground-measured rainfall data. The Mahaweli River Basin (MRB) is the largest river basin in Sri Lanka and it covers 1/6th of the total land area of the country. Mahaweli River is the heart of the country and the water of it is being used for many activities, including hydropower development, water supply, irrigation, etc. Therefore, analyzing rainfall trends of MRB is interesting and worthwhile for many stakeholders of the river basin. Therefore, this research investigates the suitability of Satellite Rainfall Products (SRP's) as an alternative for Rain Gauge measured data in the MRB by performing trend analysis between the two datasets. Six precipitation products, namely PERSIANN, PERSIANN-CCS, PERSIANN-CDR, GPM IMERG V06, TRMM-3B42 V7, TRMM-3B42RT V7 were extracted for 10-35 years for 14 locations of the MRB spatially distributed in the three climatic zones of the catchment. Non-parametric tests, including the Mann-Kendall test and Sen's slope estimator tests, were used to detect the possible rainfall trends in precipitation products. Significant increasing trends were observed for both ground-measured and SRP's in the annual scale while mixed results were observed in monthly and seasonal scales. The trends from ground-measured rainfall and SRP's were compared and the suitability of SRP's as an alternative technique was stated.

KEYWORDS: *ground-measured rainfall data, Mahaweli River Basin, rainfall trends, satellite precipitation products, PERSIANN, IMERG, TRMM*

1 INTRODUCTION

Precipitation is of utmost importance when it comes to many hydrological studies. It plays an important role in climatic trends and the water availability on the earth. The natural water cycle is now heavily modified and had induced massive variability in the rainfall patterns throughout the country, thus the measurement of precipitation has become challenging and the importance of analyzing the rainfall trends has increased tremendously. The fields of hydrology, meteorology, geology, and ecology highly require and depend on proper rainfall data for future predictions and analysis to identify sudden changes in the environment and mitigate any damages to the ecosystem. Even though many global-scale trend analyses are present due to the scarcity of spatiotemporal rainfall data, researchers now have turned their focus onto carrying out trend analyses for more regional or local scales. But it is very clear that this is a difficult task if done with the use of ground gauge measurements due to several limitations it possesses. The main limitation is that ground gauge measurements are point measurements and the data cannot be applied for a wider area and therefore its coverage is very limited.

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For real-time application of rainfall data such as in flood and drought predictions, understanding global climate change, determining the water resources available to cater the human consumption, agriculture and industry, the data needs to be accurate. However, with the advancement of technology, the Satellite Rainfall Products (SRPs) had grabbed the attention of many researchers due to its ability to provide spaciotemporal rainfall data using the radar technology addressing to most of the shortcomings of the rain gauge measurements. But before using these SRPs it is of course necessary to assess the suitability of it to be used in hydrological analysis. Therefore, it is required to perform an intercomparison of these SRPs with ground gauge measurements and identify its degree of uncertainty before using them in real-time applications.

At present there are several SRPs and the methods they use to extract rainfall data differs from one to another and thus will be their accuracy. Tropical Rainfall Measurement Mission (TRMM) Multisatellite Precipitation Analysis (TMPA), Climate Prediction Center Morphing (CMORPH), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN), Multi-Source Weighted Ensemble Precipitation (MSWEP) are some of the SRPs that are widely in use with research studies. Therefore, analyzing the trend of several SRPs and comparing them with the gauge measurements is essential to obtain a sound conclusion on their levels of uncertainty and determine its suitability to be used in real-time hydrological applications. Trend analysis is suitable in these applications because it is an accurate method to predict future movements of the particular measurement.

