RAINFALL REFLECTIVITY RELATIONSHIP FOR RAINFALL NOWCASTING IN NORTHERN REGION OF PENINSULAR MALAYSIA

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RAINFALL REFLECTIVITY RELATIONSHIP FOR RAINFALL NOWCASTING IN NORTHERN REGION OF PENINSULAR MALAYSIA

by

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TABLES OF CONTENTS

CHAPTER THREE : METHODOLOGY

CHAPTER FOUR : RESULT AND DISCUSSION

CHAPTER FIVE : CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Z	Radar reflectivity
R	Rainfall rate
mm	milimeter
mm/hr	milimeter per hour
γ	cross correlation coefficient
γ_{max}	maximum value of cross correlation coefficient
r	Pearson Correlation Coefficient
R^2	Coefficient of determination
E_{NS}	Nash and Sutcliffe Coefficient of Efficiency
dBZ	Decibel

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
ASCII	American standard code for information interchange
Aselsan A.S	Turkish Armed Forces Foundation Company
BRRAA	Bureau of Royal Rainmaking and Agricultural Aviation
CAPPI	Constant Altitude Plan Position Indicator
CDF	Cumulative distribution function
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network.
Comp PPI	Composite Plan Position Indicator
DID	Department of Irrigation and Drainage
Disdrometer	a device that measures the size distribution of raindrops
DSD	Drop-Size Distribution
EF	Model Efficiency
ESA	European Space Agency
FWS	Flood Warning System
GHz	Giga Hertz
GPS	Global Positioning System
index-d	Index of Agreement
IUCCA	Inter-University Centre for Astronomy and Astrophysics
JUPEM	Department of Survey and Mapping Malaysia
KALKAN	Name of air defense radar sell by Aselsan A.S
MADA	Muda Agricultural Development Authority
MAE	Mean Absolute Error
MATLAB	Matrix laboratory

ME	Mean Error
MetEd	Part of the University Corporation for Atmospheric Research's (UCAR's) Community Programs (UCP).
MetMalaysia	Malaysian Meteorological Department
Metoffice	UK's National Weather Service.
MHF	Microwave-height finder
MOSTI	Ministry of Science, Technology and Innovation
NOAA	National Oceanic and Atmospheric Administration
NRCAN	Natural Resources Canada
NRE	Ministry of Natural Resources and Environment
Nwclimate	New World Climate
NWP	Numerical Weather Prediction
PMM	Probability Matching Method
PPI	Plan Position Indicator
QPF	Quantitative precipitation forecast
RE	Relative Error
RHI	Range-Height Indicator
RMSE	Root Mean Square Error
ROC	Radar Operations Center
RRMSE	Relative Root Mean Square Error
SMART	Stormwater Management and Road Tunnel
TIDEDA®	Time Dependant Data
TMD	Thai Meteorological Department
TMM	Traditional Matching Method
USA	United State of America

UTC	Coordinated Universal Time
WCMM	Window Correlation Matching Method
WMO	World Meteorological Organization
WPMM	Window Probability Matching Method
WSR	Weather Surveillance Radar
Z-R relationship	Radar reflectivity rainfall rate relationships

