Estimation of Rainfall-Radar Reflectivity Relationship using Buffer Probability Technique (BPT)

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Abstract: - As Thai government attempts to develop the appropriate warning system in order to minimize to losses from flash flood and landslides. The rainfall estimation from the radar reflectivity is the attractive approach for detecting rainfall over ungauged area. This research, then, was setup under the collaboration among Thai Meteorological Department, Royal Irrigation Department and Naresuan University in order to estimate the rainfall from Z-R relationship by using the measured reflectivity from radar station located at the middle of flash flood risky area. Based on the Probability Matching Method (PMM) and GIS buffer technique, the method of Buffer Probability Technique (BPT) has been developed in this study. It is apparently shown that BPT can provide good result on analyzing the relationship between radar reflectivity and gauge measured rainfall.

Key-Words: - Rainfall, Radar, Reflectivity, Z-R Relationship, Buffer, Ungauged area.

1 Introduction

In past decade, the flash flood and landslide have occurred more often over the Lower Northern Thailand which caused both losses in lives and properties. Thai government has been tried to develop appropriate warning system in order to prevent the losses from these disaster. The effective warning system needs the real time accuracy rainfall detection; however, these disasters usually occur over the mountainous area which there is the problem of rain gauge scarcity and absences. To consider the rainfall over these ungauged areas, the process of applying the radar reflectivity to detect the rainfall over the flash flood risky area is one of the attractive approaches. In Thailand, the radar stations had been installed distributed over the country, of which the active radius covers the whole area, as shown in Fig.1. Table 1 show the Band type and active radius area for the radar network in Thailand. Even though, Thai Meteorological Department (TMD) provides the weather radar data via its website of www.tmd.go.th, the application of information from radar is very limited in Thailand. Most of the researches on radar application have been undertaken for Bangkok area and the pilot area where there is dense network of automatic rain gauges [1],[2]. This study, therefore, emphasizes on the process of detecting rainfall (R) from radar reflectivity (Z) by using the radar data from the Phitsanulok station (station 3 in Table 1) located in the middle of lower Northern Thailand where the highly flash flood risky area is. Unfortunately, the radar reflectivity obtained from this station is on hourly basis, whereas the rainfall obtained from rain gauged distributed over the area is on 15-minute basis. The rainfall data therefore need to be aggregated into hourly basis prior to analysis process. In this study, the Buffer Probability Technique (BPT) was developed based on GIS buffer technique and the concept of Probability Matching Method (PMM) to estimate Z-R relationship.

The project was set under the collaboration among Thai Meteorological Department (TMD), Royal Irrigation Department (RID) and Naresuan University (NU) obtained the financial support from National Research Council of Thailand (NRCT). The objectives of the study are to process the corresponding radar reflectivity with the gauge measured rainfall and estimate Z-R relationship by using the proposed Buffer Probability Technique.

