FLOOD FORECASTING USING SEMI-DISTRIBUTED HYDROLOGICAL MODEL COUPLED WITH WEATHER RESEARCH AND FORECASTING MODEL

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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DEDICATION

This thesis is dedicated to my beloved mother in heaven “Syeda Aijaz Fatima.”

and

“Amatul Zehra Kazimi” for her unconditional love and support to me

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ABSTRAK

Lembangan Sungai Kuantan (KRB), merupakan kawasan tadahan terpenting di daerah Kuantan yang mengalami banjir sejak beberapa dekad lalu. Maklumat data hidro-meteorologi yang tidak lengkap, dan kekurangan stesen hujan dan paras air menjadi faktor utama yang mempengaruhi ketepatan ramalan banjir. Kajian ini bertujuan untuk mengatasi masalah dengan merapatkan jurang data hidro-meteorologi yang hilang dengan menggunakan model Penyelidikan Cuaca dan Peramalan (WRF) dengan gabungan kerjasama antara model Pusat Kejuruteraan Hidrologi-Sistem Pemodelan Hidrologi (HEC-HMS). Tiga kategori tahap hujan (ekstrem, berat, dan sederhana) digunakan bagi menilai keupayaan model dalam simulasi keadaan banjir. Kajian ini meliputi 4 objektif; (i) bagi menilai prestasi skema parameterisasi mikrofizik (MP) dan cumulus (CU) bagi model WRF, (ii) bagi mengenal pasti gabungan skim fizikal terbaik WRF untuk ramalan hujan di KRB iii) bagi menentukan parameter model GIS-hidrologi untuk KRB, dan (iv) bagi mengkuantifikasi keupayaan dan ketepatan rangka kerja ramalan banjir berdasarkan model hidro-meteorologi edaran separa. Prestasi 48 kombinasi skim WRF termasuk skim 8 MP dan 6 CU dinilai terlebih dahulu untuk simulasi kejadian hujan tunggal. Kemudian, 5 gabungan skema WRF terbaik yang terpilih diselidiki bagi menentukan skim prestasi tertinggi untuk mensimulasikan peristiwa bagi semua kategori dalam KRB. Kesemua hasil yang diperolehi telah disahkan dengan data hujan yang diperhatikan. Model HEC-HMS yang disepadukan dengan ArcGIS digunakan dalam membuat anggaran hidrograf banjir. Indeks statistik termasuk Kesilapan Peratusan (PE), Kecekapan Nash-Sutcliff (NSE), Ralat Kuasa Dua (RMSE), Kadar Hit (HR), Nisbah Penggera (FAR), Perkadaran Pembetulan (PC) dan Bias (B) digunakan bagi menilai prestasi model. Hasil dari 48 skim simulasi mendedahkan bahawa kesemua skema parameterisasi didapati kurang sensitif terhadap HR dan FAR. Julat purata PC (0.61 hingga 0.67), TS (0.55 hingga 0.67), dan RMSE (41.8 hingga 54.4) menunjukkan parameterWSM6GF,SBUBMJ,LinGF, MDMBMJ, dan MDMGF bertindak dengan lebih baik dalam simulasi keputusan Perbandingan objektif (ii) mengenal pasti SBUBMJ sebagai skim yang paling sesuai untuk menangkap hujan spatial dan temporal di KRB dengan PE purata ± 5.1%, ± 20.2%, ± 23.7% untuk hujan ekstrim, berat dan sederhana. Dalam penentukuran dan pengesahan aliran HEC-HMS, proses menunjukkan bahawa parameter Parameter Pemuliharaan Perkhidmatan-Curve Number (SCS-CN) dan Pekali Penyimpanan (R) didapati sensitif terhadap prestasi model. WRF dan HEC-HMS menunjukkan prestasi yang memuaskan dalam simulasi kejadian hujan lebat dengan NSE antara 0.59 hingga 0.65 dan 0.73 hingga 0.83, PE untuk pelepasan aliran tertinggi antara -23.30% hingga -36.37%, dan julat isipadu tertinggi dari -20.8% kepada -28.9%. Kesepakatan yang baik antara model telah dikenalpasti dalam kejadian hujan sederhana dengan julat NSE antara 0.73 hingga 0.83, manakala julat PE untuk pelepasan aliran tertinggi puncak antara -6.89% hingga 14.48%, dan julat isipadu tertinggi dari 4.7% hingga 4.9%. Bagi kejadian hujan ekstrem, model menunjukkan prestasi rendah dengan NSE antara 0.40 hingga 0.06, PE untuk pelepasan aliran tertinggi dari -15.74% hingga 17.23%, dan isipadu tertinggi dari -14.65% kepada -26.06%. Dari analisis keseluruhan, kajian menunjukkan bahawa model WRF boleh digunakan sebagai input meteorologi alternatif yang terbaik untuk kawasan yang kekurangan stesen pengukur hujan atau stesen pemerhatian hujan yang gagal berfungsi. Oleh itu rangka kerja model adalah penting dalam memberikan maklumat yang boleh dipercayai mengenai ramalan banjir dengan mempertimbangkan kira-kira purata ralat peratusan kira-kira ± 16% kepada ± 25% nilai pelepasan aliran.