Researchers had already performed several studies with SRPs in relation to several hydrological applications. JIANG et al., (2010) performed an evaluation of SRPs with surface rain gauge observations from Laohahe Basin in northern China and concluded that SRPs can have some large errors when it comes to high altitude and complex-terrain regions. Teng et al., (2017) and Zhu et al., (2011) integrated data from SRPs to study rainfall and soil erosivity. Bitew and Gebremichael, (2009) and Anagnostou et al., (2010) concluded that there are certain errors in the SRP data and that it can sometimes underestimate the real scenario which might be crucial when it comes to flood control analysis. Also, Bitew and Gebremichael, (2009) concluded that PERSIANN - Cloud Classification System (PERSIANN-CCS) misses rainfall rates under 1.6mm/day and therefore has difficulty in detecting light rainfall events according to the results they obtained from their study in Ethiopia. When it comes to trend analysis researches done in Sri Lanka, Khaniya et al. (2019) analyzed the rainfall trend in the Uma Oya basin for the prediction of water scarcity problems due to multi-development projects in that area. Usage of rainfall trend analysis for future flood hazard mapping was also presented by (Alahacoon et al., 2018). He had used data covering most parts of the country and concluded on an increasing rainfall trend in that area. Also, he had validated his findings with satellite images for the area of concern. Several other research studies done to determine trends and predict future adverse effects on the climate include the analysis of rainfall trends (Thevakaran et al., 2021) and (Herath and Ratnayake, 2004).

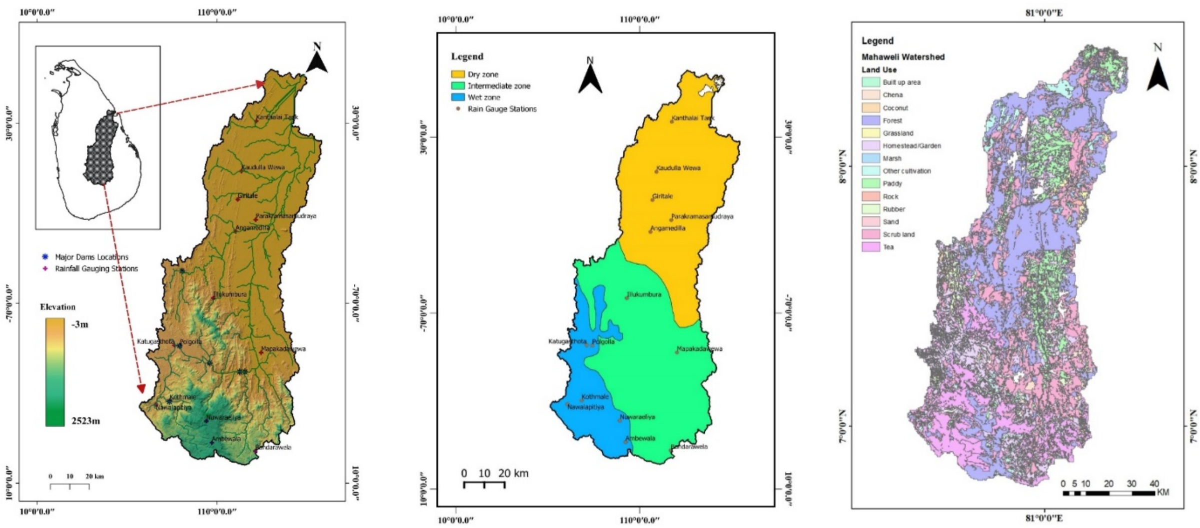
Trend analysis on SRPs and gauge measurements are being done in most of the countries and several research studies had been carried out in Sri Lanka as well as mentioned earlier. However, the researches that have been carried out in the Mahaweli River basin are mainly focused on areas such as water resource management in dry zonal paddy cultivation (Withanachchi et al., 2014), lain assessing the streamflow variability and rainfall trend of climatic zones (Shelton and Lin, 2019), drought occurrence and atmospheric circulation (Lin & Shelton, 2020) and it is clearly seen that researches which include the use of SRPs together with gauge measurements have not been done for the Mahaweli River basin which is the longest river in Sri Lanka spanning up to 335km. Being a river of utmost importance to our country due to its immense contribution to supply of water to various major activities in our country, it is definitely important to assess the availability of rain gauges in this area and find an alternative method to address any limiting rain gauge data so that future predictions can be performed accurately.