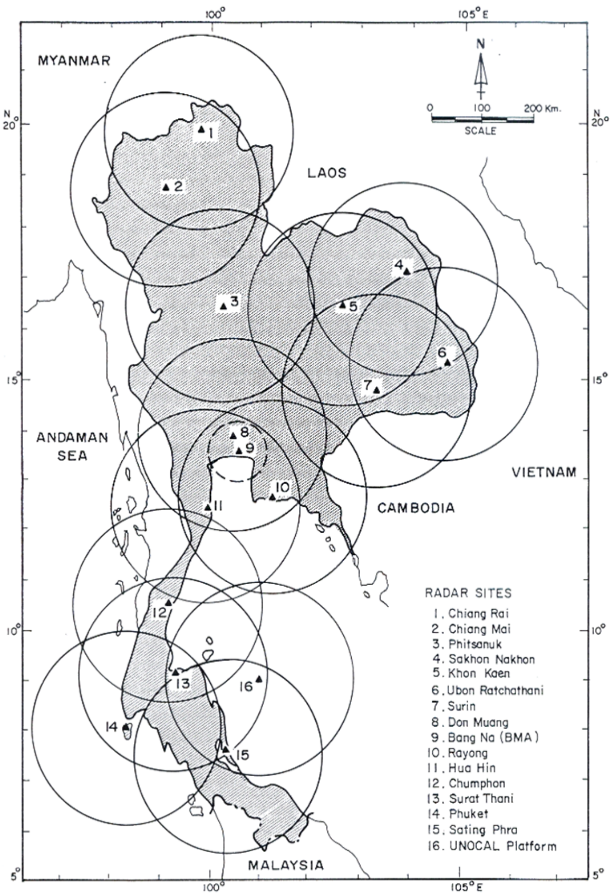

Fig. 1 Radar Network in Thailand

Source: TMD

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2 Used Data and Study Process

2.1 Study Area and Used Data

The selected study area is the flash flood risky area in the Lower Northern Thailand. This area comprises of 8 provinces of which the spatial rainfall characteristics of average annual rainfall over the area are shown in Fig.2.

Table 1 Radar Stations in Thailand

Station	Band	Maximum Range (km)	Installed
1. Chiang Rai	C	460	1994
2. Chiang Mai	C	450	1982
3. Phitsanulok	C	450	1991
4. Sakon Nakhon	C	460	1977
5. Khon Kaen	S	460	1993
6. Ubon Ratchathani	C	460	1993
7. Surin	S	450	1992
8. Don Muang	S	460	1992
9. Bangna	X	120	1995
10. Rayong	C	450	1992
11. Hua Hin	S	460	1995
12. Chumphon	C	450	1985
13. Surat Thani	S	460	1993
14. Phuket	S	450	1990
15. Sating Phra	C	450	1991
16. UNOCAL	C	480	1990
17. Phasri Charoen	C	-	2005

Source: TMD

In last couple year, there were several flash flood and landslides occurred over mountainous part of the area which caused severe losses for both lives and properties. Thus, Phitsanulok Radar station that located in the middle of the area and 27 rain gauge stations distributed over the area were selected to study. The installed radar at this station is C-type Doppler radar of DWSR-74C; of which active radius is 240 km. Fig.3 shows the active measured area with the locations of studied rain gauge stations. 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 Equation (1). The radar reflectivity has been measured in hourly basis, whereas the obtained rainfall from automatic gauge stations is in 15-minute basis. Thus, the normalized process to aggregate 15-minute rainfall into hourly rainfall has been done before analyzing process. The rainfall events occurred during August and September 2007 were analyzed in this study

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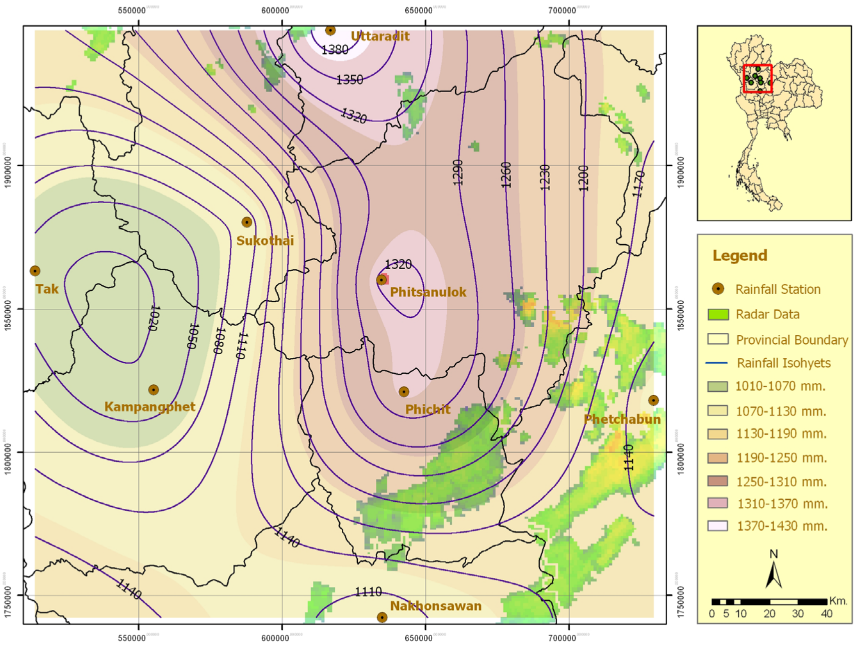


