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Rainfall Estimation from Himawari-8 Imagery during the 2017 Wet Monsoon Season in the West Coast of Peninsular Malaysia

Nur Atiqah Hazali[1], **Arnis Asmat**[1,2*], **and Wan Mohd Naim Wan Mohd**[3]

[1] *School of Chemistry and Environmental Studies, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), 40450 Shah Alam Selangor, MALAYSIA.*

[2] *Climate Change & Carbon Footprint Research Group, Universiti Teknologi MARA (UiTM), 40450, Shah Alam, Selangor, MALAYSIA.*

[3] *Faculty of Architecture Planning and Survey, Universiti Teknologi MARA (UiTM), 40450, Shah Alam, Selangor, MALAYSIA.*

**Corresponding Author (Tel: +60192244222, Email: rnis_annis@ uitm.edu.my)*

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Abstract

Short duration and high rainfall density are the main factors that cause hydrometeorological disasters such as floods and landslides. In disaster mitigation, knowing the rainfall characteristics is important but hampered due to data availability. One of the essential data sources for rainfall estimation is from cloud brightness temperature of Himawari-8 imagery. Using three selective methods were used on twenty-three very heavy rainfall events (>60mm/hour) that happened in the wet season (Northeast and Inter-Monsoon) in 201. These rainfall time frames were used to estimate rainfall using cloud brightness temperature in infrared (IR) of band 14 (11.2 µm). The results showed the estimated rainfall for all methods is quite variable. Underestimates of rainfall were found using INSAT Multispectral Rainfall Algorithm (IMSRA), meanwhile, Auto-estimator (AE) and Nonlinear Inversion (NI) have produced overestimates of rainfall. In either case, promising results of rainfall estimates from IMSRA with Mean=31.474, Bias=-0.568, and Root Mean Square (RMSE)=49.343mm which is closer to ground measurement. In essence, the Himawari cloud brightness temperature is an important source in rainfall estimates and the infrared range can be explored in accommodating the rainfall variability.

Disciplinary: Remote Sensing, Atmospheric Science, Environmental Study, Hydrology.

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1 Introduction

Rainfall data are vital not limited to flood-related studies but also for studies on climate (Tangang et al., 2012), environment (Al Mamun et al., 2018), hydrology (Nashwan et al., 2019), weather forecast (Mohtar & Tahir, 2017) and many other purposes. Despite its importance, temporal and spatial variability has significantly contributed to the difficulties in rainfall estimation (Jeniffer et al., 2010). Malaysia was experiencing seasonal monsoon rainfall, namely Northeast Monsoon (NEM), Inter-Monsoon (IM), and Southwest Monsoon (SWM). During Inter-Monsoon, the rainfall has a very high intensity which occurs at about 3% of the frequency of seasonal rainfall (Varikoden et al., 2011; Baharudin & Asmat, 2021). The annual rainfall in Peninsular Malaysia varies between 1450 mm and 2575 mm (Nashwan et al., 2019). According to Mayowa et al. (2015), during the NE monsoon, rainfall has increased at a rate of 2.7 mm per year. The magnitude of overall rainfall and its annual variability and seasonal distribution have been severely altered due to the change in the climate (Al Mamun et al., 2018). In those cases, increasing rainfall intensities during the monsoons are a source of a significant flood or flash flood and a triggering cause of major landslide events (Loo et al, 2015).

Recognizing the limitations of rain gauges presents remote sensing to replace traditional rainfall assessment methods and used data from geostationary satellites (Asmat et al., 2021; Mishra & Rafiq, 2019; Haile et al., 2012). The new geostationary satellite of Japan, known as Himawari-8, with its sensor Advanced Himawari-8 Imagery (AHI), offers better spatial and temporal resolution and more spectral bands (Bessho et al., 2016). Widely used rainfall estimation using satellite images can be extracted from cloud top temperature (Alfuadi & Wandala, 2016; Haile et al., 2010). Concerning this, the formation of rain clouds in clouds with maximum lower temperatures is imperative for the rainfall rate estimation (Hidayati & Putra, 2016). Infrared (IR) based rainfall estimation is derived from cloud top temperatures that are indirectly related to surface rainfall (Risyanto et al., 2019; Prasad & Varadarajan, 2018). Developed rainfall estimation using the geostationary satellite IR1 of Himawari-8 mainly was used to rely on where the rainfall has formed from the cloud associated with the cloud temperature (Upadhyaya, 2013). Himawari-8 Imagery has the ability rainfall cloud detection (Park et al., 2016), rainfall estimation (Ayasha, 2020; Risyanto et al., 2019; Putra et al., 2019; Sakolnakhon & Nuntakamolwaree, 2016), and mainly the amount between 0-30 mm per hour (Meliani et al., 2020; Wulandari et al., 2018; Alfuadi & Wandala, 2016; Hidayati & Putra, 2016) by cloud brightness temperature. Therefore, it is necessary to evaluate the methods used for very heavy rainfall (> 60 mm/h) from Himawari-8 Imagery.

