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EVALUATION OF TRMM MULTI-SATELLITE PRECIPITATION ANALYSIS (TMPA) PRODUCT (3B42) OVER INDONESIA (1998-2017)

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ABSTRACT: Precipitation is probably the most highly intricate climate factor, due to its uncertainty in space and time. It plays a significant role in a hydrologic cycle and processes. Rain gauges supply us with a point-based surface precipitation data; while satellite data contributes to the global and regional precipitation estimates. Therefore, it is inevitable to have a comparative evaluation of a gauge-based and satellite-based data in hydrological and water resources studies. This study evaluates the applicability and quality of TRMM (Tropical Rainfall Measuring Mission) Multi-satellite Precipitation Analysis (TMPA) product (3B42 daily data) to rain gauges data over Indonesia to better comprehend the use of satellite data of ungauged basin. Rain gauges and TRMM 3B42 data were available from 1998 to 2017.
In general, TRMM 3B42 performed adequately well with slight overestimates of precipitation on monthly average scale over Indonesia. The best estimation was achieved in February with only 0.1 mm/month difference. On monthly basis, all statistical indices vary throughout the year, exhibiting the highest R-squared value in August and the lowest bias in May. Statistical analysis shows that, when averaged over all locations, TRMM tends to estimate, a false 'base' of 40 to 150 mm/month higher than measured (the intercepts), and then, following that under measured gauge needs to increase up to 50% (the slopes). High precipitation values tend to have positive correlation with high RMSE over Indonesia. The Inverse Distance Weighting (IDW) interpolation technique displays areas with the highest precipitation in North Sumatra, West Borneo, and Papua.

Keywords: TRMM, Precipitation, Ungauged Basin, Indonesia

INTRODUCTION

In the hydrological cycle, rainfall plays an important role in contributing water to a watershed. However, the rates and duration of rainfall have an impact upon on amounts, timing, and frequency of flooding (Cai et al. 2015). Rainfall data for model calibration, simulation, and flood forecasting, and for real-time flood management are necessary for hydrological and water resources research. The uncertainty of rainfall data from sparse or poorly operated ground observations, including ungauged catchments can result in unreliable estimations of runoff. Some data are difficult to access due to technical and administrative reasons. In many watersheds, modeling is limited because of limited numbers of representative rain gauges or uneven distribution of surface network. Conventional rainfall gauges are infrequently completed. The importance of accurate measurements is needed in hydrological, meteorological and climatological processes (Guo and Liu 2016). Satellite data provide practical approach for estimating rainfall, overcoming the limitations of ground measurements, especially where ground measurements are rarely found or unevenly distributed, spatially and temporally (Michaelides 2008; Kidd et al. 2009). Hence, the use of rainfall satellite-based estimates becomes significantly important (Kneis, Chatterjee, & Singh. 2014).

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission satellite between NASA and Japan Space Agency (JAXA) which was designed to provide information on rainfall, covering the tropical and sub-tropical regions of the earth, spatially over the (50°N-50°S) latitude belt at 0.25° x 0.25° 3-hourly resolution for 3B42 and monthly temporal resolution for 3B43 (Huffman et al, 2007)

TRMM 3B42 provides rainfall values between 1998 and 2014, which exhibits one of the most valuable 17 years of spatiotemporal rainfall datasets to date. Two multi-satellite precipitation products, 3-hourly and monthly TMPA products (3B42 and 3B43), are the most widespread products because of their high spatial and temporal resolution. The daily product derived from 3B42 is also favored for those who have less need of high temporal resolution products (Liu et al. 2012).

Even though TRMM service has ended in April 2015, TMPA products will continue to be produced throughout early 2018. The continuing task is carried on by GPM, a high-tech satellite which will remotely collect rainfall data with additional instruments to measure snow and light rain (<0.5 mm/hour).

Research on evaluation of TRMM rainfall data is still limited, especially in relation to the knowledge of the accuracy of the TRMM 3B42 in its latest version 7 over the tropical regions of Asia. As such, this condition has restricted the application of TRMM rainfall data in the field of ecology, climate, and hydrology (Cai et al. 2014).

Performance of TRMM satellite is determined based on topography; such as complex terrain (El Kenawy 2015; Retalis et al. 2016) climatology; such as in summer (AghaKouchak et al. 2011) and winter (Gebregiorgis and Hussain 2013) and seasonality between dry and wet season (As-syakur et al. 2011; Guo and Liu 2016).

