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Original research article

Rainfall Data Assessment from X-Band Polarimetric Radar for Small Drainage Area

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ABSTRACT

For disaster monitoring and mitigation, an X-Band polarimetric radar can provide one or two minutes of rainfall data in small areas. However, this weather radar is not available in tropical nations such as Malaysia, which has suffered from flash floods and flooding, particularly during the monsoon season. As a result, this study evaluates rainfall estimation strategies for small drainage regions as part of a proposal for a new framework of rainfall estimation in Malaysia that employs X-Band polarimetric radar. It begins with raw data conversion, then clips the DEM, selects the drainage area in Kagoshima, and finally plots the hyetograph for rainfall events. The extraction of X-Band polarimetric rainfall data from AMeDAS ground data was investigated. The statistical validation results reveal a relatively positive association between X-Band polarimetry and AMeDAS, with an R^2 value of around 24% for model fit. Furthermore, using QGIS to compare rainfall distribution results for both data sets reveals that AMeDAS data does not accurately reflect actual rainfall monitored by X-Band polarimetric radar because there are no AMeDAS stations in the drainage area, and the X-Band polarimetric radar distribution image is also real-time. All drainages were classified as heavy rain in the upper stream, indicating the precise location of the highest intensity and the possibility that the area closest to the drainage would experience a disaster such as a flood. This paper concludes with suggestions for future works.

Keywords: Disaster risk management; Malaysia; Polarimetric radar; Rainfall; X-band MP

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1. Introduction

As the newer and more advanced technologies than rain gauges, weather radars, especially X-Band polarimetric radars, are effective tools for collecting the rainfall data, which can be further processed and analysed for disaster prevention or mitigation purposes. The X-Band polarimetric radar system was originally developed by the National Research Institute for Earth Science and Disaster Prevention (NIED), Japan, and was installed in Ebina, Kanagawa prefecture, Japan in 2003. The aim was to study the landslide disaster that was caused by heavy rainfall [1]. Since then, NIED has been conducting investigations and studies on the subject and has shown that the radar system is very useful in preparing for and preventing disasters.

The uses of X-Band polarimetric radar in disaster risk management in general are to monitor the rainfall and volcano ash whereby the radar location is nearby the volcano area such as in Indonesia [2, 3] and Japan [4-6]. Due to its coverage area characteristics (range between 30 – 80 km radius of observations), X-Band polarimetric radar is intended to monitor rainfall events for a small area, such as cities or specific drainage areas that are prone to disaster [7-9]. In addition, the excellent spatial resolution of the X-Band polarimetric radar allows it to provide precise information on the amount of rain falling in the chosen area of interest [1, 10, 11].

This paper is part of the study on a new framework for rainfall estimation that has been developed at the Disaster Preparedness Center (DPPC), UTM-KL, intended for disaster risk management in Malaysia [12]. The framework established is critical for rainfall estimation utilising a dual-polarimetric technique for localised urban countries like Malaysia which confront floods and flash floods, particularly during the monsoon season. Therefore, this paper will describe how rainfall data was examined using X-Band polarimetric radar in a limited area of Kagoshima City, Japan, as an illustration of the framework's analysis methodologies.

2. Materials and Methods

2.1 Rainfall data

In this study, the X-Band polarimetric radar (31.44°N, 130.51°E), known as Kinkouwan radar is used. The radar was located at Sabae Bay High School, about 15 km south of the centre of Kagoshima City and around 24 km from the Sakurajima volcano. The high school is facing the Sakurajima volcano across the bay.