In estimating rainfall rate using indirect approaches from cloud brightness temperature, the combination of infrared and microwave makes IMSRA provides rainfall cloud features (Prakash et al., 2010). The ability of IMSRA for the small-scale study is suitable for the study areas of Klang Valley (2,832 square kilometres). A similar study has been done by (Gairola et al., 2015) on the rainfall estimate of (15-30mm/hour) capable of estimating the short period of rain using IMSRA at small-scale study sites over the Indian region and has produced the coefficient of 0.54 with ground measurement. The Auto-estimator (AE) has a fundamental that the cloud brightness temperature inverse relationship with rainfall. This means the model is assumed in the same grid; the highest rainfall is produced from a lower temperature of the top cloud (Alfuadi, 2016; Rani et al., 2016). The Non-linear Inversion (NI) from the experiment done by the Indonesian National Institute of Aeronautics and Space (LAPAN) (Octari et al., 2015) is another method considered in the study. The technique relies on the exponential relationship between MTSAT satellite channel IR1 cloud bright-ness temperature data and ground surface rainfall and is suitable for the study area.

2 Methodology

2.1 Study Area

Five regions are exclusively involved as a study area including the Federal Territories of Kuala Lumpur, Gombak, Petaling, Klang, and Hulu Langat, located in Klang Valley, Malaysia (Figure 1). It covers approximately 2,832 square kilometres of the whole area (Fadzil et al., 2014) and receives an average daily mean temperature of 23-32°C (Al Mamun et al., 2018), average relative humidity of about 70-90% (Hua & Ping, 2018) and annual rainfall, which varies between 1800 to 2400 mm (Al Mamun et al., 2018). The Klang Valley is essential for economic, and business activities in Malaysia where extensive development is a prime focus in this area. According to (Samsuri et al., 2018; Suparta et al., 2015; D/iya et al, 2014), the occurrence of flash flood hazards in the study area is associated closely with rapid development because of inefficient urban drainage and the increase in building and infrastructures. The change in land use and land cover was green and forested areas, natural surfaces which have been replaced with roofing and concrete have limited the rate of water absorption (Samsuri et al., 2018). The worsening situation has happened during the monsoon season when the study area suffered flash floods due to heavy rainfall (Syafrina & Norzaida, 2017; Lung, 2016).

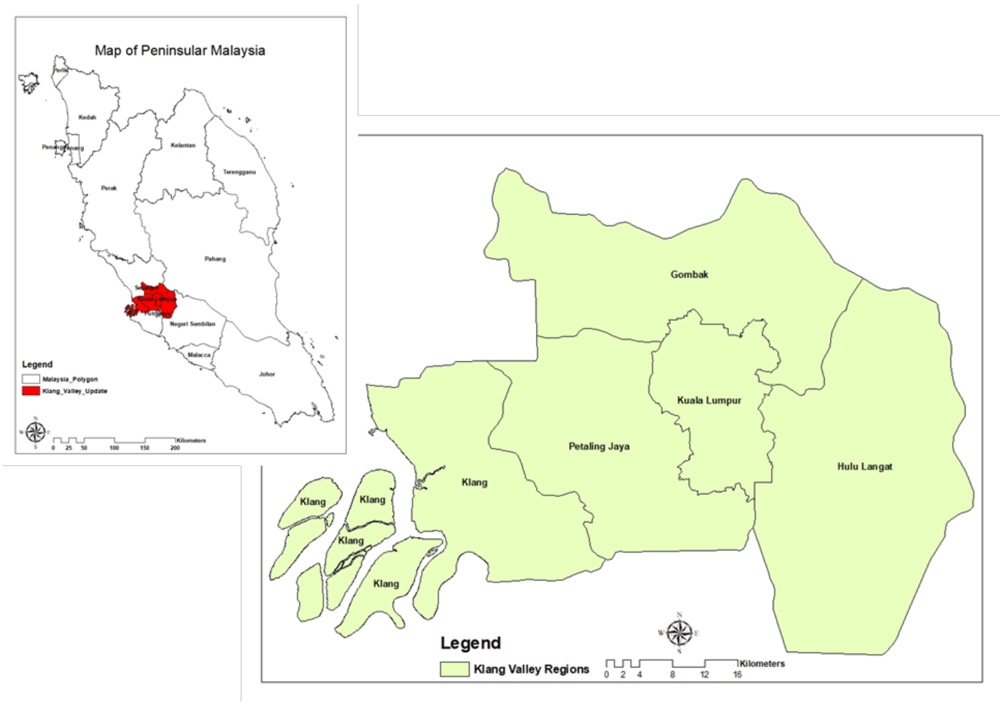


Figure 1: Map of the study area in Klang Valley, Malaysia.