KEHUBUNGAN HUJAN DAN KEBOLEHPANTULAN UNTUK PERAMALAN HUJAN DI WILAYAH UTARA SEMENANJUNG MALAYSIA

ABSTRAK

Peramalan hujan jangka pendek adalah salah satu daripada tugas peramalan yang penting dalam meteorologi. Kejayaan menjangka hujan bergantung kepada banyak faktor seperti, pengalaman peramal, kemampuan perkakasan radar dan parameter penukaran antara kebolehpantulan (Z) dan kadar hujan (R), dikenali dengan kehubungan Z-R ($Z=AR^b$). Menggunakan teknik pengoptimunan, kehubungan baru untuk Radar Alor Star telah diterbitkan. Analisis kepekaan telah dijalankan untuk memudahkan proses penentukuran. Proses penentukuran dan pengesahan dijalankan antara hujan yang dicerap oleh radar serta tolok hujan untuk mendapatkan nilai parameter *A* dan eksponen *b* yang terbaik. Peramalan hujan jangka pendek dilakukan menggunakan teknik sekaitan-silang untuk mencari halaju dan arah hujan. Seterusnya, ramalan kegigihan menggunakan penentuluaran lelurus diaplikasi untuk meramal hujan yang akan datang dengan anggapan tiada pertumbuhan dan pereputan hujan. Parameter baru kehubungan Z-R untuk Radar Alor Star ditentukan sebagai $Z = 40R^{1.6}$. Empat analisis statistik dijalankan dan dan didapati bahawa nilai Ralat Min (ME), Ralat Mutlak Min (MAE), Ralat Punca Min Kuasa Dua (RMSE) dan Pekali Penentuan (R^2) adalah dalam penujuk statistik yang diterima dengan nilai masing-masing 1.77, 2.19, 3.11, and 0.90. Peramalan hujan jangka pendek menunjukkan keputusan yang boleh diterima untuk masa mendulu 10 dan 30 minit, menurut Pekali Kecekapan Nash dan Sutcliffe dengan nilai masing-masing 0.86 dan 0.48. Sebagai kesimpulan, ramalan kegigihan sesuai digunakan untuk meramal hujan jangka pendek, manakala parameter kehubungan Z-R adalah input penting dalam kejayaan peramalan hujan menggunakan radar

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ABSTRACT

Short term rainfall forecasting is one of the most crucial forecasting tasks in meteorology. The success of rainfall forecasting depend upon many factors such as, experience of forecaster, the capability of radar hardware and the parameter conversion between reflectivity (Z) and rainfall rate (R), called the Z-R relationship ($Z=AR^b$). Using the optimization technique, new Z-R relationship parameter for Alor Star Radar was derived. Sensitivity analysis was conducted to ease the calibration process. Calibration and validation process were performed between rainfall radar and gauge data to get the best parameter of A and exponential b. Short term rainfall forecasting was conducted using cross correlation technique to find the speed and direction of rainfall. Then, persistence forecast using linear extrapolation applied to forecast the next storm with the assumption there are no growth and decay of rainfall. The new Z-R relationship parameter for Alor Star Radar was determined to be $Z = 40R^{1.6}$. Four statistical analyses were performed and it was found that the Mean Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Coefficient of Determination (R^2) value within the acceptable statistical indicators with the values of 1.77, 2.19, 3.11, and 0.90 respectively. Short term rainfall forecasting shows an acceptable result for 10 and 30 minutes lead time according to Nash and Sutcliffe Coefficient of Efficiency with the value is 0.86 and 0.48 respectively. As a conclusion, persistence forecast is suitable to forecast short term rainfall while Z-R relationship parameter value is an important input to the successfulness of rainfall forecasting by radar.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In the Holy Quran, Allah says concerning rain:

"*It is Allah Who sends the winds which stir up clouds which He spreads about the sky however He wills. He forms them into dark clumps and you see the rain come pouring out from the middle of them. When He makes it fall on those of His servants He wills, they rejoice*" (Qur'an, 30:48).

Rain is a blessed from Allah to those who knows the meaning of grateful. And, the rain just pours into the area that he wants it to happen. That is a significant reason why there are some of the countries received just small amount of water from rain.

The term hydrology comes from Greek: "*hydōr*" which is mean "water"; and "*logy*" refer to "a study of" (Mc Cuen, 2004). In other word, hydrology can be defined as a study of water and it is concerned with the origin, distribution, and properties of water on the globe. Not only hydrologist, meteorologist and geologist are also interested in the field of hydrology which is related with their own interest. For example, meteorologist is more interested in atmospheric water system, where hydrologist in surface water system and geologist in subsurface water system.

Hydrologic cycle or also known as water cycle is one of the important topics in hydrology. Water surface can be found in oceans, lakes, canals and river. Water is continually evaporating, condensing, transported, and precipitating in a never-ending cycle and precipitation is one of the most important elements in water balance. There is neither start nor end of water cycle, but to make a clear explanation, rain or precipitation always is a guide where the hydrological cycle starts. Precipitation is the process that occurs when any and all forms of water particles fall from the atmosphere and reach the ground. In Malaysia precipitation is always refer to rainfall. With different size of water droplet, rain can be measured using a device called as disdrometer.