Fig. 2 The spatial Distribution of Annual Rainfall over the Study Area

$$Z(dBz) = 10 \times \log_{10} Z(mm^6 / mm^3) \qquad (1)$$

2.1 Z-R Matching

As Z-R relationships have been widely applied for rainfall estimation, the significant point is the accuracy of the estimation process [3], [4], [5]. There are several Z-R matching techniques have been proposed such as Traditional Matching Method (TMM), Probability Matching Method (PMM), Window Probability Matching Method (WPMM) and Window Correlation Matching Method (WCMM). TMM is the approach that matches the radar reflectivity value on the space vertically with the rainfall from gauge station at the corresponding time of measurement [6]. In this method, it is assumed that there is no effect of the different altitude between radar and rainfall measurement. PMM is the process that the sampling volume, timing and location problems are not taken into account [5]. The matching is done between the Cumulative Distribution Functions (CDFs) of Z values and R from rain guage measurement as described in Equation (2).

$$\int_{R_i}^{\infty} P(R)dR = \int_{Z_i}^{\infty} P(Z)dZ \qquad (2)$$

where *P(R)* is the probability density function of rainfall from gauge measurement and *P(Z)* is the probability density function of radar reflectivity. The matching of Z and R is done at the same probability level. According that the analysis is done on frequency domain, the timing errors are then eliminated in this method.

WPMM is the process that reduces the error of geometrical mismatch and synchronization in matching [7]. In this process, the obtained Z from space window and the obtained R from time window are processed to contribute to *P(Z)* and *P(R)*. The space window of n × n provides number of Z values as n^2 and the time window of t ± i provides number of R values as 2i+1. This process can increase the number of both Z and R values. The Z-R matching is also done at the same percentile. WCMM is the process that had been further developed from the process of WPMM by extension the possible matching area of Z and optimizing Z for the best corresponding R [2]. WCPP processes Z values from both space and time window, these Z values are then analyzed to find the best corresponding R at time t. The optimal Z-R pair can be evaluated from the maximum correlation coefficient (r) as shown in Equation (3) and (4).

$$r = \frac{\operatorname{cov} ZR}{S_Z S_R} \qquad (3)$$

$$\operatorname{cov} ZR = \frac{\sum_{i=1}^{n}((Z_i - \overline{Z}) \times (R_i - \overline{R}))}{(n-1)} \qquad (4)$$

where Z_i is Z value of non-zero Z-R pair i, R_i is R value of non-zero Z-R pair i, n is the number of non-zero Z-R pair, $\overline{Z}$ and $\overline{R}$ are mean value of Z and R, S_Z and S_R are the standard deviation of Z and R, respectively. It can conclude that the matching process are based on the probability matching for all methods except TMM.

In order to simplify process of searching Z values for matching, the Buffer Probabilities Technique (BPT) has been developed in this study. BPT comprises of 2 processes of Buffering and Probability Matching. Fig. 3 shows the buffer constructed over the rain gauge stations. To reduce the error from wind effect, the corresponding reflectivity with the rainfall measured from gauge is evaluated from the average Z value over this buffer area. Fig. 4 illustrates the simplified diagram for buffer area over the rain gauge location. To avoid timing error as concept of PMM, BPT also match the Z-R pair at the same percentile, as Fig. 5.