Despite having abundant period of rainfall records, extensive studies of TRMM accuracy in estimating rainfall in South East Asia, particularly in Indonesia, remain under research. Some studies about TRMM in Indonesia are still limited in terms of a short period (As-syakur et al 2013), a low number of rain gauges (As-syakur et al. 2011), a small-scale research (Pratiwi et al. 2017) and being carried out locally (Wahdianty et al. 2016).

This research evaluates the TRMM TMPA (3B42 daily) product over Indonesia for the period of 1998 to 2017. It covers (1) performance of rainfall estimation from TRMM compared with ground stations data and (2) geospatial analysis. Following the introduction section, this paper is explained as follows: materials and methods, the details of the study area, data collection and analysis, and methods. Then, results and discussion are presented. Finally, some conclusions and recommendations for future work will be delivered.

MATERIALS AND METHODS

Study Area

Indonesia is an archipelago country located between 6° N to 11° S and 94.5° E to 114° E consisting of 16,700 islands, but only 13,445 islands have been registered with valid coordinates (BPS, 2016). Due to its geographical location, abundant annual rainfall having a magnitude of 2,000 to 3,000 mm/year makes Indonesia as one of the rainiest places in the world.

Climate in Indonesia is hot and humid throughout the year since it straddles along the equator. Indonesia is surrounded by 81% warm waters which determine a fairly constant temperature, averaging 28 °C in the coastal plain, averaging 26 °C inland and mountain areas, and 23 °C in the higher mountain regions with relatively high humidity of 70 – 90 %. (Hays, 2015).

Indonesia has many different topographical features, such as Mountainous areas to lowland areas and from humid tropical rainforest to Savannah. Several factors, including two monsoonal systems, and being in the confluence of Hadley Cell and Walker Circulation (Wiratri, 2013) make Indonesia experiences a number of climates, for example, "bioclimate" which covers 20% of Indonesia. As a result, Indonesia has abundant rainfall with the magnitude up to 3000 mm annually (Bassoullet, 1986). According to Aldrian and Susanto (2003), rainfall patterns in Indonesia can be distinguished into three main regions. Region A covers most of Indonesia, from South Sumatera to Timor Island, until part of Papua. In many areas in Indonesia, heavy rainfalls are more pronounced between November and March (indicated as Region A), while less rainfall occurs between April and October. Region B covers the northern part of Sumatra and the northwestern part of Kalimantan. Region C is the least dominant, covering Maluku and part of Sulawesi.

Rainfall Data Acquisition and Processing

Monthly rainfall data from 133 rain gauges (derived from daily measurements) over Indonesia, covering a period of 1998-2017 (Figure 3), obtained online via the website of Indonesian Agency for meteorology, climatology and geophysics Online (aka BMKG Online). These data used as references to compare with satellite estimations. These data were checked for consistency where missing values and zero values were removed. Point by point analysis was conducted between rain gauge and satellite data on a monthly time basis. Based on station location, study area is further divided into low altitude (h<100 m), mid-altitude (100 m<h<500 m) and high altitude (h>500 m). Daily rainfall data from 1998 to 2017, measured, collected and produced by TRMM TMPA 3B42 satellite data, were employed to observe Indonesian rainfall variability. Several statistical indices were used to determine Indonesian rainfall variability. The type of analysis was monthly average.

The TRMM TMPA 3B42 dataset was obtained from "Mirador interface" (https://mirador.gsfc.nasa.gov/). Then, by using "wget" command, a bulk of dataset were downloaded sequentially. The data were extracted for all BMKG location by using point by point's analysis.

