Evaluation of different WRF microphysics schemes: a case study of landslide induced by heavy rainfall in Kulon Progo

D S Permana1*, D E Nuryanto1*, R Satyaningsih1, J A I Paski2, K E Komalasari1, T A Nuraini1, Y Fajariana1, R Anggraeni1, F A Harapan1, N T Rahmadani1, U A Linarka1, E Heriyanto1, J Rizal1, U Haryoko1, N F Ria1, M S Yuliyanti1, K Aprilina1, and I U Badriah1

1Climate Research Division, Center for Research and Development, BMKG, Kemayoran, Jakarta 10610, Indonesia
2Meteorology Research Division, Center for Research and Development, BMKG, Kemayoran, Jakarta 10610, Indonesia
3Director, Center for Research and Development, BMKG, Kemayoran, Jakarta 10720, Indonesia

*donaldi.permana@bmkg.go.id (ORCID ID: 0000-0001-5674-9238); danang.eko@bmkg.go.id (ORCID ID: 0000-0002-9637-5063)

Abstract. Kulon Progo district in Yogyakarta, Indonesia experienced heavy rainfall starting from 26 November 2018 which triggered the landslide on 28 November 2018 in Samigaluh district. In this study, precipitation during this heavy rainfall event was simulated using the Weather Research and Forecasting (WRF) model in three domains with a resolution of 9-3-1 km for three days starting November 25, 2018. One of schemes in WRF model that should be configured is the microphysics scheme. Microphysics is the process of removing moisture from the air represented in a numerical model. Three microphysics schemes (Lin, Morrison and Thompson) were tested for sensitivities. The output precipitation from the model was compared to the observation stations and the closest weather radar data. The results showed that the model can simulate the spatial distribution of rainfall as observed by radar data on daily basis. The model output and in-situ data were consistent for the three stations (ARG Panjatan, ARG Waduk Sermo, and AWS Kulon Progo), except on the 27 November 2018. While the WRF model can generally capture the daily rainfall pattern, but the hourly pattern is less likely. Amongst three microphysics schemes, the Purdue Lin scheme produced a higher hourly rain rate and the Thompson scheme produced a lower rain rate over the region. In general, the model tends to overestimate the precipitation for all three schemes.

1. Introduction
Landslide is a natural hazard caused by the movement of a mass of rock, earth or debris down a slope [1]. There were 49 landslides per year from 1981 to 2007 in Indonesia [2] and according to the Geological Agency of the Ministry of Energy and Mineral Resources of Indonesia, statistically, it is about 32 casualties per event was caused due to rapid landslides during period of 2003-2007 with most of victims were located in the Islands of Java (52%), Sulawesi (24%) and Sumatra (18%). Landslides in Indonesia are often inducted by earthquakes and high rainfall [3,4].
Starting from 26th to 28th November 2018, ten well-recognized landslides occurred in Kulon Progo area, Yogyakarta, the largest of which occurred on 28 November 2018 in Samigaluh district triggered by heavy rainfall since 27 November 2018 [5,6]. Samigaluh area is dominated by high and moderate potential landslide susceptibility based on the soil characteristics such as slope angle and soil type as the conditioning factors [7]. This is the reason that rainfall and hydrologic responses then become very essential factors in landslide triggering within this area.

A previous study was conducted using the WRF model with several different Planetary Boundary Layer (PBL) parameters to show differences in heavy rain [8,9] and soil moisture [10] variations in the Kulon Progo area. The Weather Research and Forecasting (WRF) Model is a mesoscale numerical weather prediction framework designed for operational forecasting and atmospheric research needs. The WRF is an open-source, free and community-based model that has advantages compared to real measurements, such as low cost, high spatial resolution over a large area, have no missing data and can provide long time series of data in a short amount of time [11,12]. WRF was a collaborative partnership principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA) [13,14].

There were several options for microphysics in WRF including Kessler scheme [15], Purdue Lin scheme [16], WRF Single–moment 3–class and 5–class schemes [17]. In this study, we used three microphysics i.e., Purdue Lin scheme, Morrison 2–moment scheme [18], and Thompson scheme [19]. For an effective warning system to work, it is crucial to have a fine spatial and temporal resolution of precipitation forecast, which can initialize a landslide event. This study is using the National Center for Atmospheric Research Weather Research and Forecasting (WRF) version 4.2.1 model with three distinct microphysical techniques to capture rainfall on 26-28 November 2018 that caused this landslide. Therefore, this study aims to evaluate the sensitivity of the simulated rainfall to microphysics schemes during the rainfall event triggering the landslide.