2.2 Data Acquisitions

Ground rainfall data was obtained from the DID, Malaysia from 27 rainfall stations in Klang Valley as in Figure 2. The satellite Advanced Himawari-8 Imagery (AHI) of the Japan Meteorological Agency (JMA)'s has 16 spectral bands, 0.5 and 1km of spatial resolution for visible and near-infrared bands, 2km for infrared bands. Himawari-8 provides real-time monitoring of cloud activities for a 10 minutes interval (Risyanto et al., 2019; Bessho et al., 2016). Band 14 of the 11.2µm wavelength range is used in the study to derive cloud brightness temperature in Figure 3.

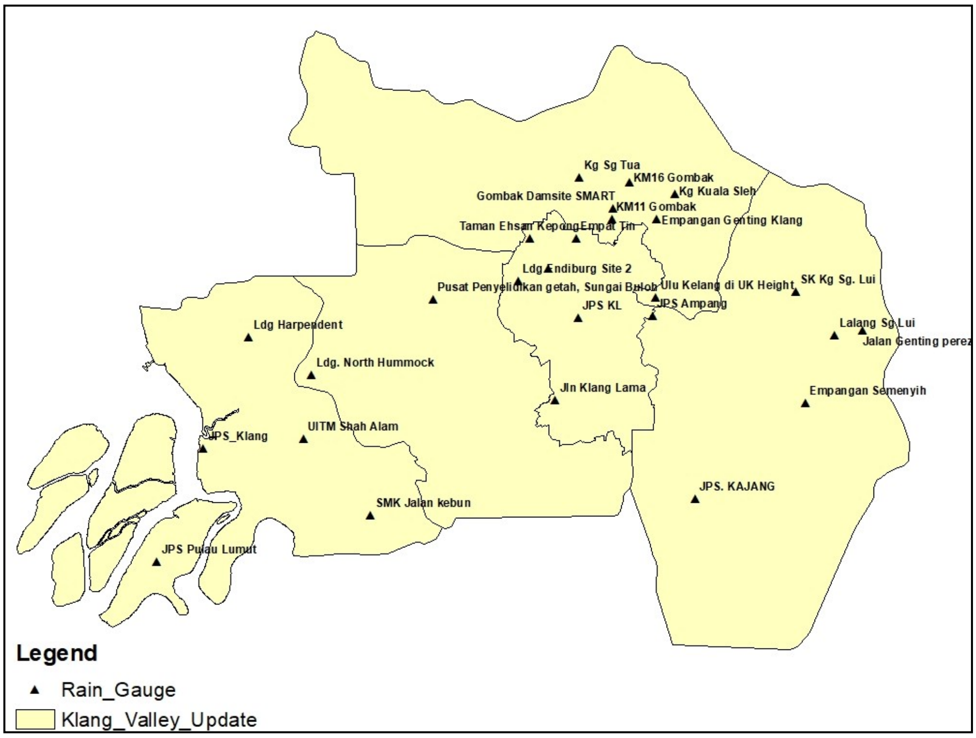


Figure 2: Spatial distribution of the rain gauge station covered in the Klang Valley.

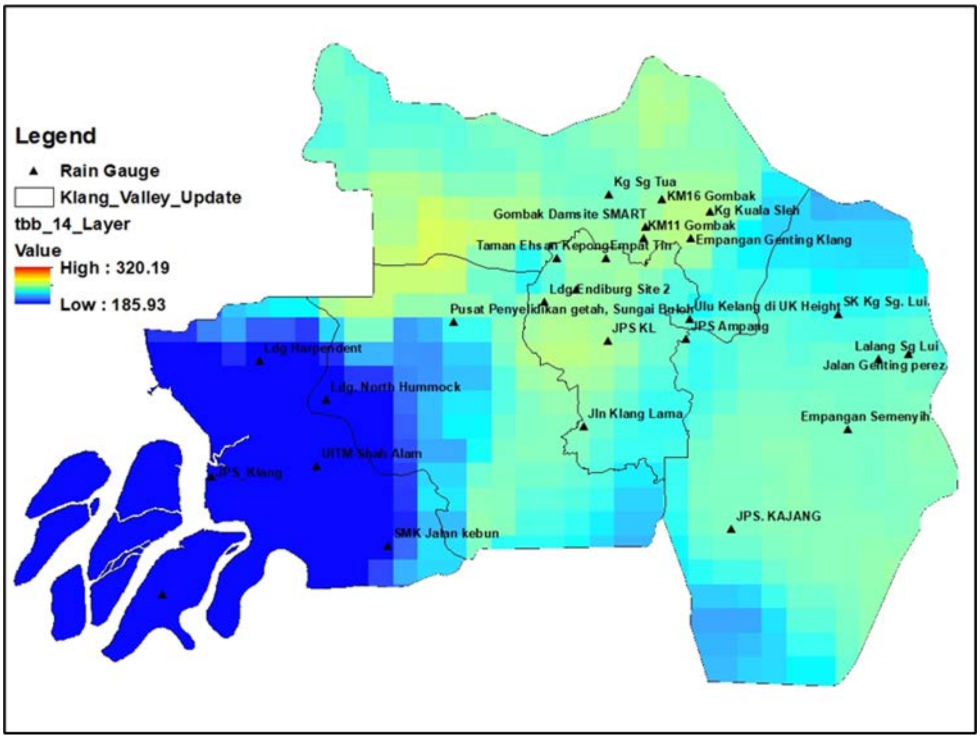


Figure 3: Data acquisitions of cloud brightness temperature from Himawari-8 data in format NetCDF using ArcGIS.