Performance of Precipitation Estimation Analysis

Statistical Analysis

The satellite product and rain gauge time series were compared to assess their accuracies and relationships using numerous statistical indices as follows:

a) Degree of Linear Association

Measuring the linear association between satellite and gauge measurements, Correlation coefficient, (CC) is used:

$$CC = \frac{\sum_{i=1}^{n}(S_i - S_{mean})(G_i - G_{mean})}{\sqrt{\sum_{i=1}^{n}(S_i - S_{mean})^2 \sum_{i=1}^{n}(G_i - G_{mean})^2}} \quad (1)$$

where CC is the correlation coefficient, S_i denotes a satellite estimates, S_{ean} represents the average of estimate values, G_i is a rain gauge measurement, G_{mean} represents the average of gauge measurements, and n is the number of data pairs.

b) Degree of discrepancy

Some quantification of discrepancies between satellite estimates and gauge measurements are Root Mean Square Error (RMSE), percent of bias and Nash Sutcliffe Efficiency (NSE) as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - G_1)^2} \quad (2)$$

$$Bias = \frac{\sum_{i=1}^{n}(S_i - G_i)}{\sum_{i=1}^{n} G_i} x\ 100 \quad (3)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(S_i - G_i)^2}{\sum_{i=1}^{n}(S_i - \bar{G})^2} \quad (4)$$

Geospatial Analysis

Geospatial analyses were conducted by using ArcGIS to display all the statistical indices obtained from statistical analysis and arrange them spatially. This work provides a clear understanding of regions with specific statistical scores. Geospatial analysis maps are provided in Appendices.

RESULTS AND DISCUSSION

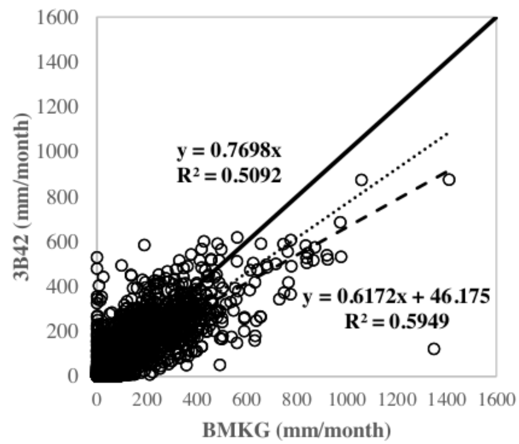
Comparing between Satellite Product and Rain Gauge Data

Monthly Analysis

Monthly analysis comparison between satellite product and rain gauge data was done for both satellite data and BMKG observation data. Monthly data were derived from daily for the period of 1998 to 2017. Data from August and October, which have the highest values of coefficient of determination (R^2), correlation coefficient (CC) and Nash-Sutcliffe Efficiency (NSE) are shown in Figure 1.

From Figure 1(a) and 1(b), in August and October, TRMM 3B42 performed adequately well with slight overestimates of the rain gauge data by 40 to 120 mm/month for wet season.

(a)



(b)

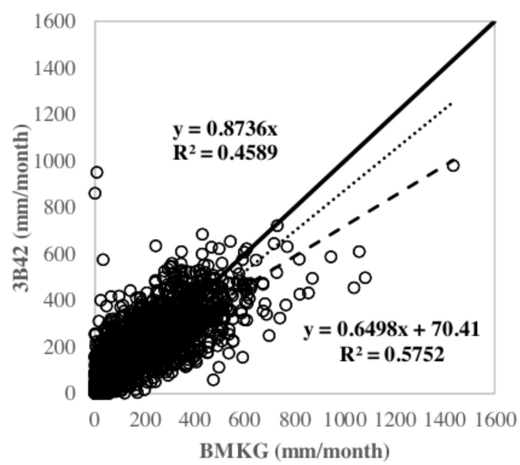


Figure 1. Scatter plots of TRMM TMPA 3B42 products versus the gauge data for monthly rainfall (1998-2017) (a) August and (b) October. Solid black line represents a 1:1 line, dashed line represents linear regression line with intercept and dotted line represents linear regression line without intercept, respectively.

Table 1. Summary of Average Monthly Comparison

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
With Intercept												
R^2	0.45	0.49	0.31	0.38	0.36	0.50	0.36	0.58	0.49	0.58	0.47	0.39
Slope, a	0.52	0.53	0.45	0.47	0.48	0.57	0.40	0.62	0.62	0.65	0.48	0.44
Intercept, b	134.70	109.43	151.46	127.81	102.15	68.23	79.34	44.72	48.98	69.36	121.95	148.92
With no intercept												
R^2	0.17	0.24	-0.15	-0.01	0.06	0.35	0.10	0.50	0.40	0.46	0.12	-0.02
Slope, a	0.87	0.84	0.92	0.88	0.83	0.80	0.61	0.77	0.79	0.87	0.82	0.82
CC	0.67	0.70	0.56	0.62	0.63	0.73	0.60	0.77	0.70	0.76	0.69	0.63
RMSE	128.70	115.88	126.75	111.49	108.47	100.33	146.36	95.16	102.36	102.18	121.69	132.35
NSE	0.10	0.15	-0.09	-0.05	-0.01	0.25	-0.45	0.37	0.30	0.41	-0.06	-0.19
Bias	-0.59	-2.83	8.63	3.50	0.05	-1.80	-6.24	-2.35	-1.09	3.06	-1.68	-6.29

