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ASSESSING SATELLITE RAINFALL ACCURACY IN DENSE TROPICAL SABAH EAST COAST FOREST, MALAYSIA: A CROSS-VALIDATION OF DOWNSCALING TECHNIQUE

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Abstract

Rainfall is one of pivotal elements in the hydrological cycle that essential for ensuring the water balance in present and in the future. Traditional in-situ observations have been the conventional method for obtaining rainfall data, but their limitations arise from discrete point measurements that fail to represent the entire area. To overcome these limitations, this study utilizes satellite based TRMM data products for rainfall estimation. The research aims to cross-validate the TRMM 3B43-v7 product against corresponding in-situ measured rainfall, focusing on error localization in Sabah's east coast. The derivation of the rainfall rate from TRMM data is adequate with additional data from three manual gauges within the plots. The correlation between TRMM and ground was good (R2 = 0.78, RMSE = 65.65 mm). The Nash and Sutcliffe Error results closed to value 1 indicate that the accuracy of the TRMM data compared to the rain-gauge data in Danum has a good agreement. This is due to the IDW downscaling method for satellite rainfall data using additional data from three manual-gauges within the plots to increase the accuracy of the TRMM data. In summary, the downscaling method proves capable of providing fine spatial resolution and increasing the number of pixels in the study area. Future research endeavours may benefit from incorporating more station data to further improve the interpolation of satellite data and derive more precise results.

Keywords: Rainfall, TRMM, satellite data, climate, downscaling

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INTRODUCTION

Accurate measurement of rainfall is crucial for understanding and modelling the Earth's hydrological cycle, particularly in the tropics that receive high annual rainfall. While traditional rain gauges offer high accuracy, they are limited to small areas, hindering a global perspective on hydrologic water balance. Remote area face challenges due to the cost of maintaining rain gauge stations, leading to measurement inaccuracies. Ground radar technology has addressed some limitations by providing high spatial-temporal capabilities, although it is still confined to a specific range of kilometres. Overall, the quest for precise rainfall data remains essential for robust hydrological modelling worldwide.

To address the limitations of traditional methods, this study employs remote sensing data, which offers valuable insights on a global scale and has been extensively utilized in various fields such as for forestry (Latip et al, 2022: Lindah Roziani et al, 2022; Jamru, Hashim and Phua, 2019; Jamru & Hashim, 2018; Jamru, 2018; Jamru & Hashim, 2015), Land use change (Jamru & Rahaman, 2018; Jamru, Rahaman & Ismail, 2013), agriculture (Jamru, Sharil & Yusoh, 2023; Jamru et al, 2023), urban (Shao et al, 2023; Latip et al, 2022) and hydrology (Mahmud et al, 2018).

In this study, rainfall rates are derived using TRMM3B43 Version 7 data obtained from the Tropical Rainfall Measuring Mission Multi-Satellites Precipitation Data Analysis, commonly known as TMPA. This dataset is chosen due to its frequent revisit times and extensive spatial coverage. The TRMM data product covering the latitude 50^{o} was provided by the TRMM multi-satellite precipitation analysis by integrated precipitation estimates from multiple satellites and rain gauge. This study used TMPA 3B42 Version 7 data product, it provides a standard three-hourly rain rate at a global scale with a resolution of 0.25 degrees. The daily amount of rainfall is obtained by multiplying the average three-hour rainfall rate by eight datasets per day. The daily rainfall amount is then accumulated to estimate monthly rainfall.

Besides the advantage given by TRMM satellite data, there are also restrictions in using these data due to the limit of the coarse spatial resolution. Thus, the fine spatial temporal is limited only to a certain extent and is not applicable to a small area. In this study, re-projection and Inverse Distance Weighted (IDW) interpolation methods were used to obtain spatial resolution data of 1m to show the variation of rainfall. For assessment of rainfall rates, nominal assessment methods were used, for instance, root means square error (RMSE), bias analysis, coefficient of determination (R^2), and Nash- Sutcliffe Efficiency (NSE) are the commonly used ones in hydrology and related industries because it is robust and understandable by natural resources managers.

This study significantly contributes to the enhancement of our knowledge on the usefulness of TRMM rainfall at varying spatial and temporal scales. The ability of the satellite to measure the hydrology element in remote areas with consistent spatial and temporal resolution provides a new opportunity in this field. Besides, with each of the same sensor capabilities improved with NASA's new sensors (e.g. Aqua and Terra Satellites), high-quality data can be produced. In addition, data providers are now starting to merge data such as the precipitation product (infrared, radar, and visible sensor) into TMPA to provide better information. Thus, the estimation of rainfall rate is now within our reach.