2.3 Methods

The rainfall category is based on the threshold adopted from the Department of Irrigation and Drainage (DID) tabulated in Table 1.

Table 1: Categorization of rainfall intensity (in one hour) (Department of Irrigation and Drainage (DID))

Categories	Threshold (mm/h)
Light Rainfall	1-10 mm/h
Moderate Rainfall	11-30 mm/h
Heavy Rainfall	31-60mm/h
Very Heavy Rainfall	>60mm/h

The rainfall events within the time frames of study are used as a reference to match with the available Himawari-8 images archive (https://www.eorc.jaxa.jp/ptree/terms.html?1). The three models are used to estimate rainfall rate from derived cloud brightness temperature from the satellite images.

2.3.1 INSAT Multispectral Rainfall Algorithm (IMSRA)

IMSRA 1.1.1 by collocating Kalpana-1 IR and WV brightness temperature with TRMM-PR rainfall in 0.25° x 0.25° grids (Li et al., 2018; Chen et al., 2014).

$$R = 8.613098 * \exp\left(-\frac{TB-197.97}{15.7061}\right) \quad (1),$$

where R is the rainfall rate, and TB is the cloud top temperature of the infrared (IR) channel in Kelvin.

2.3.2 Auto-Estimator (AE)

Auto-estimator uses an exponential in the AE method and refers to the equation below (Vicente et al., 1998).

$$R = 1.1183 * 10^{11} \exp(-3.6382 * 10^{-2} * T^{1.2}) \quad (2),$$

Where R is the rainfall rate in mm/h, and T is Kelvin's cloud top temperature.

2.3.3 Nonlinear Inversion (NI)

Nonlinear Inversion using inverse modelling is below (Octari et al., 2015).

$$Y_{est} = 1.380462 * 10^{-7} e^{\left(\frac{3789.518}{x}\right)} \quad (3),$$

Y_{est} is rainfall rate as a dependent variable and x is a cloud top temperature as the independent variable in Kelvin.

The bias measures the algorithm’s tendency in indicating the model overestimates or underestimates the rainfall (Li et al., 2018). The bias is based on the exceeding value of 1 as the method might overestimate the derived rainfall and vice versa. Meanwhile, RMSE is used to measure the estimated rainfall closeness between satellite and ground rain-fall data (Chen et al., 2014).

$$Bias = \frac{\sum_{i=1}^{n}(E-O)}{\sum_{i=1}^{n} O} \quad (4),$$

$$RMSE = \sqrt{\frac{\sum_{i=l}^{n}(E-O)^2}{n}} \quad (5).$$

where O represents the rain gauge observation, E represents satellite estimation, and n represents the total observations.

3 Result and Discussion

3.1 Seasonal Rainfall based on Categorization Intensity

The monthly and seasonal total rainfall distribution for 2017 as in Figure 4. shows the highest total rainfall in November during Northeast Monsoon with 9269.3 mm/h, followed by April (9044.5 mm/h) during Inter-monsoon. Monsoonal rain has a prolonged duration with irregular heavy pour within 24-hours and exceeds several hundred mm (DID, 2020). The inter-monsoon usually often brings about convective rain that results in heavy rainfall (more than 60 mm within two to four hours duration) (Syafrina et al., 2017; Syafrina et al., 2015; Suhaila et al., 2010) and ends up with a flash flood (Ahmad et al., 2017).

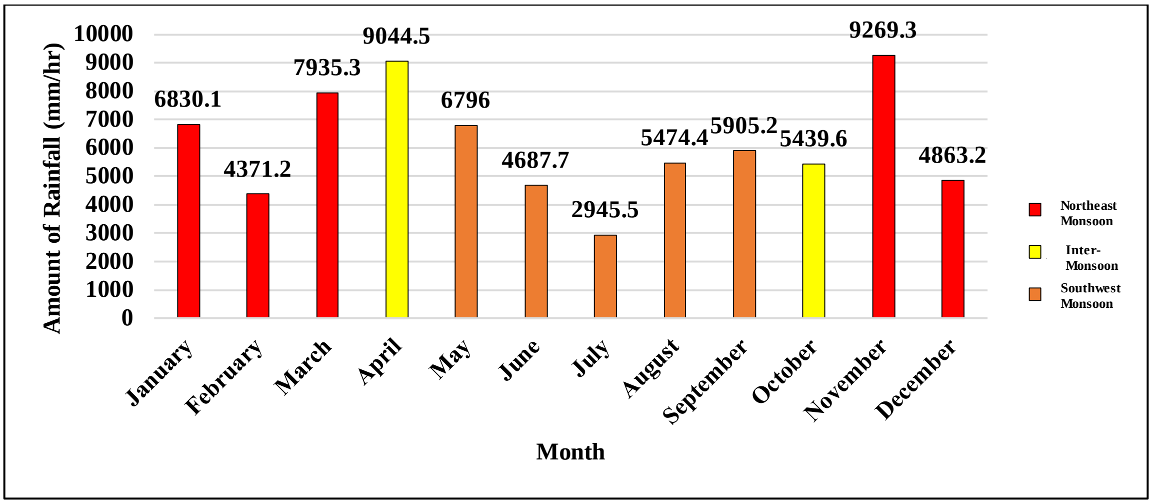


Figure 4: Total amount monthly of rainfall during Northeast Monsoon, Inter-Monsoon, and Southwest Monsoon for 2017