Rainfall data by X-Band polarimetric radar were collected in 2-minute intervals, at the spatial resolution of 100-meter mesh, and at 7 elevation angles by the sectoral CAPPI scanning were stored in the main server, named DPPC Server. The elevation angles set were, from the horizon, 2, 5, 10, 15, 20, 25 and 30 degrees. However, due to missing entries on some occasions in the raw data collected during the period, a contiguous set of full data over one month (September 2018) was extracted from the raw data set and stored in the DPPC server. This data set was used as the representative set in the study. Effectively, this X-Band polarimetric radar generates a daily set of 5040 data files of 3 to 105 kB each, which contain data values for every two minutes at every angle (720 pcs of data for each angle), in ". csv.gz" format. Therefore, the radar system generates typically 60 MB of data in a day that needs to be stored according to the set of formats that have been fixed in the DPPC server. On the other hand, the ground rainfall data is collected from Automated Meteorological Data Acquisition System (AMeDAS) in Kagoshima city, and it is located within the radius of radar observation as shown in Fig. 1. However, since the Kinkouwan radar operates in HSQ scan, it does not cover the AMeDAS_Kiire station even though it is located in the Kagoshima city. Therefore, only AMeDAS_Kagoshima (31.55°N, 130.55°E) was used for ground data validation. The data from Kagoshima AMeDAS station are tabulated as 1-hour cumulative values in ".csv" format.

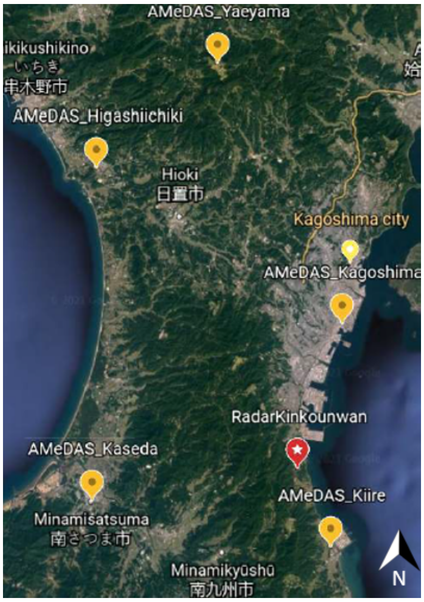


Fig. 1. Location of KinKouwan radar and the AMeDas station in Kagoshima city.

2.2 The Analysis

Before proceeding to the analysis stage, the pre-processing data was considered. Initially, the conversion into GeoTiff may occur automatically during the transfer procedure from the radar system to the DPPC server. However, communication to the actual radar is limited in this experiment, and the data obtained must be manually translated into the DPPC server. Additionally, the DPPC server used for the study was only provisional. Therefore, processing daily data is time-consuming. Since there was rainfall on September 21, 2018, the data for that day was selected and converted to space-separated delimiter types while remaining in comma-separated value file format. The radar location in UTM coordinates, the list of data text file names, and the resolution text file are all necessary. Then, a FORTRAN programme is used to establish the conversion into rainfall distribution files and ready for analysis. Fig. 2 illustrates the analysis of the rainfall process in the new framework that has been applied in this study.

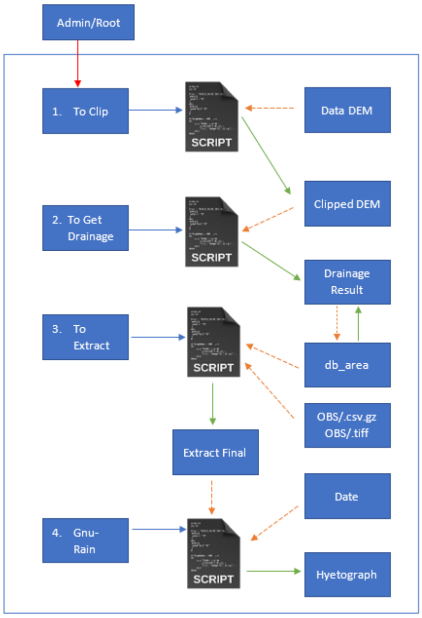


Fig. 2. The process for the rainfall analysis via DPPC server system.