LITERATURE REVIEW

Accessible Satellite-Based Precipitation Estimation

Over the years, numerous precipitation retrieval attempts have been made by launching multiple Earth-orbiting satellites (Turk and Miller, 2005). Several satellites have been launched, for instance, Climate Prediction Centre (CPS) morphing technique (Joyce *et al.*, 2004), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (Hsu *et al.*, 1997), Tropical Rainfall Measurement Mission (Huffman *et al.*, 2010), and Global Precipitation Measurement (GPM).

Among all the satellites, TRMM is the most well-known that delivers rainfall estimation from 50ºN to 50ºS in earth grid. This satellite-derived rainfall utilizes numerous advance sensors integrated together, which are active sensors (precipitation radar) and passive sensors (the visible and Infrared Scanner (VIRS) and the TRMM Microwave Imager (TMI) (Kummerow *et al.*, 1998). The TRMM TMI measured precipitation rates over the tropical regions as a collaborative science activity between NASA and the Japan Aerospace Exploration Agency (JAXA) (Maggioni, Meyers and Robinson, 2016). There are two types of rainfall measurements; and both methods had pros and cons.

First, direct methods that need visible and infrared wavelength to be incorporated together to observe cloud behaviour, for instance, temperature and external content differences. The benefit of this approach is that it is better suited for a large region. Second, the direct approach that used microwave wavelength to calculate precipitation rate (Todd *et al.*, 1995). The benefit of the direct approach is that it includes the rate of precipitation within time, which ensures that it is reliable in real time. The combination of the two types of methods contributes to a broader field of precipitation estimation of inaccurate real-time rainfall (Jobard, 2001).

TRMM rainfall is developed based on equations that combined various inputs from the available sensors. There a several versions of TRMM, such as the Version 1 data for the year 2007. The next introduction was accompanied by an upgrade in Revision 1.1 (2007), 1.2 (2007), 1.3 (2009), 1.4 (2010), 1.5 (2010), 1.6 (2010), 1.7 (2011), 2 (2012), and 2.2 (2013) for the respective years. All data released are corrected for their data limitations, failure of the sensor, uncertainty of accuracy, and enhanced coverage (Huffman *et al.*, 2010) to improve the function of an input hydrological elements and improve satellite rainfall measurement techniques. Serrat-Capdevila, Valdes and Stakhiv, (2014) evaluated the latest of satellite precipitation products (SPPs) in hydrology and water resources management and demonstrated the utility of reliable precipitation measurements for landslide modelling, flood alerts, early warning systems, and reservoir operations.

TRMM 3B42 has been shown to be better than other precipitation satellite in terms of error rates, correlation with field data, and average errors in several regions. It was due to the bias correction contained in the formula, even though the research product may be heavily biased in regions with insufficient gauge coverage. However, 3B42 indicates a low detection likelihood (below 50%) in the equatorial region (Maggioni, Meyers and Robinson, 2016).

METHODOLOGY

Two data sets were used in this study, which are satellite-based precipitation and in-situ ground-based rainfall (rain gauge). Rainfall derived from TRMM satellite-based data product and ground rainfall data for station Sandakan and Tawau provided by Meteorological Department of Malaysia, and ground data in Danum Valley was collected by researcher. Both satellite and in-situ data used are from March 2015 until March 2016. Figure 1 shows the process of derivation rainfall data.