When rain falls onto the earth, it just does not sit there, but it starts moving according to the laws of gravity (Howard, 2016). A portion of the precipitation seeps into the ground to replenish Earth's groundwater. Most of it flows downhill as runoff. Runoff is extremely important in that not only does it keeps rivers and lakes full of water, but it also changes the landscape by the actions of erosion and deposition (Ribeiro, 2014; Sommer, 2017). Runoff is that the balance of rain water, which flows or runs over the natural ground surface after losses by evaporation, interception and infiltration. Hydrologist is concerned with the amount of surface runoff generated in a catchment for a given rainfall pattern, and attempts have been made to analyze historical rainfall, infiltration, evaporation, and streamflow data to develop predictive relationships

Water that fall from the atmosphere will return to the origin by two major processes; evaporation and transpiration. Nearly 90% of the moisture in the atmosphere is returned via evaporation, with the remaining 10% being contributed by plant transpiration (Howard, 2016). This cycle will continue and keep balancing each other as depicted in Figure 1.1.

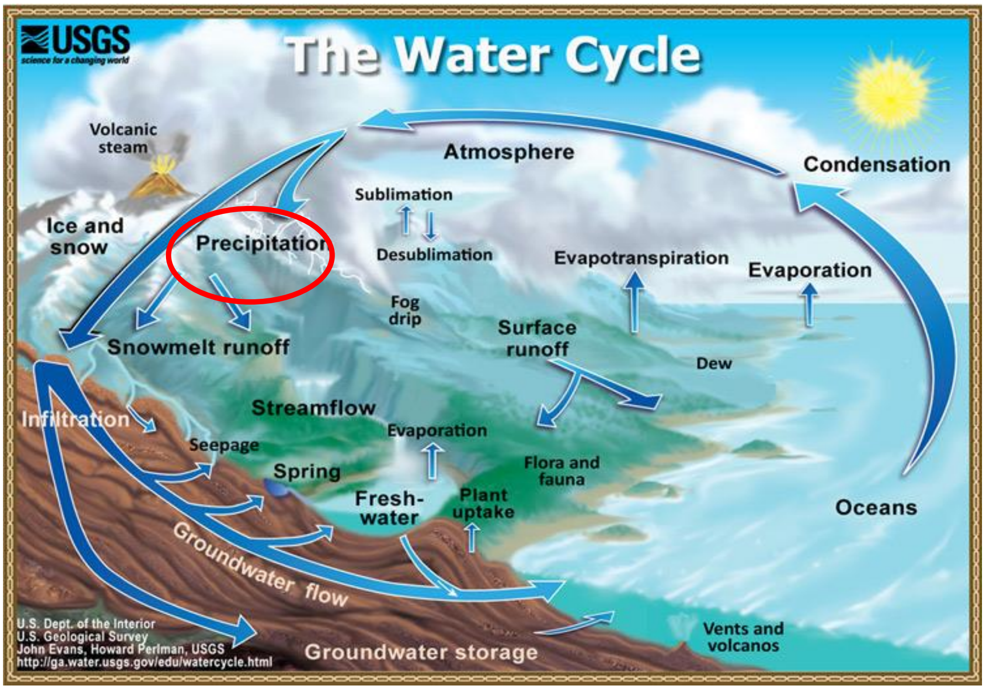

Figure 1.1: The overall concept of water cycle (John and Howard, 2014)

It is essential to learn and research about precipitation and their behaviours to ensure the upcoming processes are on the right track. Accurate analysis of rainfall can help to reduce the impact of flood due to heavy rainfall and draught when the rain is scare. Further it is also help farmers to grow the crop and grain for harvesting as mention in verse below.

"*And We sent down blessed water from the sky and made gardens grow by it and grain for harvesting*" (Qur'an, 50:9).

Knowledge of precipitation can lead to other research associated with precipitation such as rainfall forecasting, flood forecasting, flood mitigation and others. Among the various topic of research which involves rain, rainfall forecast is one of the most important things to consider before making a decision such as planning of agriculture development.