Therefore, in this research main focus is given to address this issue. Here, the Satellite Precipitation Products are compared with Gauge Measurements to analyze the trend and determine the accuracy of SRPs through non-parametric tests such as the Mann Kendal (MK) Test. Any uncertainties will be then quantified using Sens Slope Estimator for the Mahaweli River Basin, Sri Lanka. The results obtained will definitely be helpful to address the research gap that was identified in this area and be suitable for use in future hydrological studies.

2 STUDY AREA AND DATASETS

2.1 Study Area

The area of interest in this study is the Mahaweli River Basin (MRB), Sri Lanka. MRB is the longest river in Sri Lanka spanning to 335km. With Amban Ganga and Kotmale Oya inside the catchment, MRB flows from Horton Plains national park in Nuwara Eliya district to the sea from the southwestern side of the Trincomalee Bay. The MRB watershed is 10448km2 covering one sixth of the land mass in the country. Depending on the climatic and geographical distribution of annual rainfall amount, three climatic regions (wet, intermediate, and dry zones) are present in the Mahaweli catchment (Lin and Shelton, 2020). Also, the annual rainfall to the country is influenced by four monsoon seasons of Southwest Monsoon (SWM) in the months of May to September, Northeast Monsoon (NEM) from December to February, First-Inter Monsoon (FIM) during March and April and Second-Inter Monsoon (SIM) during October and November. Having the wet zone of the catchment in the southwest part of the country and dry zone in the northeast part of the country, the annual rainfall on the MRB is dependent on all these four seasons with the main ones being SWM and NEM (Malmgren et al., 2003). MRB is the main water supplier for agricultural activities in the eastern dry zone of the country irrigating more than 1000km2 of land. The hydroelectricity produced from six dams of the MRB supplies more than 40% of the country's electricity (Zubair et al., 2003). The elevation map, land use map and catchment distributed in the three climatic zones of MRB are shown in Figure 1.



(a) (b) (c)

Figure 1. (a) Rainfall Gauging Stations and Major Dam Locations of MRB, Sri Lanka, (b) Land Use Map, (c) Climatic Zone Map of MRB

2.2 Datasets

2.2.1 Ground Observed Rain Gauge Data

For the analysis, 25+ years of rainfall data were used. 14 rain gauge stations in the MRB covering all three wet, intermediate, and dry zones were obtained from the Department of Meteorology, Sri Lanka which is the official authority for the meteorological data collection of the country. The stations were selected considering the spatial resolution coverage of chosen satellite rainfall products as well. The spans of data were of different time scales. The 14 rain gauge stations that was selected with their location and time span are listed in Table 1 below.

Table 1: Details of Rain Gauge Stations

Rain Gauge Stations	Latitude	Longitude	Time Span
Ambewala	6° 52' 9.36"N	80° 47' 44.34"E	1983-2016
Angamedilla	7° 51' 18"N	80° 54' 25.19"E	1983-2018
Bandarawela	6° 49' 47.88"N	80° 59' 52.71"E	1983-2016
Giritale	8° 0' 16.10"N	80° 54' 58.58"E	1983-2017
Illukumbura	7° 32' 38.86"N	80° 48' 6.43"E	1983-2015
Kanthalai Tank	8° 22' 16.47"N	81° 0' 10.46"E	1987-2018
Katugasthota	7° 19' 26.78"N	80° 37' 13.96"E	1990-2019
Kaudulla Wewa	8° 8' 12.52"N	80° 56' 1.86"E	1983-2017
Kothmale	7° 3' 52.91"N	80° 35' 54.79"E	1985-2018
Mapakadawewa	7° 17' 21.55"N	81° 1' 32.78"E	1983-2016
Nawalapitiya	7° 2' 51"N	80° 32' 3.99"E	1989-2017
Nuwaraeliya	6° 58' 11.99"N	80° 46' 11.99"E	1990-2019
Parakramasamudraya	7° 54' 36.23"N	81° 0' 1.78"E	1983-2018
Polgolla	7° 19' 20.98"N	80° 38' 45.94"E	1988-2018