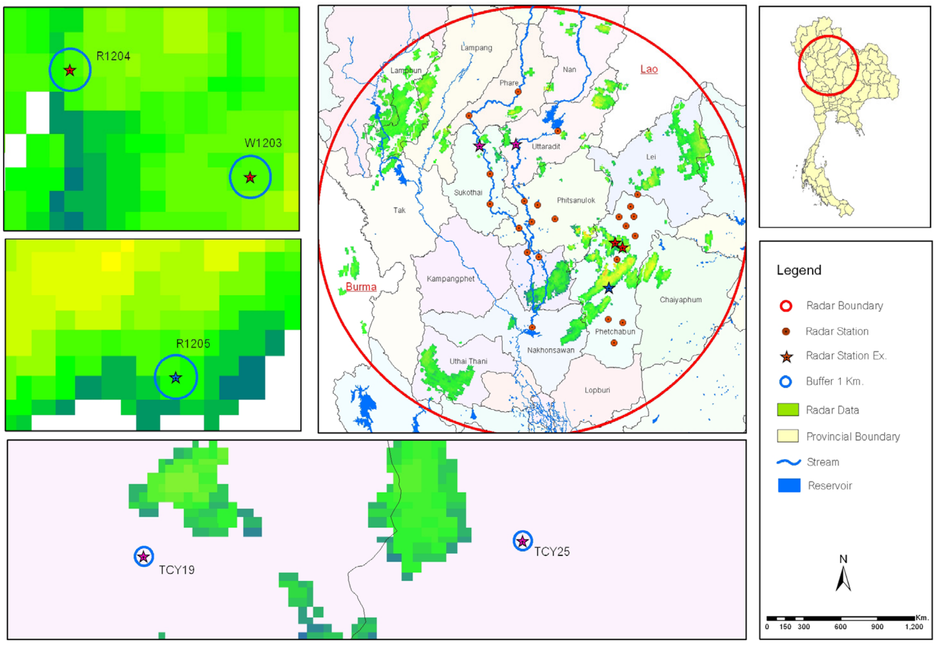


Fig. 3 The Active measured area and Buffer Constructed over the Studied Rain Gauge Stations

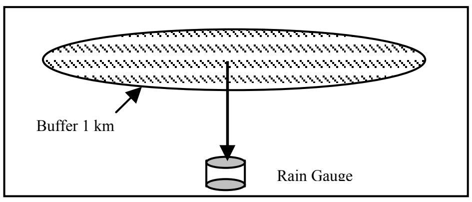


Fig.4 The Buffer Area over the Rain Gauge

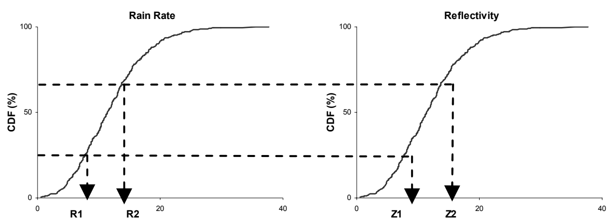


Fig.5 Z-R Probability Matching

2.2 Z-R Relationship

The Z-R relationship can be described by the empirical power law relationship [8],[9] which can be expressed in form of:

$$Z = aR^b \tag{4}$$

where a and b are coefficients that depend on location and difference in climatology such as season, type of rain. These coefficients are independent on rainfall itself. For equilibrium rainfall condition as steady tropical rain, the linear Z-R relationship was proposed, as well [10].

2.3 Study Process

The rainfall from automatic rain gauges was measured every 15-min, whereas the reflectivity from radar was measured once an hour. Thus, the normalized process for rainfall should be done prior to BPT process. The 15-min rainfall was normalized by aggregating into hourly rainfall with the same time interval as radar measurement.