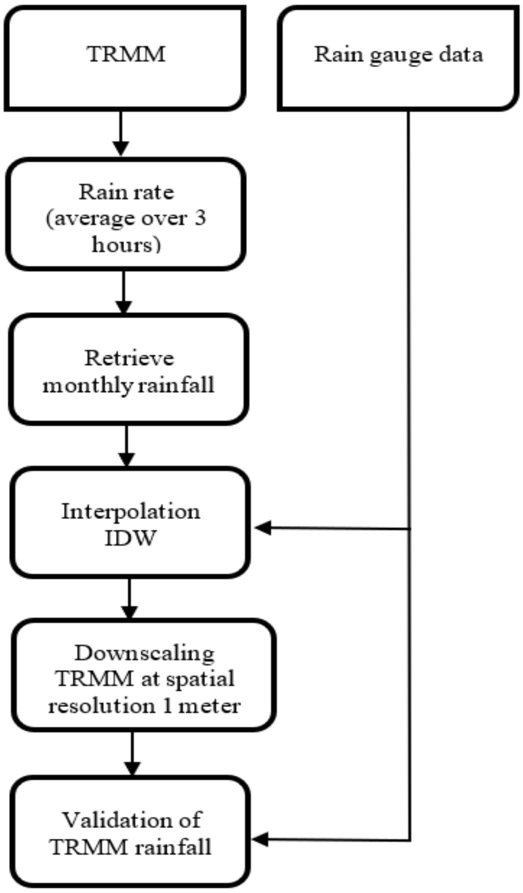


Figure 1: Flowchart processing of rainfall data

TRMM Multi Satellites

The TRMM Multi Satellites Precipitation Analysis (TMPA) presents the rainfall data. In this study, the hourly gross rainfall is downloaded from the official website http://mirador.gsfc.nasa.gov with a temporal resolution of three hours and spatial resolution 0.25 degrees. Hourly precipitation data is derived by summing up all sets of three hourly TRMM precipitation for one day and multiplied by days in a month. The data in the Hierarchy Data Format (HDF) provide information such as rainfall, relative error, and gauge relative weighting. The monthly data from March 2015 to March 2016 were acquired. Table 1 summarized the general description of the product. The spatial resolution of 5km was downscaled to 1m using IDW resampling method.

Table 1: Summary of the TRMM satellite data product

Satellite	Tropical Rainfall Measuring Mission
Data provider	Nasa Aeronautics and Space Administration (NASA)
Product name	3B42
Data format	HDF
Data coverage	4° 00' to 7° 00' N latitudes and 115° 20' and 119° 20' E longitudes
Spatial resolution	0.25 degrees
Date of data acquisition	March 2015 until March 2016

In order to derive the monthly basis rainfall (mm), the TRMM unit mm per hour is multiplied by 24, which represents 24 hours per day and multiplied by the number of days per month as described in equation 1.0 (TRMM Instruction Manual, 2005).

$$Rs = R_{TRMM} \ . H_t \ . D_m \tag{1.0}$$

where, R_s is the monthly satellite-based rainfall estimation; R_{TRMM} is a raw TRMM satellite data; H_t is a total of hours per day (set to the constant of 24), and D_m is the total day per month. The original spatial resolution of TRMM data is 5km, to standardise spatial resolution with other data, the downscaling processes were carried out. The IDW interpolation method was used to obtain a finer spatial resolution of 1m. Table 2 shows the location of the gauges used to downscale the TRMM data.

Table 2: The coordinate location for rain guage within the study area

Name	Y	X
Danum	4.963457	117.802877
Rhino	4.9700401	117.808465
Baru	4.976347	117.812072
Tembok Gajah	4.973476	117.816282
Sandakan	5.899698	118.057375
Tawau	4.31122	118.121187

In -situ Gross Rainfall

Ground rainfall data for station Sandakan and Tawau provided by Meteorological Department of Malaysia, and ground data in Danum Valley was collected by researcher. For rainfall measurements, there are three manual rain gauges with a diameter of 11.6 ±0.2cm, located in an open area at a distance around 100m from the plot and 20m from the forest boundary. The automatic rain gauge located at 903.77m from the plot area was used as a reference for daily rainfall. Rainfall volume collected was measured using a graduated cylinder with an accuracy of 1ml. The rainfall volume of each collector was determined using the equation in Hornberger et al. (2014). Figure 2 shows the location of three main rain gauges for gross rainfall located within the study plots.

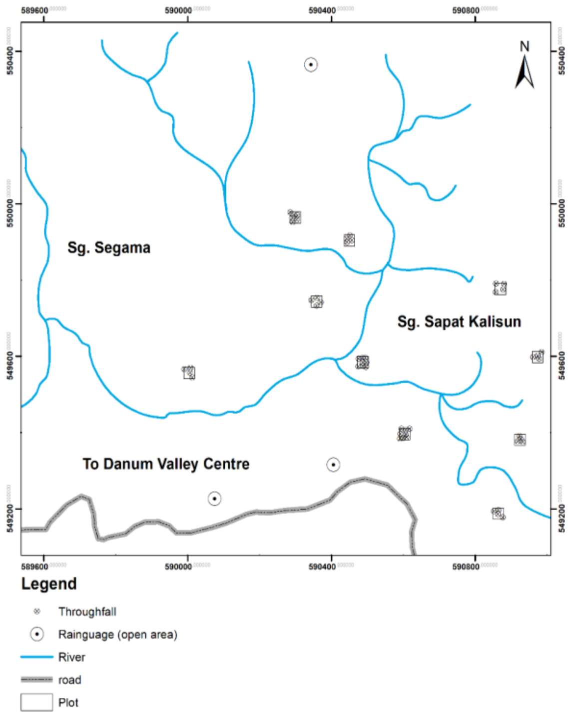


Figure 2: Map showing the location of main rain gauges

Downscaling Satellite Data

Monthly rainfall at 1m resolution was generated using IDW interpolation method in the ArcGIS software package. The TRMM data was downscaled from the original 5km resolution to a resolution of 1m. The original rainfall value of the TRMM data was retained. Merging the in-situ data to downscale the satellite data in the tropics is useful, such as the process done by Yatagai et al. (2014) and Mahmud et al. (2018).