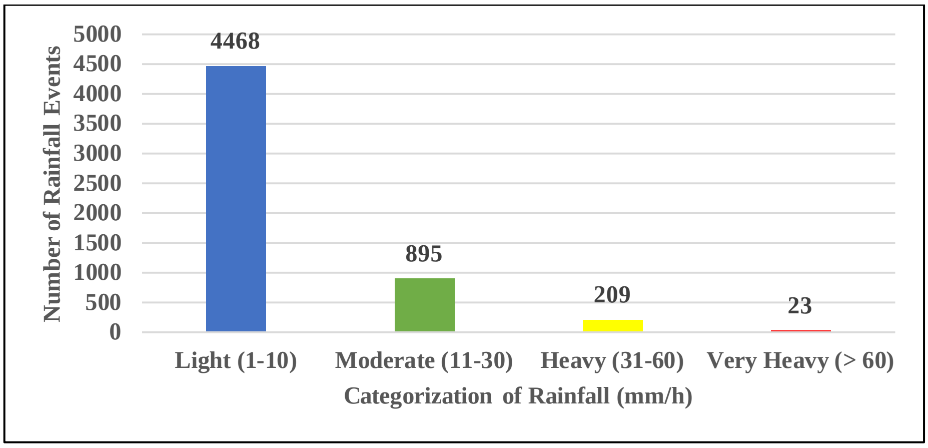
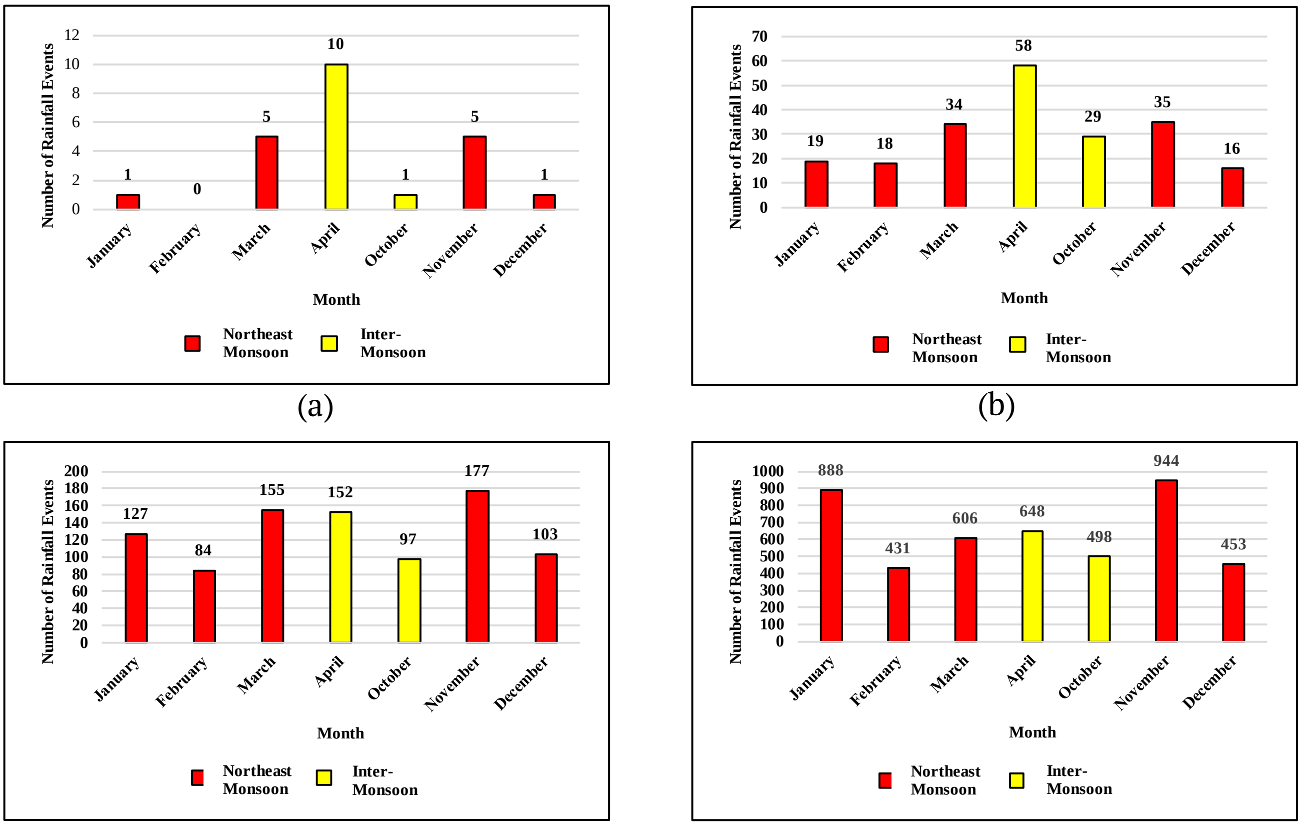


Figure 5: Number of rainfall events based on the rainfall categories during the wet season (Inter-monsoon and Northeast Monsoon) in 2017.