2. Data and methods

2.1 Model configuration

In this study, we used the National Center for Atmospheric Research Weather Research and Forecasting (WRF) model version 4.2.1 [14] to simulate the rainfall inducing the landslide in Samigaluh on November 28, 2018. The model used three one-way nested domains (D01, D02, and D03) with horizontal resolutions of 9, 3, and 1 km, respectively (Figure 1a). The analysis was performed for the innermost domain (D03), particularly the Kulon Progo regency (Figure 1b).
Three microphysics schemes were considered, i.e., Purdue Lin scheme [16], Morrison 2-moment scheme [18], and Thompson scheme [19]. The three microphysics schemes used in this study are bulk microphysics schemes, where particle size distribution is approximated by the exponential distribution and gamma distribution in the Purdue Lin scheme and Morrison scheme, respectively. Microphysics parameterization in the Thompson scheme assumes each type of hydrometeor, except snow, follows a gamma distribution.

Other physical parameterizations included Yonsei University (YSU) scheme [17] for planetary boundary layer, RRTMG scheme for radiation [20], Unified Noah land surface model [21], and a newer Tiedtke scheme [22] for cumulus parameterization (Table 1). The parameterizations are the same for all domains, except for the cumulus scheme, which was only applied for the outermost domain (D01). In typical simulations performed at high spatial resolution (≤ 4 km) such as inner (D02) and the innermost (D03) domains, the cumulus convection is assumed to be explicitly resolved. The National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) analysis (0.25°×0.25°, 6-hourly) is used as initial and boundary conditions for the outermost domain.

**Table 1.** Model physics options

| Physics option                  | D01                                      | D02                                      | D03                                      |
|---------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| Microphysics                   | Purdue Lin, Morrison 2-moment, Thompson  |                                          |                                          |
| Planetary boundary layer       | Yonsei University (YSU)                  |                                          |                                          |
| Radiation                      | RRTMG scheme                             |                                          |                                          |
| Land-surface model             | Unified Noah                             |                                          |                                          |
| Cumulus parameterization       | A newer Tiedtke scheme                    | -                                        | -                                        |
2.2 Observational data

For verification purposes, we use point and spatial measurement. We used 4 locations of rainfall observation stations for verification of the WRF model. The four observation points are Kalibawang, Panjatan, Waduk Sermo and Kulon Progo (Figure 1b). As for spatial observations, we use radar observations.

The Baron C-band Doppler radar in Yogyakarta (7.731645S, 110.354311E, 182 m above sea level) was used to extract the high spatial resolution rainfall for 26 – 28 November 2018. The radar data were available for every 10 min in volumetric format, consisting of ten plan position indicator (PPI) scans (0.5, 1.5, 2.4, 3.5, 4.3, 6.0, 9.9, 14.6, 19.5, 25.0) containing reflectivity in decibels (dBZ) unit with maximum horizontal coverage of 200 km. Radar data was processed by wradlib library in Python programming [23], including reading data formats, georeferencing, clutter removing [24] and attenuation correction [25], converting reflectivity to rainfall intensity, and data visualization. For each radar data, the column maximum of PPI (CMAX) was extracted and converted into NetCDF file based on Cartesian coordinates with spatial resolution of 500 meters. The hourly CMAX data was calculated from the average of six 10 mins data within the hour. The quantitative precipitation estimation (QPE) value was obtained from the following Z–R relationship: \( Z = AR^b \), where \( A = 250 \), \( b = 1.2 \), \( Z \) is the reflectivity, and \( R \) is the rainfall rate [26]. For the radar network in Indonesia, this has been conducted by BMKG [27–29].

3. Results and discussion

Figure 2 depicts the spatial distribution of daily and 3-days accumulation rainfall over the Kulon Progo from the radar observation during 26-28 November 2018. It can be seen that the rainfall on the 27th was higher than on the 26th or 28th. On the other hand, the spatial distribution of rainfall on the 28th was lower than on the two previous days. The 3-days accumulation rainfall reached 180 mm in the Kulon Progo area which was likely the main factor triggering landslides in Samigaluh district, Kulon Progo.
Figure 2. Spatial distribution of total rainfall from radar observation for (a) 26th, (b) 27th, (c) 28th and (d) accumulation 26 – 28 November 2018.