The outcome of the spatial downscaling processes managed to produce a higher resolution of the TRMM data. Figure 3 (a) shows the raw satellite data, (b) first process is re-gridding the raw satellite data, and (c) re-calculating the values of each pixel and combining them with the six rain gauges data for rainfall. The proposed downscaling method can be used to create high resolution rainfall maps in the highly dynamic hydro-meteorology status quo of humid tropics, with less complex computation and more reliable results (Mahmud et al., 2018).

(a) (b) (c)

Raw Satellite data | Re-gridded satellite data | Downscaled satellite data

Figure 3: Flowchart processing of meteorological data
(Source; Mahmud et al., 2018)

RESULTS AND DISCUSSION

The Correlation Estimation Rainfall Interstation data with TRMM data

Rainfall has high spatial variability in both space and time. As a result, the measurement of daily rainfall has a constraint, especially in the study area. There is no automatic rain-gauge within the study area. Figure 4 presents the correlation of rainfall data collected by automatic gauges, manual gauge data, and TRMM data. Pg1 is rainfall data from the automatic gauge in Danum Centre; Pg2 is rainfall data from gauge 2; and Pg3 is rainfall data from gauge 3. The relationship between Pg1 and Pg2 with Pg3 data shows a high correlation with R^2 of 0.83 and 0.75, respectively. However, Pg3 has a low correlation with R^2 of 0.26. The variation of rainfall data from gauge 3 only corresponds to about 26% of the TRMM data, while the remaining 74% was due to spatial distribution that affected the amount of rainfall.

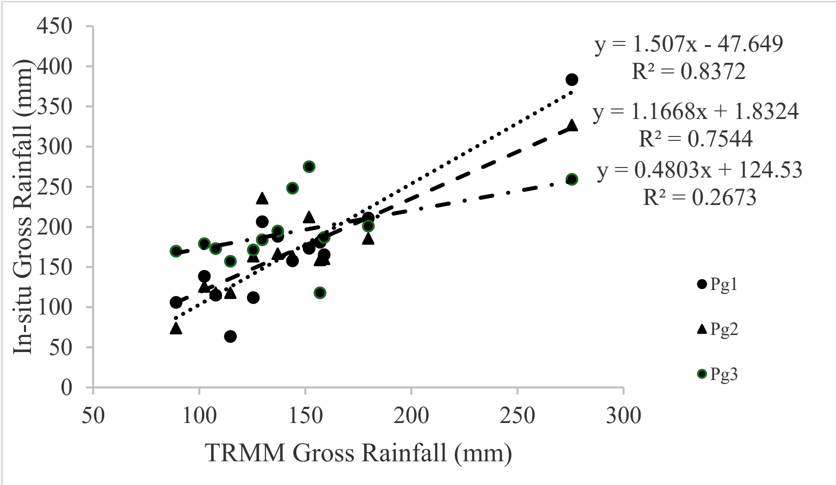


Figure 4: Correlation of rainfall data collected by automatic gauges, manual rain-gauges, and TRMM

The effect of Pg derived from TRMM data with a correlation coefficient of interstation rainfall gauges can be analysed using the Pearson correlation, as shown in Table 3. There is a significant correlation between the three rainfall gauges and TRMM data in the study area. The Pg from gauge 1 and TRMM data have the highest correlation, while the Pg from gauge 2 shows low correlation at p >0.01. This suggests that, although the spatial distribution of rainfall distribution is significant, there is no difference between plots. Still, the conditions may be different when examining storms separately and it is essential to note that the data set from the manual gauges is obtained on the basis of the cumulative measure of several rainfall events. Therefore, there may be some possibility to overestimate or underestimate the rate of rainfall in manual gauges.