2.2.2 Satellite Rainfall Products

Similar to the gauge measurements, satellite rainfall products were also obtained for the 14 station locations mentioned in Table 1. The data range available varied with respect to when the satellite estimates began. However, the analysis was done for each satellite model data with each rain gauge station data depending on the data availability range of each of the datasets. 6 satellite data models were used in this analysis namely,

- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)
- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (PERSIANN – CCS)
- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Climate Data Record (PERSIANN – CDR)
- Integrated Multi-Satellite Retrievals for GPM (IMERG) Version 6
- Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) Version 7 3B42
- Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) Version 7 3B42RT

The general details of the SRP's that were used in the analysis are provided in Table 2 below.

Table 2: Details of SRPs

Product	Data Provider	Temporal coverage	Finest time resolution	Spatial resolution	Spatial coverage
PERSIANN	CHRS*	March 2000-present	1 hour	0.25°×0.25°	60°N-60°S
PERSIANN-CSS	CHRS	January 2003-present	1 hour	0.04°×0.04°	60°N-60°S
PERSIANN-CDR	CHRS	January 1983-present	1 day	0.25°×0.25°	60°N-60°S
TMPA-3B42	NASA*	January 1998-12/2019	3 hours	0.25°×0.25°	50°N-50°S
TMPA-RT	NASA	March 2000-12/2019	3 hours	0.25°×0.25°	60°N-560°S
IMERG	NASA	June 2000-present	30 minutes	0.10°×0.10°	90°N-90°S

*National Aeronautics and Space Administration, U.S.A. (NASA)
*Center for Hydrometeorology and Remote Sensing (CHRS)

2.3 Data Extraction

The six satellite products used in this study was extracted in different methods. PERSIANN group of products were directly obtained from CHRS data portal as CSV files. IMERG and TRMM products were obtained as NetCDF (Network Common Data Form) files from NASA GESDISC portal. Afterwards, IMERG was extracted through the process of merging the files in Climate Data Operator (CDO) followed by the extraction using R coding in RStudio. The TRMM products were merged using similar approach as in IMERG, but the extraction of the point rainfall data was done using MATLAB 9.6.

3 METHODOLOGY

Non-parametric tests were used to analyze the trend in the two datasets and to find the magnitude of the trends observed. Ultimately, the trend observed in both satellite data and rain gauge data were obtained through these tests.

To analyze the trends in the rain gauge and satellite data, the Mann Kendall (MK) Test was used. After obtaining the positive or negative trends from the MK Test, Theil's & Sens Slope Estimator was used to quantify the trends that were observed.

3.1 Mann Kendall Test

The MK Test (Mann, 1945 , Kendall, 1948) provides the significance of the trends that are observed in the rain gauge and satellite data. MK Test uses the hypothesis of H0 for no trend scenario and H1 when a trend is present in the datasets. The Mann Kendall Statistic, S is given by the following equation,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{1}$$

$$sgn(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases} \tag{2}$$

An increasing trend will be the outcome if S is having a very high positive value and decreasing trend if S is having a very low negative value. To compute the probability associated with the calculated S and the sample size to obtain a significance of the trend, (Kendall, 1948) describes a normal – approximation test incorporating the Mann Kendall Statistic, S. A normalized test statistic, Z is computed along with the probability associated with the Z value, f(z).

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad \text{where}, Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{t} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

Here, n = number of datasets, t = number of tied groups and t_i = number of datasets in the i^{th} group.