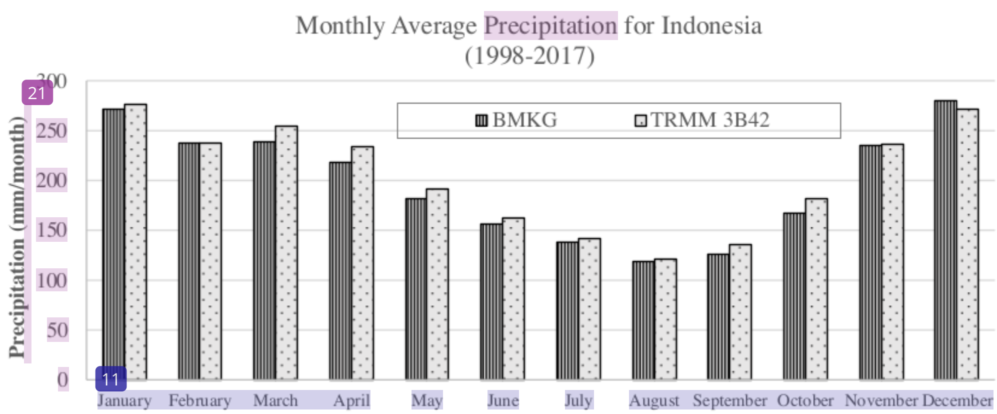


Figure 2. Overall Monthly Average Precipitation for Indonesia (1998-2017)

However, in dry season (such as in March), the performance of TRMM 3B42 was less reliable with the highest bias of 8.63% (as indicated in Table 1).

The summary of all 12-monthly comparison (January to December) with all statistical indices are presented in Table 1. The results show that TRMM data tends to have adequately strong correlation with BMKG data with correlation coefficient above 0.60 in all months, except in March (0.56). NSE values vary significantly, showing no trend. In addition, half of NSE values were under zero, which indicates poor estimation. The best NSE values were achieved in August and October.

Figure 2 displays the overall monthly average precipitation for Indonesia from 1998 to 2017. TRMM 3B42 data were following quite well the trend of BMKG observation data with two peaks in January and December, indicating a monsoonal climate. Most TRMM 3B42 data are slightly overestimates the BMKG precipitation data. The best estimation was achieved in February with only 0.2 mm/month difference. It is indicated that TRMM 3B42 performed well in wet season (as also mentioned in As-Syakur 2011). The worst estimate was in March with 16.2 mm/month difference.

Geospatial analyses were done by using ArcGIS software with some tools in ArcMap. In appendices, the Geospatial analyses are presented. Figure 3a shows the location of all 133 BMKG stations with elevation differences. Most stations (about 82.6%) are in low altitude (<100 m) as shown in small red circles, about 9.6% is in mid-latitude (100 m <h<500 m) as shown in bright green circles and about 7.6% is in high latitude (>500 m) as shown in dark blue circle, respectively. The location of BMKG stations will influence the accuracy of TRMM estimates as stated in As-Syakur (2011).

Figure 3b and 3c display the monthly average precipitation from BMKG stations and TRMM 3B42, respectively. Most TRMM data are overestimated precipitation from BMKG stations, especially in the west coast of Sumatera Island and in mountainous area of Java Island. It indicates that TRMM estimation are less reliable in the area due to elevation and wind from the ocean that might influence the performance.

The largest errors found in Belitung, west coast of West Kalimantan and island of NTT as shown in Figure 4a. The large errors were indicated in some areas at the western coast of Sumatera, mountainous areas in Java island, some coastal in Sulawesi and Papua. This result may due to a complex coastal convergence zone.