Table 3: Correlation coefficient of interstation rainfall gauges

		Pg1	Pg2	Pg3
Pg1	Pearson Correlation	0.901**		
	Sig. (2-tailed)	0.000		
Pg2	Pearson Correlation	0.520	0.599*	
	Sig. (2-tailed)	0.69	0.031	
TRMM	Pearson Correlation	0.915**	0.869	0.517
	Sig. (2-tailed)	0.000	0.00	0.070

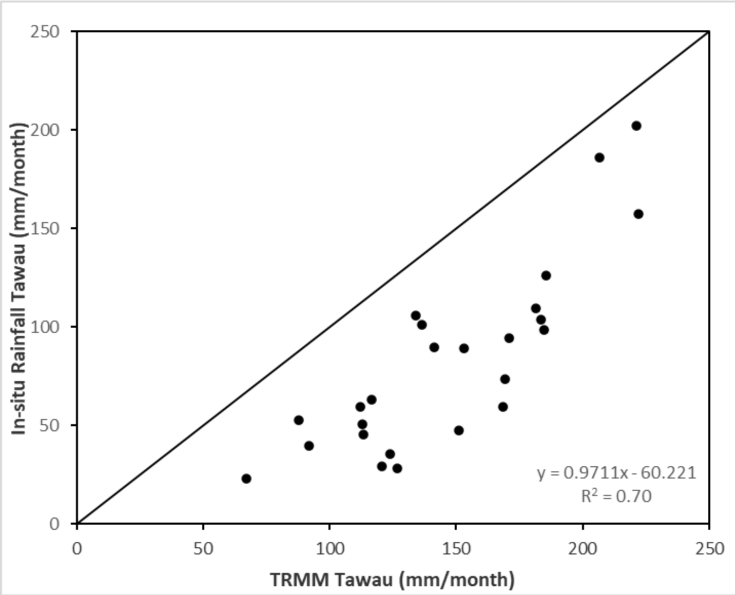
**: Correlation is significant at the 0.01 level (2-tailed).

Validation on the TRMM Data Products

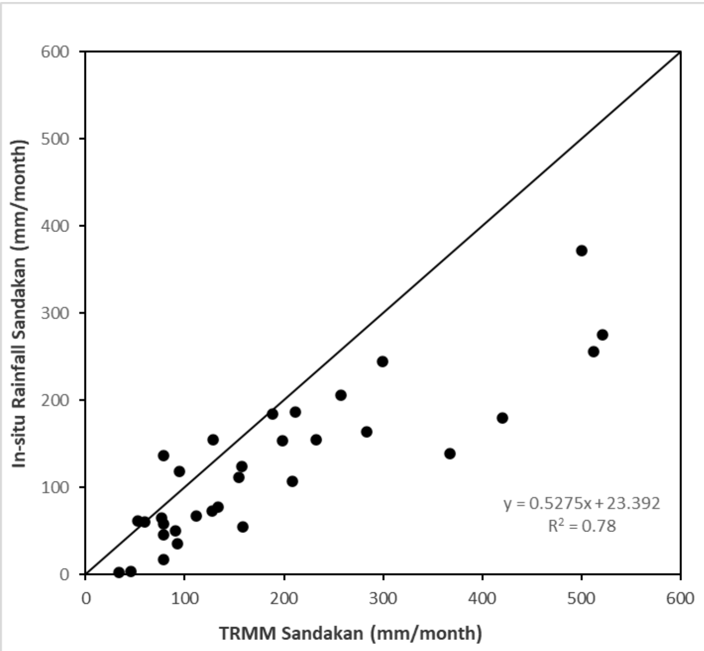
Figure 5 shows the correlation between TRMM satellite data and ground measurement. Based on linear regression, Tawau, Danum and Sandakan recorded R^2 with 0.70, 0.78, and 0.70, respectively. Overall, the R^2 for the three stations show a good correlation between satellite data and ground measurement with p-value (<0.0001). The lowest monthly rainfall recorded for Tawau, Sandakan, and Danum are 22.88mm, 33.74mm, and 82.34mm, respectively. While the highest monthly rainfall recorded for Tawau, Sandakan, and Danum are 331.62mm, 520.95mm, and 254.65mm, respectively.

As can be seen, there are significant differences in the highest and lowest rainfall recorded by the station in Tawau and Sandakan with 58% and 37%, while Danum recorded a 20% difference. Spatial homogeneity at the regional scale in the temporal pattern within the three-station region relates to the effects of land-sea interaction in coastal regions (Johnson and Priegnitz, 1981) and the influence of various large-scale air flows (for instance equatorial easterlies and equatorial westerlies) in central and eastern Sabah (Kripalani and Kulkarni, 1998).

