UNIVERSITI TEKNOLOGI MARA

QUANTITATIVE PRECIPITATION FORECAST USING NWP WRF-ANN MODEL FOR HYDRO-METEOROLOGICAL FLOOD FORECASTING

INTAN SHAFEENAR BINTI AHMAD MOHTAR

Thesis submitted in fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Civil Engineering)

Faculty of Civil Engineering

July 2023

ABSTRACT

Flood forecasting accuracy is crucial for authorities so that they can make better plans. There are many variables involved to provide accurate flood forecasting. The case study area is at Kelantan River Basin, where it experiences the northeast monsoon. QPF from the NWP model was processed, analyzed and applied as an alternative to traditional rain gauge system to be the input to an integrated hydro-meteorological flood forecasting system. The direct QPF outputs from the WRF model with a horizontal resolution of 4 km x 4 km was validated against gauged rainfall measurements. The findings demonstrate that the WRF model have the ability to produce QPF for rainfall forecasting, though the accuracy is found to be not very satisfactory. In order to improve the accuracy, ANN model was applied which incorporates several WRF model products. The ANN based post-processing of WRF model products (rainfall, relative humidity and temperature) involved several training algorithms, i.e., LM, BR and SC, and experimented to obtain the optimum algorithm. The training results indicate that the most effective training algorithms for the period of 365 days are LM and BR, and the SC performs the worst. After the post-processing using ANN, the accuracy of the QPF had greatly improved. The findings demonstrate that the best value of r increased significantly from 0.79 (direct QPF) to 0.99 after the ANN post processing. The enhanced QPF model was applied to be the alternative input to a rainfall-runoff model. A rainfall-runoff model was created using HEC-HMS with incorporation of GIS data from the ArcGIS software to produce a better result that includes all the parameter's variables involved in flood formation. The results indicate that the NSE value for HEC-HMS using rainfall from rain gauge as an input is 0.752 and the NSE value after calibration is 0.932. While the NSE value for the HEC-HMS using WRF-ANN QPF rainfall as data input is 0.489 and after calibration, the NSE value is 0.764. Even though the NSE value is lower than the NSE using rain gauge as input, the result is still considered satisfactory where the value of NSE is near one, and it can be used to support the rain gauge data as for purpose to forecast flood. The obvious advantage is the WRF-ANN QPF can provide rainfall forecast hours ahead compared to the traditional gauge rainfall input. As an outcome, WRF-ANN based rainfall can provide an early warning system by forecasting future floods and aiding Search and Rescue (SAR) authorities in the decision-making process.

ACKNOWLEDGEMENT

dfSBsB^Sfe

Bersabda NABIMUHAMMAD S.A. W:
"Bahawa barang siapayang menolong melapangkan dari seseorang mukmin satu kedukaan dari kedukaan-kedukaan duniayang sangat menggelisahkan hati dan perasaannya, nescaya Allah akan melapangkan pula daripadanya dari segala kedukaan pada Hari Kiamat ".

Praise to the Al-mighty Allah for his blessing that was given to me in completing this thesis.

This research would not have been possible without the generous support of those involved in making it a reality. My deepest appreciation and love to my daughters, and and my husband,
who helped to support my ups and downs for this study, as well as my late mother and father, without whom I were unable to persisted, not to mention my appreciation for the moral support that comes from my immediate family.

My deepest gratitude is to my supervisor, Prof. Ts. Dr. Wardah Tahir. I was extremely fortunate to have a supervisor who gave me the freedom to explore on my own while also providing the guidance I needed to recover when my steps faltered. She has also been commenting on my ideas and assisting me in understanding and enriching them. Her patience and support enabled me to overcome numerous crisis situations and accomplish this thesis. I'd also like to thank my co-supervisors, Assoc. Prof. Datin Dr. Amis Asmat and Dr. Marfiah Wahid, for their time, expertise, and valuable suggestions in enhancing my work. I appreciate their contribution and their good-natured guidance.

Special thanks to the Malaysian Ministry of Higher Education and Universiti Teknologi MARA (UiTM) for the scholarships and the opportunity to pursue my PhD. Many friends have helped me stay rational during these challenging times. Thank you especially to Aisar, Asma, Yazmeen, and Shazwani. Throughout many years of our friendship, their support and care enabled me to overcome hardships, enlighten me, and stay focused on my studies. They have consistently supported me in maintaining perspective on what is essential in my life and in learning to cope with reality.

TABLE OF CONTENTS

		Page
CONFIRMATION BY PANEL OF EXAMINERS		**ii**
AUTHOR'S DECLARATION		**iii**
ABSTRACT		**iv**
ACKNOWLEDGEMENT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**xi**
LIST OF FIGURES		**xiii**
LIST OF ABBREVIATIONS		**xix**
CHAPTER ONE INTRODUCTION		**1**
1.1	Research Background	1
1.2	Problem Statement	3
1.3	Research Question	4
1.4	Objectives	4
1.5	Significance of Study	5
1.6	Scope of Study	5
1.7	Limitation of Study	6
CHAPTER TWO LITERATURE REVIEW		7
2.1	Introduction	7
2.2	Rain Classifications	9
2.3	Types of Rainfall	9
	2.3.1 Convectional Rainfall	10
	2.3.2 Frontal Rainfall	10
	2.3.3 Relief Rainfall	11
	2.3.4 Measurement of Rainfall	12
2.4	Quantitative Precipitation Forecast (QPF) in Flood Forecasting.	12
2.5	Flood Forecasting in Malaysia	13
2.6	Numerical Weather Prediction (NWP) Model.	15

2.6.1 Theoreti cal B ackground 15
2.7 Numerical Weather Prediction (NWP) Model for Quantitative Precipitation Forecast (QPF) 17
2.8 NWP models in Malaysia 19
2.9 Weather Research Forecast (WRF) model 20
2.9.1 Introduction 20
2.10 Use of the WRF Pre-processing System by ARW 24
2.11 WRF Governing Equations 25
2.11.1 Vertical Coordinate and Variables 26
2.11.2 Flux-Form Euler Equations 27
2.11.3 Map Projections, Coriolis and Curvature Terms 29
2.11.4 Perturbation Form of the Governing Equations 31
2.12 Post-processing of WRF Model Output for QPF Development and ANN Application 33
2.13 Theoretical Background of Artificial Neural Network (ANN) 41
2.14 Backpropagation Algorithm 43
2.14.1 Levenberg-Marquardt (LM) 46
2.14.2 Bayesian Regularization (BR) Algorithm 47
2.14.3 Scaled Conjugate Gradient (SCG) 48
2.14.4 The network activation function 50
2.15 Rainfall-Runoff Modelling 51
2.15.1 Rainfall-runoff model: HEC-HMS Model 51
2.16 Review on the HEC-HMS Model 53
2.17 Summary 55

CHAPTER THREE RESEARCH METHODOLOGY 60
3.1 Introduction 60
3.2 Study Area Data Pre-Processing for Classification 62
3.3 Case study of Kelantan River Basin 62
3.4 Data collection and processing 63
3.4.1 General 63
3.4.2 Rainfall Data 64
3.5 Mean Areal Rainfall Estimation 66