The number of rainfall events is based on the rainfall categories in an hour during the wet season (Inter-monsoon and Northeast Monsoon) in the year 2017 in Figure 5. The highest number of rainfall events was in the light threshold (1-10 mm/h), with a total of 4707 events (80.01%) and only recorded 23 events (0.39%) as a very heavy threshold (>60 mm/h). About 65% of rainfall events occurred over a wet season (Northeast Monsoon and Inter-Monsoon) compared to during the dry season (Southwest Monsoon).

The monthly distribution of rainfall events during Northeast Monsoon and Inter-monsoon in 2017 was divided into categories of light, moderate, heavy and very heavy in Figures 6(a) - 6(d). The observed pattern showed that very heavy rainfall events tend to occur during Inter-Monsoon. A similar pattern of intense rainfall is observed during the inter-monsoon season with a higher hourly total amount of rainfall also found in Syafrina & Norzaida (2017), Syafrina et al. (2015).



(a) (b)

(c) (d)

Figure 6: Total number of rainfall events during Inter-monsoon and Northeast Monsoon in 2017 a) Very heavy rainfall events b) Heavy rainfall events c) Moderate rainfall events, and d) Light rainfall events

3.2 Rainfall Estimation from Cloud Brightness Temperature

About twenty-three events of rainfall have been categorized as very heavy rainfall during the wet season (Inter-monsoon and Northeast Monsoon). This latter was used to estimate rainfall from IMSRA, AE, and NI (Figure 7).

The RMSE value indicates a significant difference between observed and estimated rainfall (Rani et al., 2016). Table 2 shows the estimated rainfall for all methods is quite variable. Underestimates of rainfall were found using IMSRA, meanwhile, AE and NI have produced overestimates of rainfall. In either case, promising results of rainfall estimates from IMSRA with

Mean=31.474, Bias=-0.568, and Root Mean Square (RMSE)=49.343mm which is closer to ground measurement.