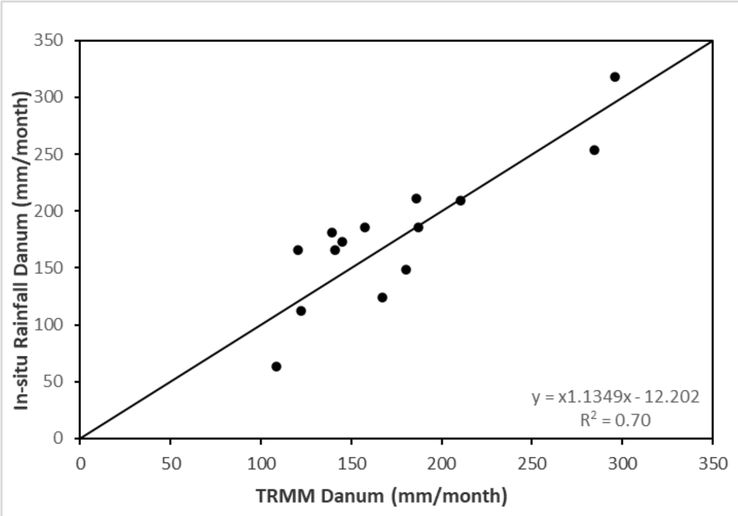
This shows the influences of strong maritime and local topographic variations at the local scale. Sandakan and Tawau are located near the South China Sea, while Danum is not affected by the maritime condition, but by the topographical terrain. According to Cosma, Richard and Miniscloux, (2002), topographic control of rainfall patterns is well understood on a scale of tens or hundreds of kilometres, while Sharon and Arazi (1997) proved that the topography also influences rainfall patterns on a very fine scale of several tens or hundreds metres. In addition, findings by Bidin and Chappell (2003) noted that there is high spatial variability in seasonal rainfall over only a few 100 metres, which will make it difficult for researchers to monitor reliable rainfall records.


250
200
150
100
50
0
0
50
100
150
200
250
In-situ Rainfall Tawau (mm/month)
TRMM Tawau (mm/month)
y = 0.9711x - 60.221
R² = 0.70

(a)


600
500
400
300
200
100
0
0
100
200
300
400
500
600
In-situ Rainfall Sandakan (mm/month)
TRMM Sandakan (mm/month)
y = 0.5275x + 23.392
R² = 0.78

(b)



(c)

Figure 5: In-situ monthly rainfall against TRMM rainfall plotted on 1:1 line and the regression equation for stations (a) Tawau; (b) Sandakan; (c) Danum

As for the RMSE, Tawau, Sandakan, and Danum recorded errors of 69.25mm, 72.25mm, and 65.65mm, respectively. Therefore, the bias analysis results show that the Tawau station reported the highest overestimated bias with 64.47mm, while Danum reported the lowest bias with 0.29mm. Since the bias in the study area shows less than 5%, this presupposes that the variation of rainfall can be estimated directly from TRMM data, and the calibration may not always be necessary.

Based on Figure 6, the values of NSr for Tawau, Sandakan, and Danum are -1.193, 0.84, and 0.89, respectively. The NSr results, close to value 1, show that the accuracy of TRMM data compared to the rain-gauge data in Danum has a strong agreement. This is due to the downscaling method of IDW approach to satellite rainfall data using additional data from three manual rain-gauge within plots in Danum Valley capable of improving accuracy, compared to the Tawau and Sandakan stations. More importantly, the downscaling method has been able to provide fine spatial and increase the number of pixels in the study area. This suggests that the more station data we used to interpolate TRMM data, the more accurate it was. Overall, from the analysis data, there is a strong indicator that the quality of TRMM data varies within different regional environments and conditions, including local factors, such as wind, topography, and maritime influences, which have significant impacts.

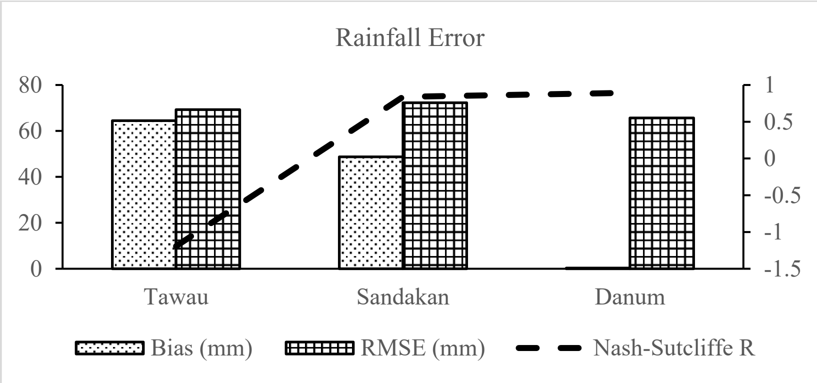


Figure 6: Precipitation errors of the stations in Tawau, Sandakan, and Danum

CONCLUSION

The use of remote sensing measurements to assess rainfall is a significant and relevant step in understanding the hydrological process in the watersheds. This study provides a basic guideline on how to monitor and evaluate rainfall using remote sensing observations. Many demonstrations on the use of remote sensing have been developed for the estimation and mapping of the spatial distribution of rainfall with a combination of field data. The collection of sufficient information on the spatial distribution of rainfall will need the installation of an additional ground station at high spatial coverage, which would be expensive for logistics. However, derived rainfall data from remote sensing data for monitoring can complement field data by providing consistent observations and minimize the costs.