The probability density function, $f_{(z)}$ for a normal distribution with a mean of 0 and a standard deviation of 1 is given by,

$$f_{(z)} = \frac{1}{\sqrt{2\pi}} e^{\frac{z^2}{2}} \tag{4}$$

Taking a 95% significance level, trend will be determined to be decreasing if Z is negative and the probability is greater than 0.95. Similarly, the trend will be determined to be increasing if Z is positive and probability is greater than 0.95. If the probability is lesser than 0.95, then it was concluded that no trend is present in the datasets (Khambhammettu, P, 2005).

3.2 Theil-Sens Slope Estimator Test

To quantify and obtain a magnitude of the trends observed from the MK test, Sens Slope Estimator was used (Sridhar and Raviraj, 2017). Since the data sets used corresponds to the same time intervals and upon arranging the data sets in ascending order with time, the slope of each time series data pair was calculated using the following equation,

$$Q_k = \frac{X_j - X_k}{j - i} \tag{5}$$

where j > k, X corresponds to a data value at a j/k time and k = 1,2,…N

Upon arranging the N values in ascending order, the median value of the Sens Slope, Qi will be calculated using the equation given below,

$$Q_i = \begin{cases} Q_{\frac{n+1}{2}}, if\ N\ is\ odd \\ \frac{1}{2}\left(Q_{\frac{n}{2}} + Q_{\frac{n+2}{2}}\right), if\ N\ is\ even \end{cases} \tag{6}$$

4 RESULTS AND DISCUSSION

Mann Kendall Trend test was used to identify any significant trends in the observed data and SRPs. Then in order to quantify the trends obtained, Sen's Slope Estimator was used on the datasets.