BPT was developed with the assumption that raindrops may not vertically fall into the rain gauge because of wind effect. To reduce this error, the Z value which corresponds to measured rainfall can be determined from the average Z values over 1 km buffer area above the rain gauge. The probability matching as PMM was selected to use in this study in order to avoid the timing error, as well. Therefore, the Cumulative Density Function (CDF) of both R and Z were generated to consider Z-R matching at the same percentile. The process of study is summarized in the schematic diagram of Fig. 6

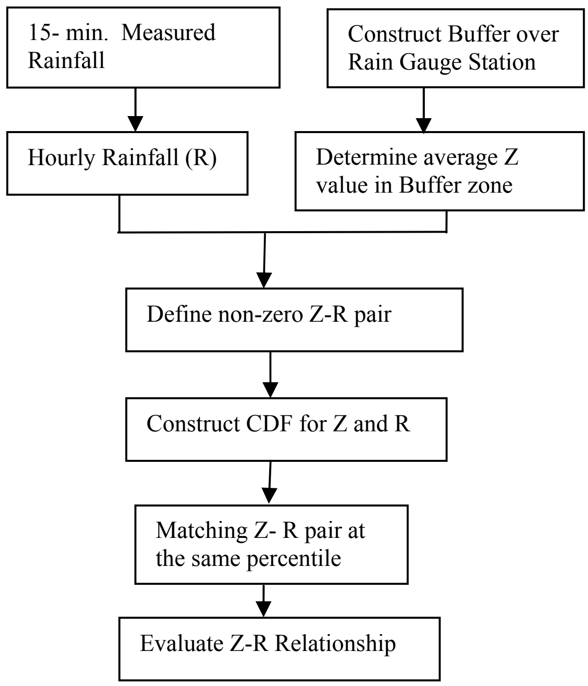


Fig. 6 Study Process

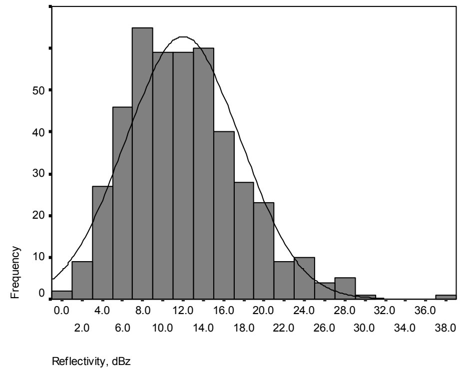
3 Results

There are 448 non-zero Z-R pairs obtained from rainfall events occurred during August-September 2007 of which statistical characteristics and histogram plotting with normal distribution are shown in Table 2 and Fig.7, respectively.

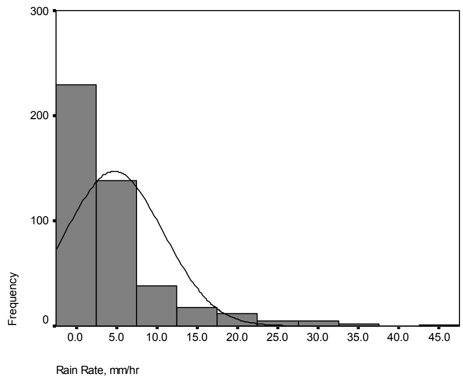
Table 2 Statistical characteristic of dBz and R

Parameter	Average Reflectivity, dBz	Rainfall, R
Mean	12.00	4.74
Standard Deviation	5.68	6.07
Sample Variance	32.30	36.85
Skewness	0.69	2.73
Range	37.17	42.00
Minimum	0.5	1
Maximum	37.67	43.00
Number of Data	448	448

With these non-zero Z-R pairs, the linear relationship between dBz and Rain Rate was then determined. Fig. 8 shows the scattering plots of data set with the linear function estimation. Considering obtained R^2 of 0.0177, it can summarize that the relationship can not describe with linear function. The further step of Probability Matching then was processed by generating CDFs of both dBz and R to define the matching Z-R pairs as shown in Fig. 9.