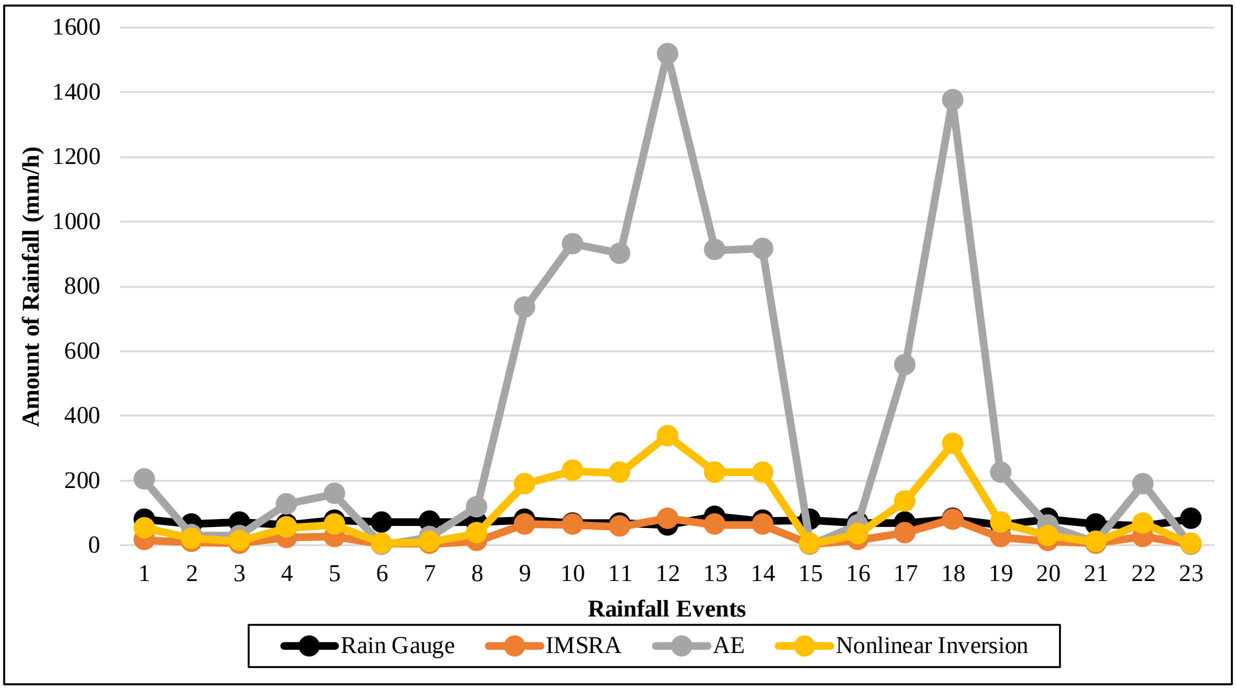


Figure 7: Comparison of rainfall estimation based on IMSRA, AE, and Nonlinear Inversion (NI) with rain gauge observation from cloud brightness temperature for 23 events of very heavy rainfall event during the wet season (Northeast Monsoon and Inter-Monsoon).

Table 2: Mean, Bias, and RMSE of rainfall estimation using IMSRA, Auto Estimator, and Nonlinear Inversion

Methods	Mean	Bias	RMSE
IMSRA	31.47	-0.56	49.34
Auto Estimator	395.46	4.43	565.98
Nonlinear Inversion	103.03	0.41	108.58

3.3 Case Study of IMSRA Model

The IMSRA model was used to validate the consistency of the method by estimating rainfall at specific stations: Empangan Semenyih Station and KM11 Gombak Station dated 17 January 2017 (Figure 8 and Figure 9). It shows that the rainfall started at 0200h until 0300h and reached its highest peak in the late afternoon (1700h). A similar pattern of rainfall estimated can be seen at station KM11 Gombak. Varikoden et al (2011) also found that the peaks of rain occurrences have been observed at 1700h high and occurrences of rainfall in the late afternoon may happen due to warm moist air (Wu et al., 2009). This condition is normally induced by diurnal heating at low attitudes with intense solar irradiance. Table 3 explains the RMSE for Empangan Semenyih Station was 22.962, while KM11 Gombak Station was 27.561. It agrees that the lowest RMSE, mean, and bias is usually the closest to the observed rainfall (Chen et al., 2014; Alfuadi & Wandala, 2016). Overestimated rainfall is observed from the result of both stations and this may be caused by the uncertainty of ground data measurement (Rani et al., 2016). The insufficient data observation on collecting time, accurate and continuous rainfall data also contribute to the inaccurate result (Asmat et al., 2021; Rani et al., 2016).

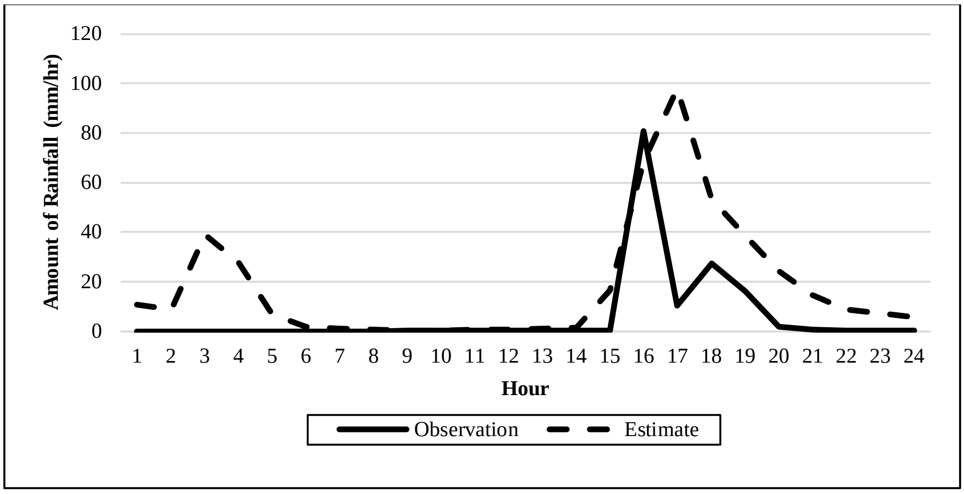


Figure 8: Comparison of hourly data between rainfall estimation and observation of rainfall rate on 17 January 2017 for Empangan Semenyih Station