The ALOS 30-meter DEM data from the thematic raster data set was then trimmed for the Kagoshima region. By clicking the outlet point (features in the system), the area of drainage is selected. As indicated in Fig. 3, four drainage areas were chosen for the analysis: drainage (A) with 6.278 km2, drainage (B) with 3.787 km2, drainage (C) with 9.714 km2, and drainage (D) with 3.237 km2. The drainage areas were chosen for their proximity to a large population and infrastructure facilities, including schools, health centres, homes, and offices. Further analysis of these places is necessary to assess the risk of calamity. The rainfall-masked data for each drainage is then extracted, which contains the masked data value for every two minutes of rainfall. This masked data included cell size, number of masked pixels, the total number of pixels, cell area, sum, and the mean value for drainage pixel. Then the retrieved results were used to build the hyetograph for each drainage. The analysis was carried out to ensure that rainfall data produced by X-Band polarimetric radar is reliable and the information provided, such as the amount of rainfall for certain minutes in certain resolution, is suitable for disaster preparedness or prevention actions. Therefore, data should be accumulated at the lowest angle of radar scanning, which is two degrees, to validate data radar. As a result, the files with the lowest angle are gathered and examined.

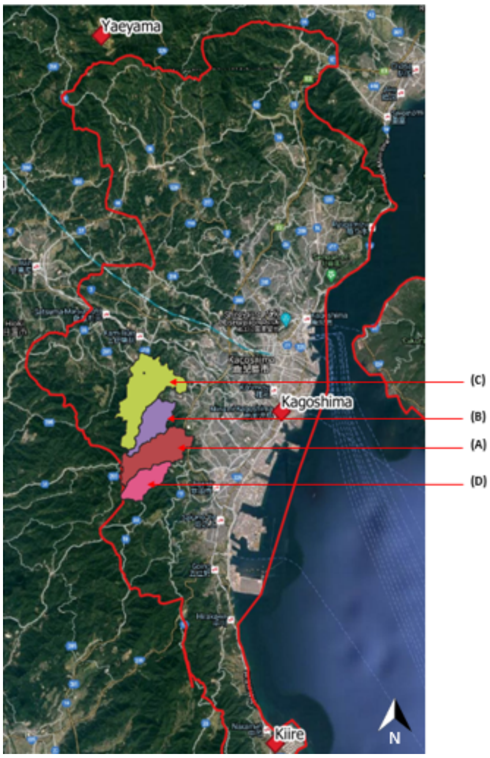


Fig. 3. The four selected drainage area used in this study.

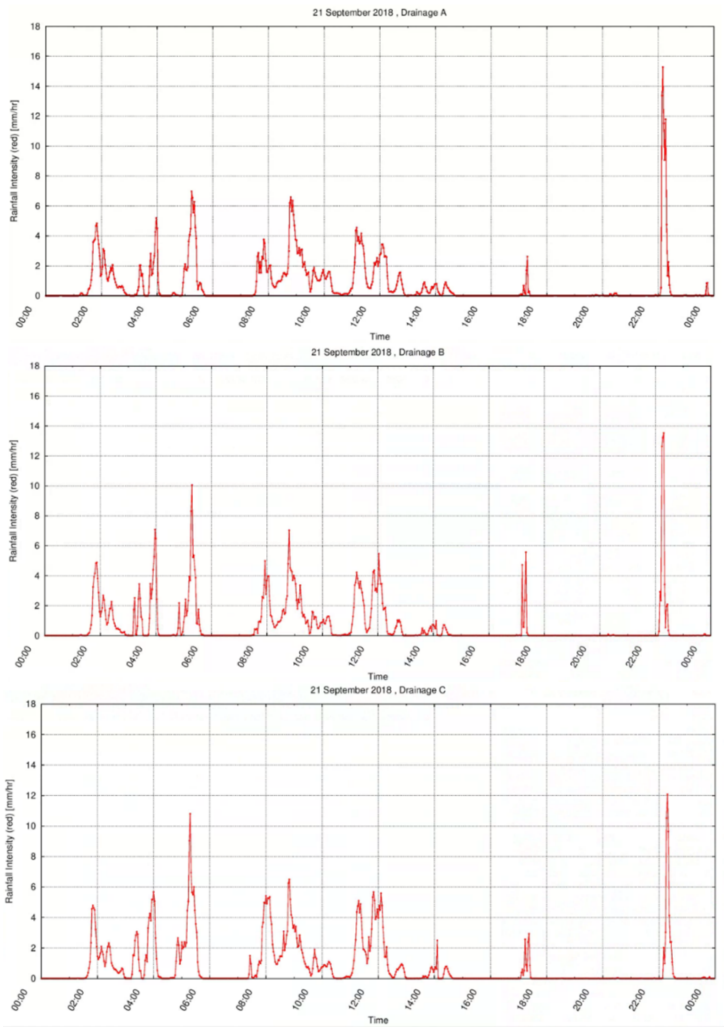
A FORTRAN program is established for the interpolation of rainfall data by X-Band polarimetric radar towards the ground AMeDAS sites. Rainfall data scanned by X-Band polarimetric radar, the AMeDAS position and radar location in UTM format where all the files are recorded in ".csv" format and must be in space- separated delaminated values, are processed alongside a list of rainfall data text file names. The program starts by reading the radar location and AMeDAS position in coordinates and then transferring them into Polar coordinates from the Cartesian coordinate. Next, it reads the list of radar data text file names and checks the format and the times' stamps. Further, it reads and interpolates the radar rainfall data (which is original data in ".csv.gz" format) corresponding to each AMeDAS site or point for every two minutes. Then hourly interpolated rainfall values are derived by adding the interpolated data from every two minutes and totalling them together.

