Calibration of rainfall-reflectivity in Northern Region of Peninsular Malaysia

1Mahyun A.W., 2Abdullah, R., 3Abustan, I., 4Adam, M.K.M., 1M.Z.M. Salwa., 2Nur Atiqah A.A., 2Nor Amirah A.S., 5Shafizah, S

1School of Environmental Engineering, Universiti Malaysia Perlis 02600 Arau, Perlis, Malaysia.
2School of Civil Engineering, UniversitiSains Malaysia Engineering Campus, 14300 NibongTebal, Pulau Pinang, Malaysia.
3Visiting professor at King Saud University & School of Civil Engineering, UniversitiSains Malaysia, Engineering Campus, 14300 NibongTebal, Pulau Pinang, Malaysia.
4 Malaysian Meteorological Department, Main Meteorological Office, Kuala Lumpur International Airport, Selangor DarulEhsan, Malaysia.
5Department of Civil Engineering, TuankuSultanahBahiyyah Polytechnic, Kulim Hi-Tech Park, 09000 Kulim, Kedah

ABSTRACT

Capabilities of radar to measure rainfall offer an enormous potential to improve the quality of rainfall measurement. In order to estimates rainfall from radar data, the reflectivity data have to convert using an empirical equation called reflectivity-rainfall (Z-R) relationship. The Z-R relationship that is used in Malaysia was based on Marshall and Palmer (1948) and this equation is seen no longer suit with Malaysia condition. Therefore, a new equation should be developed. The reflectivity data between year of 2005 and 2008 at Alor Star Radar and the rainfall gauged data form 14 rain gauge in the Northern of Peninsular Malaysia were synchronized. Calibration and validation process were performed between rainfall radar and gauge data. Four statistical measures such as Mean Error, Absolute Mean Error, Root Mean Square Error and Bias were used as indicators. By minimising the errors, the Z-R relationship for the Alor Star Radar was determined to be Z = 40R1.6. To determine the best fit Z-R relationship, it was found that the validation analysis has given an acceptable statistical indicator, making it suitable for radar rainfall prediction for the Northern Region of Peninsular Malaysia.

INTRODUCTION

Application of radar-rainfall forecasting is not new however in Malaysia, its application is still at the early stage especially in hydrological modelling works [1]. In a relationship between measured radar reflectivity and rainfall rate, the power empirical equation is commonly used to convert the reflectivity into the rainfall intensity

\[ Z = AR^b \]  

(1)

Where A and b are the relationship parameters, Z is the reflectivity data in mm$^6$/mm$^3$, and R is the rainfall rate in mm/hr. As the radar reflectivity, Z (mm$^6$/mm$^3$) commonly varies across many orders of magnitude, therefore Z used in this study is the reflectivity expressed in term of dBz as:

\[ Z(dBz) = 10 \times \log_{10} Z \left( \frac{mm^6}{mm^3} \right) \]  

(2)

In this study, Marshall and Palmer [2], had developed an equation \( Z=200R^{1.6} \) and was used until today by many countries such as Thailand, Australia, Libya and Malaysia [3, 4, 5, 6]. This equation was used as initial equation before the new derived equation was developed locally. The parameters A and b are usually different according to the location and variation of the raindrop size distribution in both space and time. According to Suzana and Wardah[5], the use of Marshall-Palmer equation for the Z-R relationship is no longer appropriate for rainfall estimation and suggested the most suitable Z-R relationship for particular location need to be developed. Therefore, in this paper, the main aim is to derive the new Z-R relationship for Alor Star Radar from the northern region of Peninsular Malaysia data.

Corresponding Author: Mahyun A.W., School of Environmental Engineering, Universiti Malaysia Perlis 02600 Arau, Perlis, Malaysia.
E-mail: mahyun@unimap.edu.my,shafizah@ptsb.edu.my
Data Collection:
In this study, there are two important sets of data collected from two different government agencies. Rainfall data was gathered from Department of Irrigation and Drainage (DID) whilst Malaysian Meteorological Department (MMD) under Ministry of Science, Technology and Innovation are responsible to supply radar reflectivity data.

MMD has collected the reflectivity data in two different types which is Composite Plan Position Indicator, CompPPI (make from 2 to 4 PPI scan), and Volumetric data (contain 15 PPI scans at 0.5, 1.2, 1.9, 2.7, 3.5, 4.7, 6.0, 7.5, 9.2, 11.0, 13.0, 16.0, 20.0, 25.0 and 32.0 degree elevation). In this study, reflectivity data collected from Alor Star Radar which captured at Perlis rain gauges locations was chosen for an investigation of the Z-R relationship since the study area close to the radar location and the scan range cover for the whole catchment area is less than 100km.

Rain gauge data is provided by Department of Irrigation and Drainage Malaysia (DID). Rainfall data were derived according to time interval of radar which is in 10 minutes interval. Data retrieved using Time Dependant Data (TIDEDA®). The available data from 2005 to 2008 collected at 14 stations were used for the calibration of the Z-R relationship.

Methodology:
Archived data from 14 rainfall gauges and daily Alor Star Radar data were used to determine the climatological Z-R relationship. Firstly, the radar reflectivity was converted using Marshall-Palmer Z-R relationship (Z=200R^{1.6}). These 10-minute rainfall fields were then accumulated into daily rainfall totals. Similar process was done to rainfall data gathered from DID. Daily data were used because calibration of the Z-R relationship on an event basis (hourly time interval) requires storm of diverse characteristics that originate from different meteorological systems such as thunderstorm and frontal storms [4].