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REFERENCES

Abdul Latip, N., & Umar, M. U. (2022). A SUSTAINABLE CARBON FOOTPRINT ANALYSIS FOR THE CITY OF KUANTAN, PAHANG MALAYSIA. *PLANNING MALAYSIA*, *20*(23). doi:10.21837/pm.v20i23.1147

Abdul Latip, N., Roystones Steven, S., Rashid, R., Karim, R., Umzarulazijo Umar, M., Hussin, R., Pirdaus Yusoh, M., Stephen, J., Andin, C., & Kanyo, N.-I. (2022). CHANGE OF FOREST LAND USE BASED ON CONSERVATION POLICY AND PRACTICE: A CASE STUDY IN DANUM VALLEY, MALAYSIA. *PLANNING MALAYSIA*, *20*(23). doi:10.21837/pm.v20i23.1150

Bidin, K. and Chappell, N.A. (2003). First evidence of a structured and dynamic spatial pattern of rainfall within a small humid tropical catchment. *Hydrology and Earth System Sciences Discussions*. *7*(2), 245–253.

Cosma, S., Richard, E. and Miniscloux, F. (2002). The role of small-scale orographic features in the spatial distribution of precipitation. *Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography*. *128*(579), 75–92

Hsu, K., Gao, X., Sorooshian, S. and Gupta, H. V (1997). Precipitation estimation from remotely sensed information using artificial neural networks. *Journal of Applied Meteorology*. *36*(9), 1176–1190.

Huffman, G.J., Adler, R.F., Bolvin, D.T. and Nelkin, E.J. (2010). The TRMM multi-satellite precipitation analysis (TMPA). In *Satellite rainfall applications for surface hydrology*. Springer, pp.3–22.

Hornberger, G.M., Wiberg, P.L., Raffensperger, J.P. and D'Odorico, P. (2014). *Elements of physical hydrology*, JHU Press.

Jamru, L. R., Sharil, M. N., & Yusoh, M. P. (2023). ASSESSING THE EVOLUTION OF PADDY CULTIVATION IN KOTA BELUD, SABAH USING GIS AND REMOTE SENSING TECHNIQUES. *PLANNING MALAYSIA*, *21*(28).

Jamru, Lindah Roziani, Mohamad Nazril Sharil, Adi Jafar, Oliver Valentine Eboy, Colonius Atang & Mustapa Abdul Talib. (2023). The Effectiveness of Remote Sensing Techniques for Land use Classification in Kota Belud, Sabah. Asian Journal of Research in Education and Social Sciences, [S.l.], v. 5, n. 2, p. 90-97, june 2023. Available at: <https://myjms.mohe.gov.my/index.php/ajress/article/view/22567>

Jamru Lindah. Roziani and Hashim, Mazlan. (2019). LiDAR Sensing for biophysical structure of vegetation in Sub-urban Kluang, Johor, International Graduate Conference of Built Environment & Surveying. Vol 1, 507-515. doi: 10.7717/peerj.4397 ISSN: 2167-8359

Jamru Lindah. Roziani, and Hashim, Mazlan. (2018). Treetop detection from LiDAR using local maxima algorithm. ACRS 39th (Remote Sensing Enabling Prosperity). Vol 5, pg 2692-2700

Jamru, Lindah. Roziani, and Hashim, Mazlan. (2015). Modeling LiDAR cloud point to estimate tree height and delineation of tree crown for selected vegetation in suburban Kluang, Johor. In *36th Asian Conference on Remote Sensing: Fostering Resilient Growth in Asia*.

Jobard, I. (2001). Status of satellite retrieval of rainfall at different scales using multi-source data. In *MEGHA-TROPIQUES 2nd Scientific Workshop 2-6 July*.

Joyce, R.J., Janowiak, J.E., Arkin, P.A. and Xie, P. (2004). CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution. *Journal of hydrometeorology*. *5*(3), 487–503.

Johnson, R.H. and Priegnitz, D.L. (1981). Winter monsoon convection in the vicinity of North Borneo. Part II: Effects on large-scale fields. *Monthly Weather Review*. *109*(8), 1615–1628.