There are several aspects of error to estimates of the rainfall such as radar range [13-15] elevation [16], rainfall duration [16] and rainfall intensity [17]. To reduce the error, internal radar calibration is required, which requires information such as *Kdp*, *Zdr,* and *Zh*, which is difficult to obtain due to the limitations of data collection activities. Due to that, one method to check the reliability of X-Band polarimetric radar data is by comparing rainfall intensity with ground data [18]. Therefore, in this study for the reliability analysis, the rainfall intensity by data from X-Band polarimetric radar was compared with AMeDAS data. Both data sets are prepared in hourly intervals and analysed by using the R script. The ground data location in this analysis was chosen based on the availability of ground data downloaded from JMA websites. The ground station's distance must be within the radius of radar scanning observation and study area, which is up to 30 km. Thus, the AMeDAS_Kagoshima station is approximately 12.87 kilometres away from the Kinkouwan radar, which is sufficient for reliability consideration.

The extracted file data were analysed using QGIS to check the rainfall distribution by X-Band polarimetric radar. For AMeDAS data, the Inverse Distance Weighting (IDW) approach is utilised for interpolation since it can estimate values based on distances to nearby measured points, giving more weight to closer points. This is important for rainfall data because it typically fluctuates smoothly across space. Both sets of data were compared to determine the distribution of rainfall in selected drainages.

3. Results and Discussion

Fig. 4 presents the rainfall estimation results of four drainage selected. The drainage A had the highest intensity of rain on, at 2210 hrs. with 15.271 mm/hr. Meanwhile, the drainage B recorded the highest intensity at 2218 hours, with 13.525 mm/hr. While at 2218 hours, 12.075 mm/hr. was recorded for drainage C, and 43.417 mm/hr. was recorded for drainage D on September 21, 2018. From the hyetograph for each drainage, it is found that the rainfall occurred between 0200 and 2300 hours on that day, with the greatest intensity occurring in drainage D.



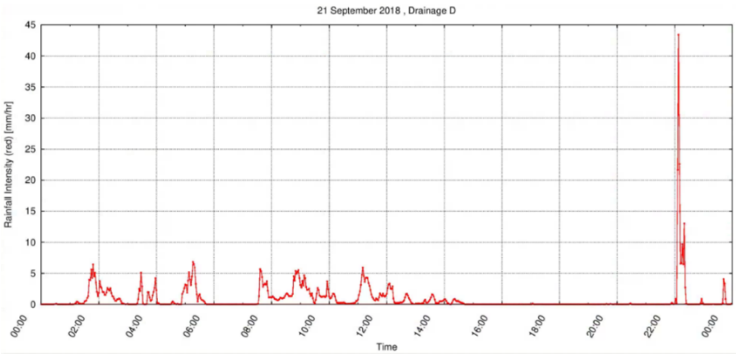


Fig. 4. The rainfall intensity for 21 September 2018 from 0000 hrs to 2358 hours for the four drainage area.