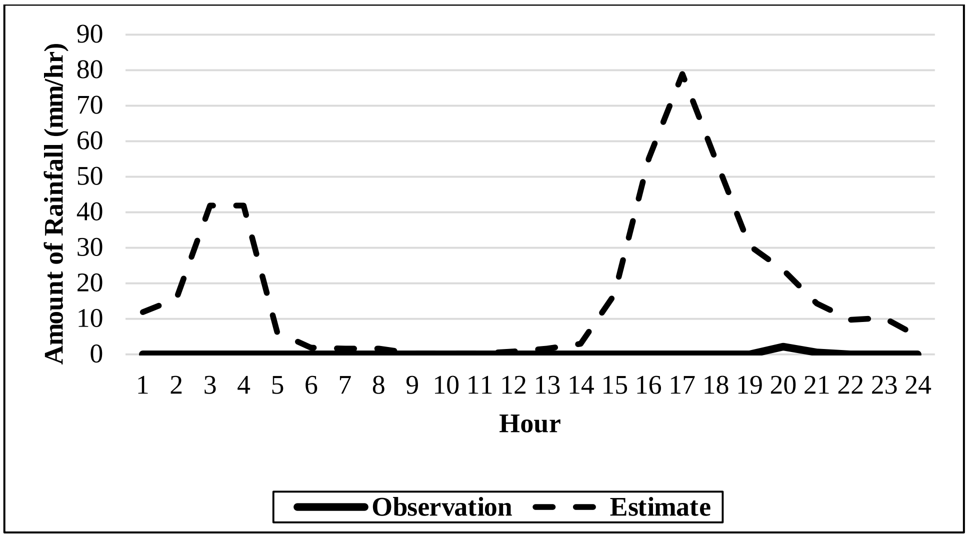


Figure 9: Comparison of hourly data between rainfall estimation and actual observation of rainfall rate on 17 January 2017 for KM11 Gombak Station

Table 3: Mean, Bias, and RMSE of rainfall estimation using IMSRA Model

Stations	Mean	Bias	RMSE
Empangan Semenyih	18.12	2.15	22.96
KM11 Gombak	17.74	169.32	27.56

The rainfall pattern can be affected by the topography factor which reduces the accuracy of estimation, especially during the highest rainfall (Mishra & Rafiq, 2019; Alfuadi & Wandala, 2016). Another challenging issue that hampered the accuracy is the missing data or insufficient rainfall stations (Nashwan et al., 2019; Mayowa et al., 2015); wind effect at the mouth of the rain gauge during very heavy rainfall events (Waken et al., 2018; Varikoden et al., 2011); sparse network locations failed to observe spatial variability of rainfall (Long et al., 2016). In circumstances overestimated rainfall estimation from a satellite happens during summer convective precipitation due to the misidentification of cold clouds such as cirrus (Yilmaz et al., 2005).

The uncertainty of rainfall is estimated from imagery when there is an indirect relationship between cloud top observation and surface rainfall, especially during very heavy rainfall. According to Flossmann et al. (2019), cloud formation, classification, and characteristics are essential in precipitation to understand rainfall estimation on a sufficient scale to get a more accurate result. To improve the accuracy of rain estimates using satellites it is highly recommended to resolve the regional bias (Asmat et al., 2021), the orographic effect must also consider making algorithms more robust and reliable for operational use (Prakash et al., 2009). The accuracy of rainfall estimation also relies on the physical process during rainfall development, affecting the retrieval of rainfall from cloud top temperature (Suseno, 2013).

4 Conclusion

Satellite-based derived rainfall estimation techniques have attempted to find a relationship at varying levels of success between cloud brightness temperature and rainfall rate. The imagery cloud brightness temperature of Himawari-8 gives a great alternative for high-intensity rainfall estimation. In essence, the Himawari cloud brightness temperature is an important source in rainfall estimates and it can be optimized in accommodating the rainfall variability by exploring the multiband infrared range. The study also concluded that the IMSRA method provides promising results in estimating rainfall from cloud brightness temperature. Further improvement has to address the overestimation and underestimation of rainfall over the specified regions by correcting the regional bias and orographic effect of the study area.

5 Availability of Data and Material

Data can be made available by contacting the corresponding author.

6 Acknowledgement

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Nur Atiqah Hazali is a PhD candidate at the School of Chemistry and Environmental Studies, Faculty of Applied Sciences at Universiti Teknologi MARA (UiTM), Malaysia. She obtained her Bachelor's degree in Surveying Science and Geomatic from UiTM, Malaysia. She got a Master's degree in Geographical Information Science (GIS) from UiTM, Malaysia. She has been UiTM Postgraduate Teaching Assistant and Trainer in Geographical Information System (GIS) and Remote Sensing. Her research interest revolves in the field of Meteorological, Rainfall Extreme Events, Rainfall Estimation using Ground and Earth Observation Measurement

Dr.Arnis Asmat is an Associate Professor at the School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Selangor, Malaysia. She got a PhD degree in Environmental Remote Sensing and Spatial Analysis from Southampton University, United Kingdom. His research focuses on Environment, Atmospheric Aerosol, Air Quality, Extreme Weather, Climate Change and Carbon Footprint. Her research is on Rainfall Extreme Events, Urban Air Quality and Vertical Air Quality Modelling, Pollution Source, Prediction for Water and Air using Ground and Earth Observation Measurement.

Professor Dr. Wan Mohd Naim Wan Mohd is a Professor at the Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA (UiTM), Selangor, Malaysia. He received his BSc Degree in Surveying Science (Hons) from the University of Newcastle Upon Tyne, Master of Applied Science in Topographic Science (Photogrammetry and Digital Mapping) from Glasgow University and his PhD in Geographical Information System from the University of Edinburgh, United Kingdom. His research interest include GIS and Remote Sensing for Environmental Modelling, Crime Mapping, Applications of Geospatial Technology for Climate Change, Urban Microclimate Modelling and GIS for Disaster Management