The spatial variation of daily rainfall from WRF model output with three different microphysics is depicted in Figure 3. On 26 November 2018, all of WRF model output were able to capture the low rainfall (up to 20 mm/day) in Kulon Progo, except in the southern part of Kulon Progo. On 27 November 2018, the WRF model also captured rainfall patterns in the northern part of Kulon Progo, though the Morrison scheme produced overestimate rainfall over the Indian Ocean. Whereas on 28 November 2018, the Lin scheme produced overestimated rainfall in the northern part of Kulon Progo, while the other schemes were relatively able to capture rainfall patterns in the region. Overall, the spatial pattern of 3-days accumulation rainfall from WRF model was able to simulate the heavy rainfall over the north Kulon Progo as being observed by weather radar.
Figure 3. Spatial distribution of rainfall from output WRF model each microphysics schemes on each 26, 27 and 28 November 2018 also accumulated 26 - 28 November 2018.

In addition, the evaluation of WRF model output was also performed on hourly data from four rainfall observation stations (Figure 4). At ARG Kalibawang station (Figure 4a), rainfall was observed at 06-11 UTC on 26 November 2021 with a total of ~50 mm and 06-16 UTC on 27 November 2021 with a total of ~20 mm and no rainfall on 28 Nov 2021. In comparison, the radar observed rainfall at 14-18 UTC on 27 November 2021 with a total of ~60 mm. On the other hand, the model output indicated a different temporal variation of hourly rainfall amongst microphysics schemes. Lin and Morrison’s schemes show less rainfall on 26 November 2021 and heavy rainfall at 06-10 UTC on 27 November 2021. Meanwhile, the Thomson scheme likely can predict the hourly rainfall on 26 and 27 November 2021.

The hourly rainfall data were relatively uniform for the other three rainfall stations (ARG Panjatan, ARG Waduk Sermo, and AWS Kulon Progo), which observed the heavy rainfall at 08-18 UTC on 27 November 2018 with a total of ~100 mm for each station (Figure 4b-d). Likewise, the radar data was also comparable with rainfall stations data, but radar data seems to underestimate the station data. The performance of WRF model for these three stations varies. However, the accuracy of the timing and rate of rainfall varies greatly and only the Lin scheme can capture rain events at 08-11 UTC on 27 November 2018, although the rainfall intensity is quite low.
The rainfall peaks simulated by all microphysics schemes occurred earlier in comparison with rainfall peaks observed in Panjatan, Waduk Sermo, and Kulon Progo (Figure 4). However, in Kalibawang, the rainfall peaks simulated by all microphysics precede the peaks of rainfall detected by radar and occurred later compared to the rainfall peak measured by the rain gauge at the sites.

In general, the Purdue Lin scheme produced a higher hourly rainfall rate compared with two other microphysics schemes in all locations (Figure 4). This is likely because the scheme includes nonhydrostatic pressure, enabling the cloud to maintain a longer mature stage which eventually can generate more precipitation that are capable to reach the ground [6]. The Morrison 2-moment scheme was developed to investigate the formation and evolution of the stratiform precipitation entrained. This scheme produces a large and prominent trailing stratiform precipitation and the rain rate in the stratiform region is higher but slightly smaller in the convective region [8]. For this reason, it is likely that the spatial extent of the simulated daily total rainfall on 26 and 27 November using the Morrison 2-moment scheme was wider compared to that of using other schemes (Figure 3), whereas the temporal distribution of hourly rainfall varied among the locations (Figure 4). The simulated hourly rainfall using the Thompson scheme generally has lower rates compared to those simulated using two other schemes (Figure 4). This scheme was developed for midlatitude convective, orographic, and snowfall conditions [12], addressing a new snow parameterization [9], and hence seemingly producing a lower rainfall rate.

Figure 4. Temporal distribution of hourly rainfall from observation (station and radar) with each microphysics scheme of WRF model for location (a) Kalibawang, (b) Panjatan, (c) Waduk Sermo and (d) Kulon Progo.
4. Conclusion
In this study, we run the WRF model with three different microphysical schemes (Lin, Morrison dan Thompson) with the initial time on November 25, 2018, to capture the spatial and temporal rainfall pattern that triggered the landslide on November 28, 2018, in Samigaluh Kulon Progo. To evaluate the model performance, the observed rainfall data from four in-situ stations and radar were used. The WRF model can generally capture daily rainfall patterns, but is less likely to capture the hourly rain rate patterns. In general, when compared to two other microphysics schemes, the Purdue Lin scheme produced a greater hourly rainfall rate in all areas. Conversely, compared to simulations employing two other schemes, the Thompson scheme produces lower hourly rainfall rates.

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