To verify the reliability of radar rainfall, the correlation and regression analysis is carried out. The Pearson correlation is used for determining the strength and direction of a linear relationship between two variables which are AMeDAS_Kagoshima and Kinkouwan radars as illustrated in Fig. 5.

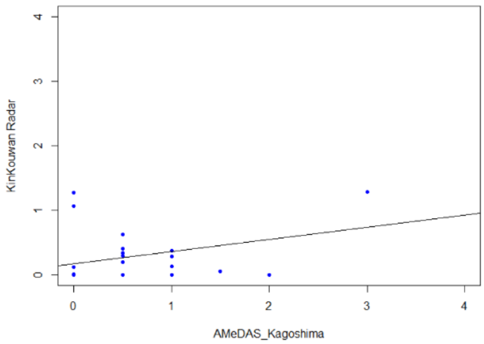


Fig. 5. The scatter plot for X-Band Polarimetirc radar with ground AMeDAS.

With a value of 0.522, it shows a moderate uphill relationship between the variables. For the residual, the distribution is not symmetrical and is skewed to the right. The ordinary least square method shows that the equation of this model is y= 0.18850*x* + 0.17950 and a 95% of confidence interval shows that the actual slope is between 0.052 and 0.32. Meanwhile, the multiple R^2 = 0.273 implies that the fitted model between the X-Band polarimetric radar near the AMeDAS_Kagoshima ground station is only 27.3% and it is not a good fit by the model. The adjusted R^2 = 0.2399 shows about 24% of the variation for X-Band polarimetric radar and AMeDAS_Kagoshima data. Meanwhile, the p-value of 0.008817 indicates there is a relationship between the variables but it is not so strongly significant. The hourly intensity of rainfall (from 0000 – 2300 hours) data for Kinkouwan radar and AMeDAS_Kagoshima is shown in Fig. 5. At 1100, the highest intensity recorded by AMeDAS_Kagoshima is 5.5 mm/hr. while 1.33 mm/hr. was recorded by Kinkouwan radar.

As shown in Fig. 6, X-Band polarimetric radar can provide rainfall estimations that are nearly identical to AMeDAS_Kagoshima. Although the amount of rainfall intensity for AMeDAS_Kagoshima is much higher than for X-band polarimetric radar, this is due to the AMeDAS_Kagoshima being located downstream of Kagoshima city, where excess rainwater from the upper stream is expected to stagnate at the same time as Kinkouwan radar. Also, around 1100 hours, the hyetograph intensity shows high intensity for AMeDAS_Kagoshima but not for the X-Band polarimetric radar. Based on this, the Kinkouwan radar's, X-Band polarimetric radar can provide rainfall intensity amounts for a very localised area, though this is not particularly significant in providing rainfall intensity for light rain. Furthermore, the differences in intensity between the ground data are due to the lack of a closer ground observation tool near the radar. According to JMA the rainfall situation which is the strength of rain that can help the local authority to prepare to prevent any disaster. Rain of more than 20 mm/hr is considered very heavy rain and if this situation happened for long it will cause drainage overflow and can cause the possibility of small streams flooding [8] .

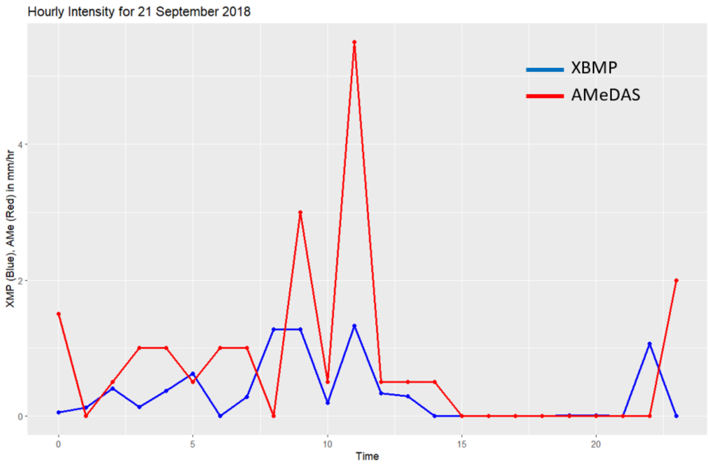


Fig. 6. The hourly rainfall itensity of X-band Porlarimetric radar with ground AMeDAS_Kagoshima data.