Figure 4b represents the IDW interpolation for average monthly of BMKG stations. The 'bull eye' of IDW interpolation shows high precipitation in North Sumatera, West Kalimantan, and West Papua, indicating great influence of monsoonal system to rainfall patterns in region A and region B of Indonesia.

CONCLUSIONS

In general, TRMM TMPA 3B42 performed comparably well with a slight overestimation of the precipitation at monthly average scale over Indonesia. Statistical assessment shows on monthly basis, TRMM 3B42 has good agreement during wet season and less reliable in dry season. The 3B42 algorithm tends to have more accurate values when the amounts of rainfall are high. In addition, high precipitation values show a positive correlation with high elevation and high RMSE over Indonesia (Figure 3-4 in appendices). This result has also been found by As-syakur (2011). IDW interpolation technique displays areas with high precipitation in North Sumatra, West Borneo, and West Papua, representing the rainfall pattern of region A and B in Indonesia. In summary, TRMM TMPA 3B42 daily products have considerable reliability for hydrological research and application, especially for ungauged basin, where cautious calibrations are included.

ACKNOWLEDGMENTS

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Appendices

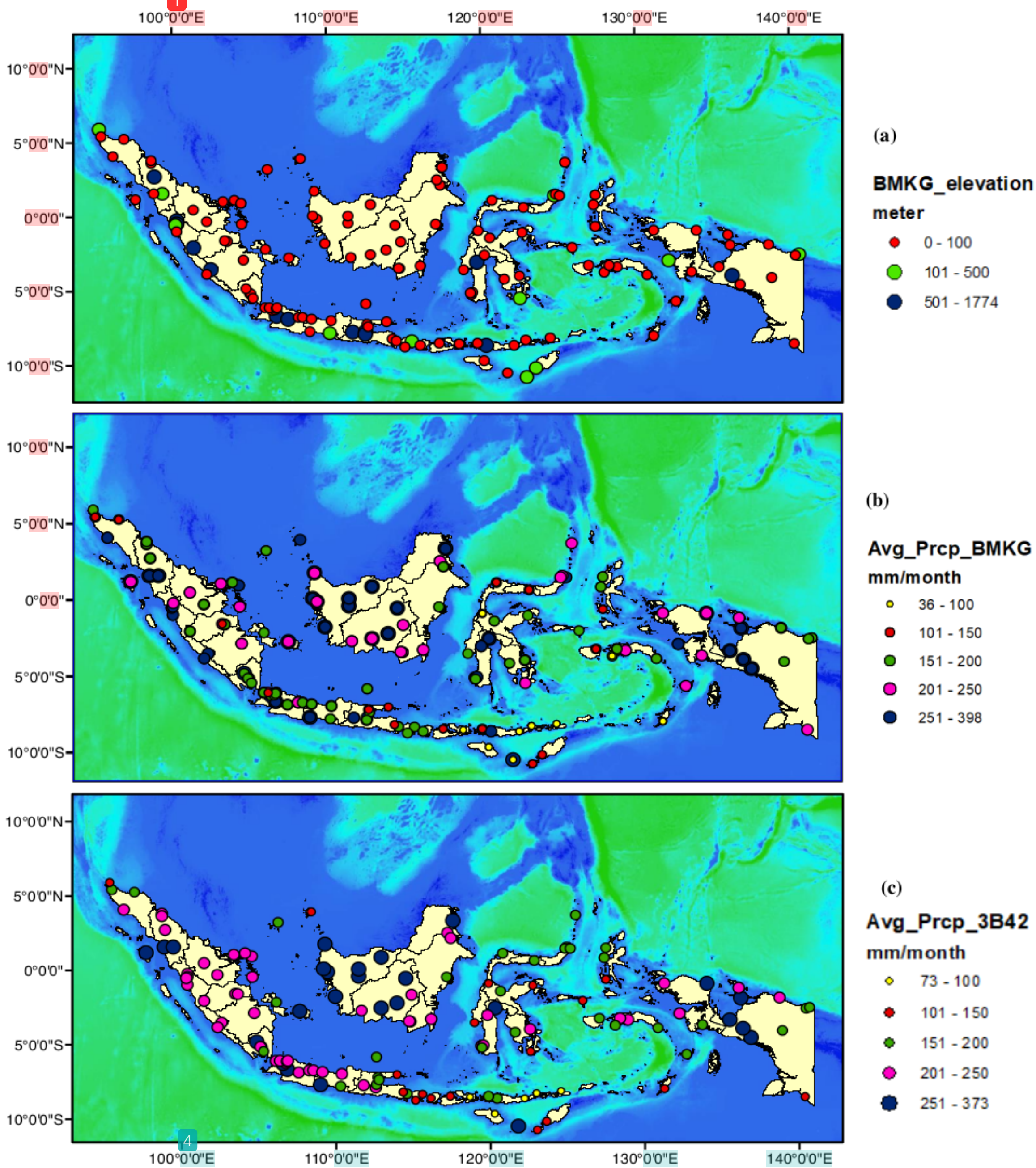

Figure 3. (a) Location of 133 BMKG stations with different elevations
(b) Average Monthly Precipitation from 133 BMKG stations
(c) Average Monthly Precipitation from TRMM 3B42

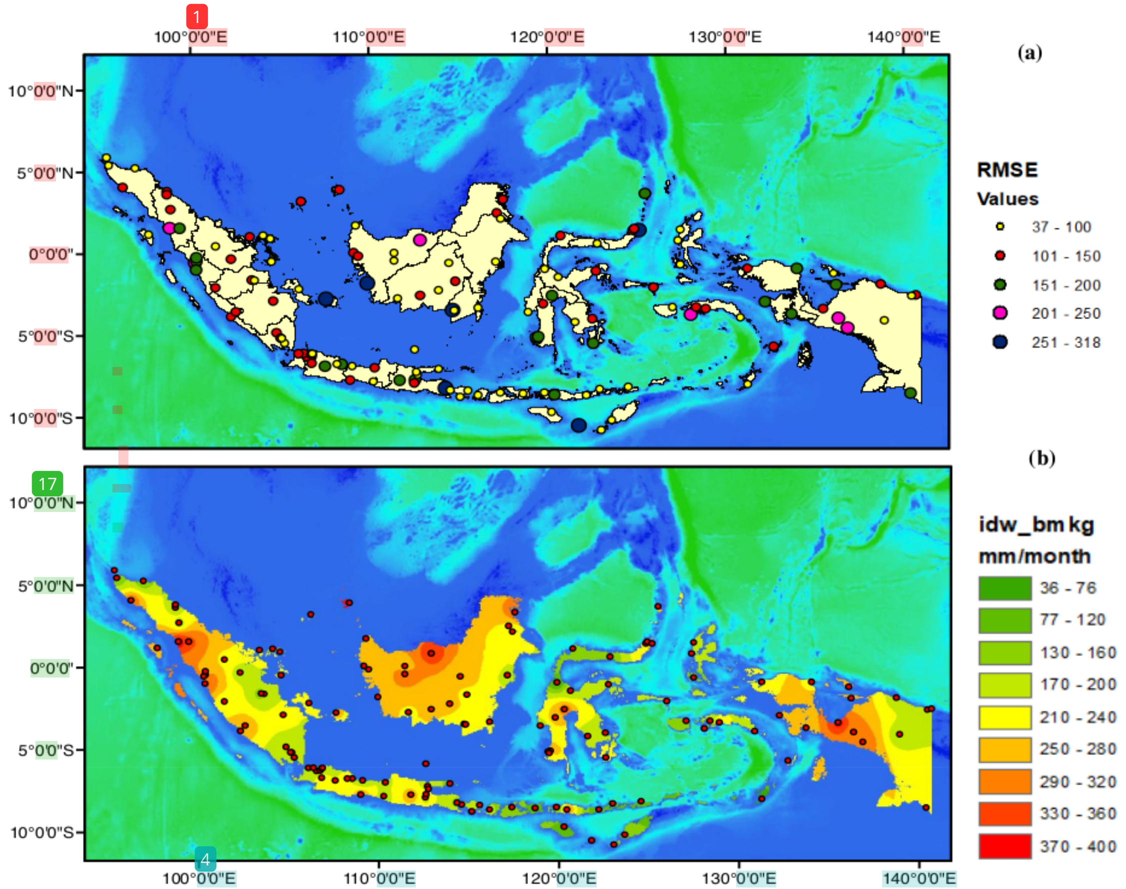

Figure 4. (a) RMSE values of all 133 stations
(b) IDW interpolation for average monthly precipitation of BMKG stations

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