1.2 Problem Statement

Although Malaysia is blessed with the strategic location (out of Ring of Fire), Malaysia still faces disaster of flood. Of all natural disasters, floods impact on the greatest number of people across the world (Robert *et. al.*, 2005; Doocy *et. al.*, 2013). The two most important problems associate with the quantity of water are flooding and water supply (Zoppou, 2001; Basta and Bower, 2015), and flood is a common problem occur in most of the city in the world including Malaysia (McCuen, 2004; Ibrahim and Fakhru'l, 2006; Nola, 2012). Heavy rainfall is one of the most frequent and widespread severe weather hazards with 49% of the natural disasters was resulted from the heavy rain (Shaluf, 2007; Yang, 2013). Rainfall is the most important element of weather forecasts that seems to be most concern to the general public. Further rainfall can be classified into light, moderate and heavy according to their intensity and the capability of destructiveness (Chiang and Chang, 2009).

From the suggested non-structural flood mitigation such as flood hazard map, relocation and flood forecasting and warning (FWS), research on rainfall forecasting is actually can be a good start before the implementation of FWS (Peng *et al*., 2015; Siqueira *et al*., 2016). Rainfall forecasting can be a reference and early warning to the authorities before any emergency action can be taken (Rogers and Tsirkunov, 2011; Wilhite *et al.,* 2014). Any warning systems must depends upon the accurate real-time provision of rainfall information, and hydrological model structures that function during extreme conditions (Collier, 2007).

Short term rainfall forecasting (up to 6 hours ahead) in the tropic has long been recognized as one of the most difficult prediction problems in meteorology and the demand for rainfall forecasts with high spatial and temporal resolution has increased interest recently (Fraedrich and Leslie, 1988; French *et al.*, 1992; Toth *et al.*, 2000; Kim and Barros, 2001; Matthew *et al.*, 2003; Boudevillain *et al.*, 2006; Mandal and Jothiprakash, 2012; Zahraei *et al*, 2013). Moreover, precipitation can be used as an input to hydrologic models, e.g. for flood event modelling (Damrath et al., 2000).

In Malaysia, weather radar plays an important role in meteorological applications especially in aviation safety and flood warnings through monitoring of rainfall intensity (Adam and Subramaniam, 2012). However, application of radar-rainfall forecasting in Malaysia is still at the early stage and still needs to be explore (Suzana and Wardah, 2011a; Suzana and Wardah, 2011b).

In general, the rainfall forecasting uses weather radar as a tool to do forecasting. As radar cannot directly measure the depth of rainfall, therefore, there is a power law equation between reflectivity (Z) and rainfall intensity (R) (known as Z-R relationship) that is commonly used to calculate the rainfall depth. Ochou *et al.*, (2011) stated that parameter A and exponential *b* has great variability in Z-R relationship in space and time, from a rainfall event to another (e.g., convective versus stratiform) and even within a single rainfall event. Hence, theoretically, *A* and exponential *b* parameters in Z-R relationship is one relationship that site specific and not uniform (Mapiam and Sriwongsitanon, 2008).

In the history of Z-R relationship parameters development, Marshall and Palmer (1947) during the summer of 1946 used the Royal Canadian Air Force microwave-height finder (MHF). The wave produced is static at 8° horizontally and 1.5° vertical extent at the range of 8.8 km. The signal strength was keeping at constant height. The quantity of reflectivity (Z) has been determined by catching samples of rain on Whatman No. 1, filter papers which had been treated with a trace of powdered gentian-violet dye. The rainfall drop left the stains that function of the diameter of the original raindrops. The diameters of the stains on the dyed papers were measured with a transparent ruler which was calibrated to read directly the diameters of the original raindrops. From the experiment and few revision from 1947 until 1955, they successfully derived and proposed the well-known value for parameter *A* and exponential *b* for Z-R relationship parameters ($Z = 200R^{1.6}$) (Marshall *et al.,* 1955). This equation is still being used by many countries such as Thailand, Australia, Libya and Malaysia (Seed *et al.,* 2002; Mapiam and Sriwongsitanon, 2008; Kamil and Medhat, 2009; Suzana *et al.,* 2011; Adam and Subramaniam, 2012)

According to Suzana and Wardah (2011a) and Adam and Subramaniam (2012), the used of Marshall-Palmer parameter for Z-R relationship in Malaysia is no longer appropriate for rainfall estimation. It can be seen from the KLIA Weather Radar data that shows more than 80% of the data obtained from the radar were overestimated when compared to rain gauge. Therefore, the most suitable Z-R relationship for particular radar shall be developed to increase the accuracy of rainfall estimation by radar as well as the radar rainfall forecasting.