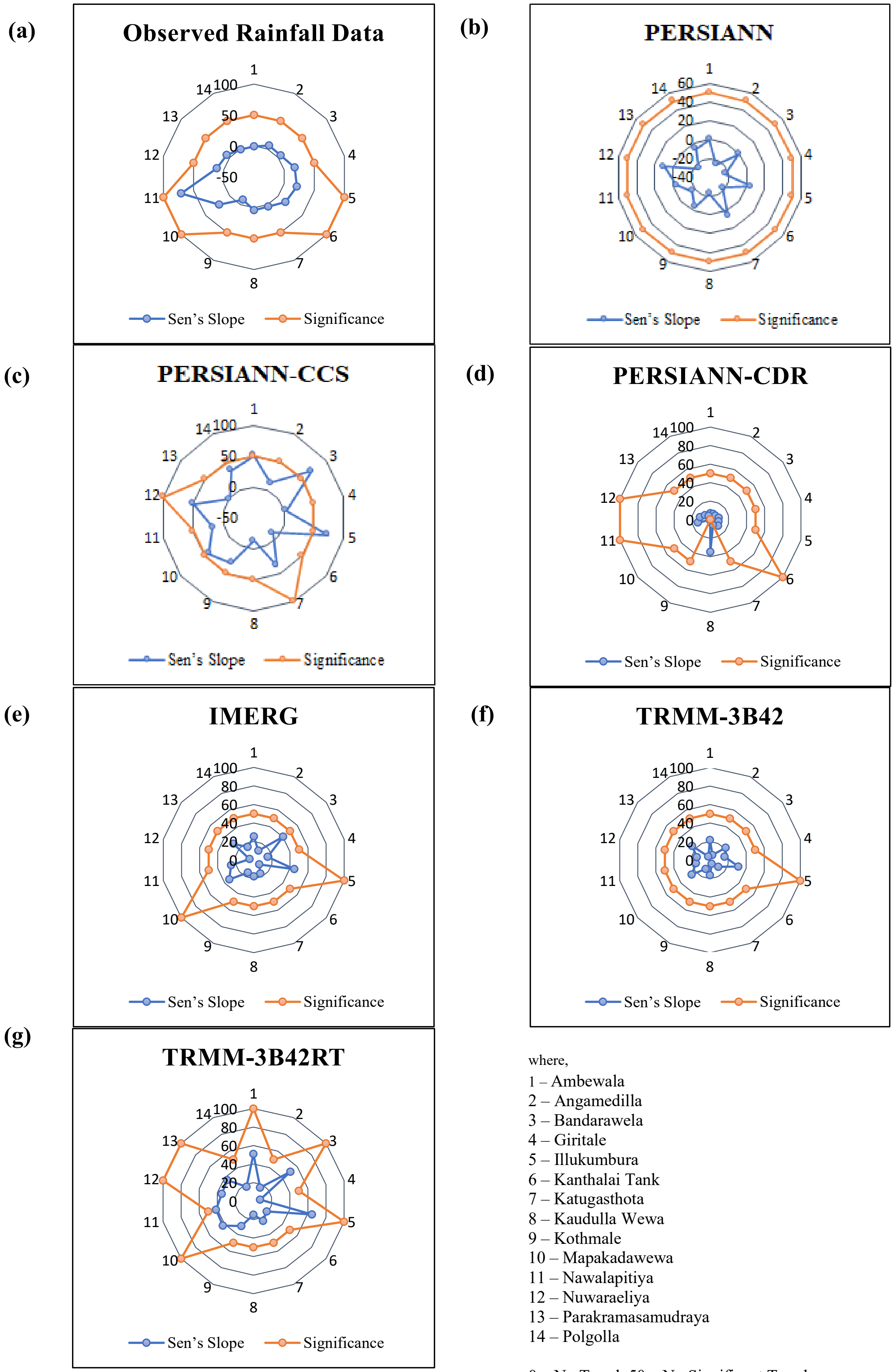
4.1 Mann Kendall Test

From the MK test that was performed for monthly, seasonal and annual time scales of the observed rainfall gauge data, showed significant increasing trends mostly in the intermediate zone of the catchment. Increasing trends in the seasonal analysis was mostly in the second inter-monsoon season. In the annual and monthly analysis, wet zone also showed significant increasing trends. IMERG product agreed more with the trends observed in the rainfall gauge data in the monthly and annual time scales. TRMM-3B42 showed significant increasing trends during the Second Inter monsoon in the intermediate zone. In TRMM-3B42 and PERSIANN-CDR, from the monthly analysis it was negative significant trends (dry zone) that were mostly observed. In all three time scales, PERSIANN-CCS showed increasing trends in the wet zone. However altogether, PERSIANN-CDR and TRMM-3B42RT showed mixed results while PERSIANN showed no significant trends in all three time scales.

4.2 Sens's Slope Estimator Test

The Sen's Slope (magnitude) of the trends obtained from MK test indicated a slope >1.5mm month-1 in the monthly analysis for the observed data. For the annual and seasonal analysis, the slopes were >20mm year-1 and >9mm month-1 respectively. In the monthly analysis IMERG indicated an increasing trend of >6mm month-1. High intensity increasing trend of >30mm year-1 in the annual time scale were observed in IMERG and both TRMM products. TRMM-3B42 showed increasing trends of >12mm month-1 during the second inter-monsoon season in the intermediate zone. The increasing trends shown by PERSIANN-CCS were >10mm year-1 in the annual analysis. The following Figure 12 highlights the MK and Sen's Slope Estimator results obtained for the annual time scale.

From this nonparametric analysis, the results concluded that IMERG product agrees more with observed rainfall data in monthly and annual time scales. This was further validated by Khalid et al., (2021) with his findings which concluded that IMERG product shows good agreement with rain gauge data when describing monthly trends in his study done in United Arab Emirates. Similarly, TRMM-3B42 appeared to agree more in the seasonal analysis and similar agreement in TRMM products has been observed in a study done in India which concluded that this product shows similar trend patterns to ground measured rainfall data in the annual and seasonal time scales (Mondal et al., 2018). So, depending on these results, careful choosing of products for the different zones in the catchment is required. It should be noted that the uncertainties observed in these products needs to be accounted for prior to using them in real-time applications (Mondal et al., 2018 and Feidas et al., 2006). This showed that even in the same catchment, products behave differently with trend patterns depending on the climatic seasons and zones of the catchment.