Similar technique proposed by Seed et al [4] and Fields et. al [7] were applied to determine the suitable Z-R relationship. In this technique, the exponent b was fixed to 1.6 and parameter A was adjusted to minimise the error. Parameter A and exponent b are the relationship parameters in the empirical equation used to convert the reflectivity to rain rate (Z=AR^b). Therefore, the estimation of parameters A and b is the aim of this study. From the literature, initial parameter A can be determined from Equation 3.

\[
A_1 = \frac{A_0}{m^b}
\] (3)

Where \(A_1\) is the new multiplicative term A in Z-R relationship, \(A_0\) is the initial parameter A, \(m\) is the gradient of the regression line between the predicted and the observed rainfall obtained from the standard Z-R relationship (Z=200R^{1.6}), and b is the exponent in the Z-R relationship. The determination of A was done by trial and error and a good fit between radar and gauge, estimated mean radar rainfall and mean gauge rainfall were compared using four statistical measures recommended by Seed et. al[4] as shown in Table 1. Result which give smaller number is considered the best.

| No | Statistical measure | \(ME = \frac{1}{n} \sum_{i=1}^{n} (\tilde{R}_i - \tilde{G}_i)\) | \(MAE = \frac{1}{n} \sum_{i=1}^{n} |\tilde{R}_i - \tilde{G}_i|\) | \(RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\tilde{R}_i - \tilde{G}_i)^2}\) | \(B = \frac{\sum G_i}{\sum \tilde{R}_i}\) |
|----|-------------------|-----------------|-----------------|-----------------|-----------------|
| 1  | Mean Error (ME)   |                 |                 |                 |                 |
| 2  | Mean Absolute Error (MAE) |                 |                 |                 |                 |
| 3  | Root Mean Square Error (RMSE) |                 |                 |                 |                 |
| 4  | Bias              |                 |                 |                 |                 |

Extensive trials of value of A were done to obtain the suitable relationship of rainfall-reflectivity for this study. Relationship that gives the minimum of the four statistical measures will be chosen as the new relationship. Finally, validation process will be performed to validate the calibrated values of A and b.
RESULTS AND DISCUSSIONS

Daily rainfall data from 14 rain gauges and radar were synchronised to determine the correlation between two different measurements of the rainfall. Using Equation 3, from the calculation made, the $m$ value is equal to 2.4765 and therefore the initial parameter $A$ is equal to 46.9. In the calibration process, the initial value of $A$ is 50 and $b$ is fixed to 1.6. The value of $A$ is determined by alteration until the error is minimised. After several attempts made, the most suitable value for $A$ was found to be 40 and $b$ is remained constant at 1.6. The result shows that, new Z-R relationship gives the minimum value of error as shown in Table 2.

Table 2: Comparisons of the statistical measures gained from the different Z-R relationships

<table>
<thead>
<tr>
<th></th>
<th>MP = 200$R^{1.6}$</th>
<th>$Z = 50R^{1.6}$</th>
<th>$Z = 40R^{1.6}$</th>
<th>$Z = 30R^{1.6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME (mm)</td>
<td>15.48</td>
<td>5.48</td>
<td>2.69</td>
<td>-1.515</td>
</tr>
<tr>
<td>MAE (mm)</td>
<td>15.48</td>
<td>5.73</td>
<td>3.75</td>
<td>5.425</td>
</tr>
<tr>
<td>RMSE (mm)</td>
<td>17.43</td>
<td>8.51</td>
<td>7.06</td>
<td>7.24</td>
</tr>
<tr>
<td>BIAS (mm)</td>
<td>0.54</td>
<td>0.77</td>
<td>0.89</td>
<td>1.063</td>
</tr>
</tbody>
</table>

From the statistical analysis, it clearly shows that new equation provides a better result than Marshall-Palmer equation. Figure 1 shows scattered plot between gauge rainfall and radar data that have been converted using the standard equation (Marshall-Palmer equation) and new equation obtained from this study. From Figure 1, it shows that radar data that have been converted using the new equation performs better compared to the scatter plot produced using the previous relationship.

Radar rainfall estimated using the new equation ($Z=40R^{1.6}$) and gauge rainfall for the daily interval for calibrated data sample were plotted and compared with the radar rainfall estimated using the Marshall-Palmer equation as shown below.

![Fig. 1: Scatter plot of mean radar rainfall based on the relationship $Z=200R^{1.6}, Z=50R^{1.6}$ and $Z=40R^{1.6}$ 'versus' mean gauge rainfall](image)

Comparison between gauge rainfall and radar rainfall for specific gauge rainfall also performed to see the correlation as shown in Figure 1 and it shows new equation is more accurate. Validation process was performed and another ten daily data were chosen. New equation was used to convert the reflectivity data and the results were compared to observed gauge rainfall and rainfall estimated using previous equation. Time series plot validate that new equation give accurate value as shown in Figure 2.

To justify the new relationship ($Z=40R^{1.6}$), validation process has been performed. Similar statistical analyses were performed and it was found that the Mean Error, Absolute Mean Error, Root Mean Square Error, Bias and correlation coefficient ($r$)and coefficient of determination ($R^2$) value within the acceptable statistical indicators with the values of 2.65, 3.29, 3.81, 0.85, 0.95 and 0.90 respectively[7].
Fig. 8: Time series plot of mean gauge rainfall and radar rainfall using the relationship $Z=40R^{1.6}$

Time series of mean radar rainfall and mean gauge rainfall has confirmed that new equation is suit well for radar Alor Star. Moreover, validation process performed to ensure the calibrated equation can be used and the result also gives high correlation coefficient ($r$) and coefficient of determination ($R^2$) value.

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