(a) Reflectivity, dBz



(b) Rain Rate

Fig. 7 Histogram with Normal Distribution Plots

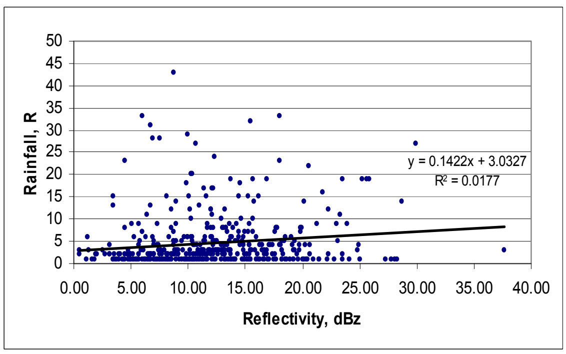
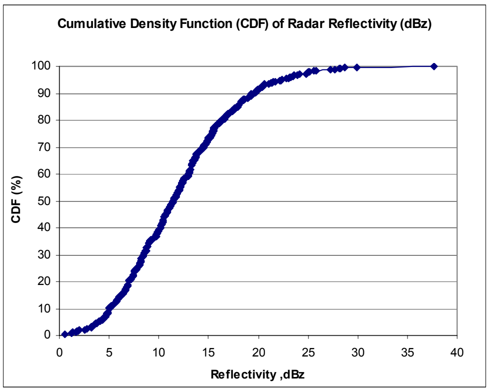
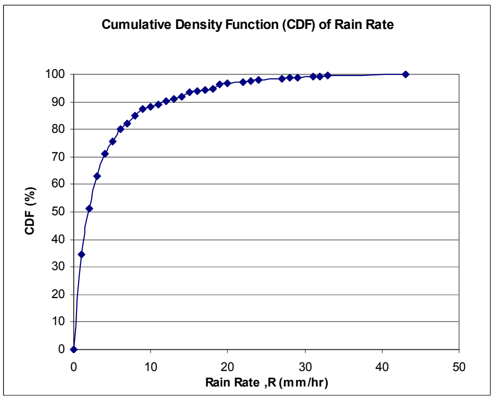


Fig. 8 Linear Relationship between dBz and R

From these CDFs, the dBz and R at the same percentile can be obtained. These matching pairs can be used for evaluation of Z-R relationship. By testing with the common form of Z-R relationship, $Z = aR^b$, the result shows high correlation between these matching pairs with the R^2 of 0.9896, as shown in Fig. 10.



(a) Reflectivity, dBz



(b) Rain Rate, R

Fig. 9 Cumulative Density Function (CDF)

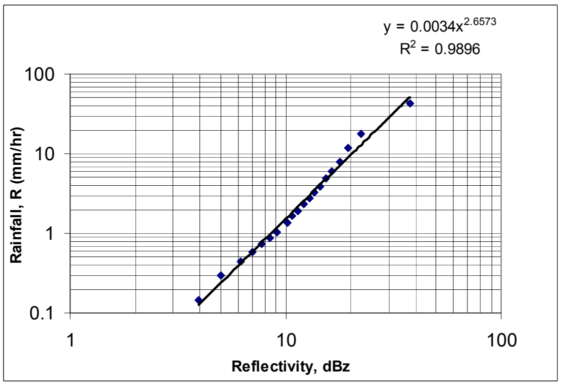


Fig. 10 Obtained Z-R Relationships

4 Conclusion

Under the collaboration among Thai Meteorological Department, Royal Irrigation Department and Naresuan University, the primary work on attempting to utilize the measured reflectivity from radar station at the flash flood risky area to estimate the Z-R relationship in Thailand was undertaken. In this study, the simplified technique of Buffer Probability Technique (BPT) was developed, based on GIS buffer technique and Probability Matching Method. The results shows that the obtained Z-R relationship from BPT can described in empirical power form as the common concept of Z-R relationship. Thus, BPT is one of the methods that can be used to analyze Z-R relationship, as well. This process can be applied further on real time rainfall detecting for flash flood warning system for ungauged area.

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