where,
1 – Ambewala
2 – Angamedilla
3 – Bandarawela
4 – Giritale
5 – Illukumbura
6 – Kanthalai Tank
7 – Katugasthota
8 – Kaudulla Wewa
9 – Kothmale
10 – Mapakadawewa
11 – Nawalapitiya
12 – Nuwaraeliya
13 – Parakramasamudraya
14 – Polgolla

0 – No Trend, 50 – No Significant Trend,
100 – Significant Trends

Figure 2. MK and Sen's Slope results for annual analysis (a) Observed Rainfall Data (b) PERSIANN, (c) PERSIANN-CCS, (d) PERSIANN-CDR, (e) IMERG, (f) TRMM-3B42, (g) TRMM-3B42RT

5 CONCLUSION

In this research study, six SRPs (PERSIANN, PERSIANN-CCS, PERSIANN-CDR, IMERG, TRMM-3B42, TRMM-3B42RT) were evaluated against observed rainfall gauge data. Observed data at 14 locations spatially distributed in the three climatic zones of the MRB, Sri Lanka were selected. The spatial resolution of the selected satellite products was also taken into consideration when selecting these station locations. From the non-parametric tests done on the two datasets (SRP and observed rainfall data) to identify any significant trends, it was concluded that IMERG product agrees more with observed rainfall data in monthly and annual time scales while TRMM-3B42 agrees more in the seasonal scale. In all three time scales, PERSIANN-CCS showed increasing trends in the wet zone. However altogether, PERSIANN-CDR and TRMM-3B42RT showed mixed results while PERSIANN showed no significant trends in all three time scales.

So, depending on these results, careful choosing of products for the different zones in the catchment is required. This showed that even in the same catchment, products behave differently with trend patterns depending on the climatic seasons and zones of the catchment. It was also clear that these products possess significant errors which cannot be ignored when using them in real-time hydrological applications. However, in places of scarce rainfall data in the MRB, IMERG product proved to be a better choice overall.

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REFERENCES

Alahacoon, N., Matheswaran, K., Pani, P., & Amarnath, G. (2018). A Decadal Historical Satellite Data and Rainfall Trend Analysis (2001–2016) for Flood Hazard Mapping in Sri Lanka. Remote Sensing, 10(3), 448. https://doi.org/10.3390/rs10030448

Anagnostou, E., Maggioni, V., Nikolopoulos, E., Meskele, T., Hossain, F., & Papadopoulos, A. (2010). Benchmarking High-Resolution Global Satellite Rainfall Products to Radar and Rain-Gauge Rainfall Estimates. IEEE Transactions On Geoscience And Remote Sensing, 48(4), 1667-1683. https://doi.org/10.1109/tgrs.2009.2034736

Bitew, M., & Gebremichael, M. (2010). Spatial variability of daily summer rainfall at a local-scale in a mountainous terrain and humid tropical region. Atmospheric Research, 98(2-4), 347-352. https://doi.org/10.1016/j.atmosres.2010.07.008

Feidas, H., Noulopoulou, C., Makrogiannis, T., & Bora-Senta, E. (2006). Trend analysis of precipitation time series in Greece and their relationship with circulation using surface and satellite data: 1955–2001. Theoretical And Applied Climatology, 87(1-4), 155-177. https://doi.org/10.1007/s00704-006-0200-5

Herath, S., & Ratnayake, U. (2004). Monitoring rainfall trends to predict adverse impacts—a case study from Sri Lanka (1964–1993). Global Environmental Change, 14, 71-79. https://doi.org/10.1016/j.gloenvcha.2003.11.009

Hussein, K., Alsumaiti, T., Ghebreyesus, D., Sharif, H., & Abdalati, W. (2021). High-Resolution Spatiotemporal Trend Analysis of Precipitation Using Satellite-Based Products over the United Arab Emirates. Water, 13(17), 2376. https://doi.org/10.3390/w13172376

Jiang, S. H., Ren, L. L., Yong, B., Yang, X. L., & Shi, L. (2010). Evaluation of high-resolution satellite precipitation products with surface rain gauge observations from Laohahe Basin in northern China. Water Science and Engineering, 3(4), 405-417.