The extracted drainage rainfall data by X-Band polarimetric radar for drainages (A), (B), (C), and (D) are shown on the left side of Fig. 7, while the interpolation results for AMeDAS_Kagoshima data are shown on the right side. These statistics depict the distribution of rainfalls at 22 hours on September 21, 2018. Rainfall estimation based on AMeDAS data (on the right) is not reflecting actual rainfall monitored by X-Band polarimetric radar (on the left) very well. This is because there is no AMeDAS station in the drainage drainages (A), (B), (C), and (D) and the distribution image from X-Band polarimetric radar also is in real-time. In addition, the results say that all the drainages have recoded as heavy rain in the upper stream of drainage according to X-Band polarimetric radar distribution image. It was also exposed that; the exact location had the highest intensity and showed the probability that the area closest to the drainage would face a disaster such as a flood in Drainage C for example.

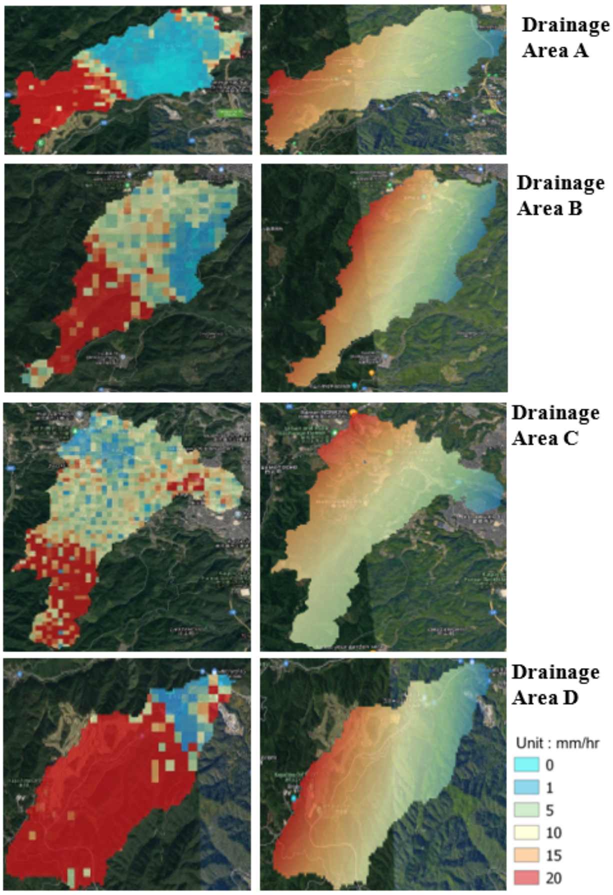


Fig. 7. The distribution comparison of X-Band Polarimetric radar (left) and AMeDAS (right) for each drainage area as at 2200 hours on September 21, 2018.

4. Conclusion

This study has concluded that the assessment approach for radar data by X-band polarimetric radar provides rainfall information for small areas prone to disaster such as on hillsides in almost real-time compared to ground data, AMeDas. Although the results do not show the strong significance among others, hence the assessment proves that the information provided by X-band polarimetric radar will help the local authority or responsible agency in preparing any disaster event that will occur. However, more exploration of rainfall estimation outcomes using more ground tools positioned near radar locations and selected drainage areas is required for future studies to improve rainfall estimation results [18]. Aside from that, more research into extreme rainfall occurrences is required to ensure the rainfall estimation results are credible particularly in tropical region [19].

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