Kripalani, R.H. and Kulkarni, A. (1998). The relationship between some large-scale atmospheric parameters and rainfall over Southeast Asia: A comparison with features over India. *Theoretical and Applied Climatology*. *59*(1–2), 1–11.

Kummerow, C., Barnes, W., Kozu, T., Shiue, J. and Simpson, J. (1998). The tropical rainfall measuring mission (TRMM) sensor package. *Journal of atmospheric and oceanic technology*. *15*(3), 809–817.

Jamru, L. R., Sharil, M. N., & Yusoh, M. P. (2023). ASSESSING THE EVOLUTION OF PADDY CULTIVATION IN KOTA BELUD, SABAH USING GIS AND REMOTE SENSING TECHNIQUES. *PLANNING MALAYSIA*, *21*(28). https://doi.org/10.21837/pm.v21i28.1327

Lindah Roziani Jamru, Mazlan Hashim, Mui How Phua, Ang Kean Hua, Adi Jafar, Zulayti Zakaria, Mohamad Pirdaus Yusoh & Fera Cleophas. (2022). proceedings of universiti malaysia sarawak social sciences & humanities research conference 2022. eISBN 978-967-2298-96-0. pg 147-158. https://www.fssh.unimas.my/images/2022/pdf/SSHR2022Proceedings

Lindah Roziani Jamru and Zullyadini A Rahaman. (2018). *IOP Conf. Ser.: Earth Environ. Sci.* **169** 012106**DOI** 10.1088/1755-1315/169/1/012106

Lindah Roziani, Jamru., Zullyadini, A. R., & Wan Ruslan, I. (2013). Permodelan perubahan tanah bencah di lembangan sungai Setiu, Terengganu menggunakan logistik regresi dan aplikasi Sistem Maklumat Geografi (GIS). *International Journal of Environment, Society and Space*, *1*(1), 75-97.

Lindah Roziani Jamru. (2018). Correction pit free canopy height model derived from LiDAR data for the broad leaf tropical forest. *IOP Conf. Ser.: Earth Environ. Sci.* **169** 012113

Mahmud, M., Hashim, M., Matsuyama, H., Numata, S. and Hosaka, T., (2018). Spatial downscaling of satellite precipitation data in humid tropics using a site-specific seasonal coefficient. *Water*, *10*(4), p.409.

Maggioni, V., Meyers, P.C. and Robinson, M.D. (2016). A review of merged high-resolution satellite precipitation product accuracy during the Tropical Rainfall Measuring Mission (TRMM) era. *Journal of Hydrometeorology*. *17*(4), 1101–1117.

Manonmani, R.; Prabaharan, S.; Vidhya, R.; Ramalingam, M. (2012). Application of GIS in urban utility mapping using image processing techniques. GeoSpat. Inf. Sci., 15, 271–275.

Mollalo, B.V. & Rivera, K.M. (2020). GIS-based spatial modeling of COVID-19 incidence rate in the continental United States. *Science of the Total Environment*, *728*, 13888.

Serrat-Capdevila, A., Valdes, J.B. and Stakhiv, E.Z. (2014). Water management applications for satellite precipitation products: Synthesis and recommendations. *JAWRA Journal of the American Water Resources Association*. 50(2), 509–525.

Sharon, D. and Arazi, A. (1997). The distribution of wind-driven rainfall in a small valley: an empirical basis for numerical model verification. *Journal of Hydrology*. 201(1–4), 21–48.

Shao, Z., Ahmad, M. N., Javed, A., Islam, F., Jahangir, Z., & Ahmad, I. (2023). Expansion of Urban Impervious Surfaces in Lahore (1993–2022) Based on GEE and Remote Sensing Data. *Photogrammetric Engineering & Remote Sensing*, *89*(8), 479-486.

Turk, F.J. and Miller, S.D. (2005). Toward improved characterization of remotely sensed precipitation regimes with MODIS/AMSR-E blended data techniques. *IEEE Transactions on Geoscience and Remote Sensing*. *43*(5), 1059–1069.

Todd, M.C., Barrett, E.C., Beaumont, M.J. and Green, J.L. (1995). Satellite identification of rain days over the upper Nile river basin using an optimum infrared rain/no-rain threshold temperature model. *Journal of Applied Meteorology*. *34*(12), 2600–2611.

Yatagai, A.; Krishnamurti, T.N.; Kumar, V.; Mishra, A.K.; Simon. (2014). A. Use of APHRODITE rain gauge–based precipitation and TRMM 3B43 products for improving Asian monsoon seasonal precipitation forecasts by the superensemble method. J. Clim. 27, 1062–1069

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