Kendall, M. G. (1948). Rank correlation methods.

Khambhammettu, P. (2005). Mann-Kendall analysis, HydroGeoLogic Inc. OU-1 Annual Groundwater Monitoring Report–Former Fort Ord, California.

Khaniya, B., Jayanayaka, I., Jayasanka, P., & Rathnayake, U. (2019). Rainfall Trend Analysis in Uma Oya Basin, Sri Lanka, and Future Water Scarcity Problems in Perspective of Climate Variability. Advances In Meteorology, 2019, 1-10. https://doi.org/10.1155/2019/3636158

Lin, Z., & Shelton, S. (2020). Interdecadal Change of Drought Characteristics in Mahaweli River Basin of Sri Lanka and the Associated Atmospheric Circulation Difference. Frontiers In Earth Science, 8. https://doi.org/10.3389/feart.2020.00306

Malmgren, B., Hulugalla, R., Hayashi, Y., & Mikami, T. (2003). Precipitation trends in Sri Lanka since the 1870s and relationships to El Niño-southern oscillation. International Journal Of Climatology, 23(10), 1235-1252. https://doi.org/10.1002/joc.921

Mann, H. B. (1945). Nonparametric tests against trend. Econometrica: Journal of the econometric society, 245-259.

Mondal, A., Lakshmi, V., & Hashemi, H. (2018). Intercomparison of trend analysis of Multisatellite Monthly Precipitation Products and Gauge Measurements for River Basins of India. Journal Of Hydrology, 565, 779-790. https://doi.org/10.1016/j.jhydrol.2018.08.083

Shelton, S., & Lin, Z. (2019). Streamflow Variability in Mahaweli River Basin of Sri Lanka during 1990–2014 and Its Possible Mechanisms. Water, 11(12), 2485. https://doi.org/10.3390/w11122485

Sridhar, S., & Raviraj, A. (2017). Statistical Trend Analysis of Rainfall in Amaravathi River Basin using Mann-Kendall Test. Current World Environment, 12(1), 89-96. https://doi.org/10.12944/cwe.12.1.11

Teng, H., Ma, Z., Chappell, A., Shi, Z., Liang, Z., & Yu, W. (2017). Improving Rainfall Erosivity Estimates Using Merged TRMM and Gauge Data. Remote Sensing, 9(11), 1134. https://doi.org/10.3390/rs9111134

Thevakaran, A., Suppiah, R., & Sonnadara, U. (2019). Trends in extreme rainfall events in Sri Lanka, 1961 - 2010. Journal Of The National Science Foundation Of Sri Lanka, 47(3), 285. https://doi.org/10.4038/jnsfsr.v47i3.9280

Withanachchi, S., Köpke, S., Withanachchi, C., Pathiranage, R., & Ploeger, A. (2014). Water Resource Management in Dry Zonal Paddy Cultivation in Mahaweli River Basin, Sri Lanka: An Analysis of Spatial and Temporal Climate Change Impacts and Traditional Knowledge. Climate, 2(4), 329-354. https://doi.org/10.3390/cli2040329

Zhu, Q., Chen, X., Fan, Q., Jin, H., & Li, J. (2011). A new procedure to estimate the rainfall erosivity factor based on Tropical Rainfall Measuring Mission (TRMM) data. Science China Technological Sciences, 54(9), 2437-2445. https://doi.org/10.1007/s11431-011-4468-z

Zubair, L. (2003). El Niño-southern oscillation influences on the Mahaweli streamflow in Sri Lanka. International Journal Of Climatology, 23(1), 91-102. https://doi.org/10.1002/joc.865