ABSTRACT

Kuantan River Basin (KRB), is an important watershed of Kuantan District which has been experiencing floods since decades. The incomplete information of hydro-meteorological data, and insufficient rainfall and streamflow gauging stations remain the key factors influenced on flood forecasting accuracy. This study aimed to cope with the problem by bridging the gap of missing hydro-meteorological data using Weather Research and Forecasting (WRF) model coupled with Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model. Three rainfall event categories (extreme, heavy, and moderate) were used to evaluate the model's capability in simulating flood events. The research was covered 4 objectives; (i) to evaluate the performance of microphysics (MP) and cumulus (CU) schemes parameterization for WRF model,(ii) to identify the best physical schemes combination of WRF for precipitation forecasting at KRB iii) to determine GIS-based hydrological model parameters for KRB, and (iv) to quantify the ability and accuracy of proposed flood forecasting framework based on a coupled semi-distributed hydro-meteorological model. Performance of 48 combinations of WRF schemes including 8 MP and 6 CU schemes were first evaluated to simulate single rainfall event. Then selected top 5 best WRF schemes combinations were further investigated to determine the highest performance scheme to simulate events for all categories in KRB. All the obtained results were validated against the observed rainfall data. HEC-HMS model integrated with ArcGIS was used estimate flood hydrographs. Statistical indices include Percentage Error (PE), Nash-Sutcliff Efficiency (NSE), Root Mean Square Error (RMSE), Hit Rate (HR), False Alarm Ratio (FAR), Proportion of Correction (PC), Threat Score (TS) and Bias (B) were applied to evaluate the model performances. The results of the 48 schemes simulations revealed that all the parametrized schemes were found less sensitive to HR and FAR. an average range of PC (0.61 to 0.67), TS (0.55 to 0.67), and RMSE (41.8 to 54.4) indicated the parametrization of WSM6GF, SBUBMJ, LinGF, MDMBMJ, and MDMGF performed relatively better to simulate the event Comparison results of objective (ii) identified SBUBMJ as the most suitable schemes to capture spatial and temporal rainfall in KRB with mean average PE of ±5.1%, ±20.2%, ±23.7% for extreme, heavy, and moderate rainfall, respectively. In HEC-HMS streamflow calibration and validation processes showed that the parameters Soil Conservation Service- Curve Number (SCS-CN) and Storage Coefficient (R) were found to be sensitive to the model performance. Validation results of the coupled WRF and HEC-HMS simulation revealed satisfactory performance in simulating heavy rainfall events with NSE ranges from 0.59 to 0.65 and 0.73 to 0.83, PE for peak discharge ranges from -23.30% to -36.37%, and peak-volume ranges from -20.8% to -28.9%. Good agreement between the models was identified in moderate rainfall events with NSE ranges 0.73 to 0.83, PE for peak discharge ranges from -6.89% to 14.48%, and peak volume range from 4.7% to 4.9%. For the extreme events, the models indicated low performance with NSE ranges from 0.40 to 0.06, PE of peak discharge from -15.74% to 17.23%, and peak volume from -14.65% to -26.06%. From the overall analysis, the study has determined that WRF model can be applied as the best alternative meteorological input to be used for sparse rainfall gauge areas or areas where rainfall observation stations fail to function. Hence the model framework is significant in providing reliable information on flood forecasting by considering about average percentage error of about ±16% to ±25% flow discharge values.

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LIST OF SYMBOLS

α	Alpha
β	Beta
γ	Gamma
∅	Geo-potential height
ΔS	Change in Storage
Δx	Rate of change of distance
Δt	Rate of change of time
a	Generic variable
c	Wave celerity/speed
C_A	Routing Coefficient
C_B	Routing Coefficient
$CN_{0.2II}$	CN based on AMC II condition
$CN_{0.05II}$	Modified CN based on AMC II condition
c_p/c_v	Ratio of heat capacity for dry air
dS	Rate of change of storage
ET	Evapotranspiration
F	Forecasted value
F_u	Model Physics
F_v	Turbulent mixing
F_w	Spherical Projection
$F\theta$	Rotation of the earth
Ia	Initial abstraction
I_t	Inflow storage at time
m_x	Projection map scale at horizontal direction
m_y	Projection map scale at vertical direction
η	Hydrostatic-pressure coordinate
n	Number of discharge value
n	Number of sample points
O	Observed value
O_t	Outflow Storage at time
P	Precipitation
P	Predicted value

p	Pressure for Potential temperature
p_0	Reference pressure
p_{ht}	Top boundary value
p_{hs}	Surface boundary value
q	Runoff
q_L	Later inflow
Q	Discharge
Q_{obsi}	Observed flow
Q_{simi}	Simulated flow
Q_{obs}	Observed average flow
R	Streamflow
R	Linear Parameter
R_d	Dry air gas constant
S	Potential Retention
S_t	The volume of water in storage at time
S_f	Friction Slop
S_o	Bed slop
$S_{0.02}$	The maximum potential storage based on λ 0.02
$S_{0.05}$	The maximum potential storage based on λ 0.05
μ	Mass per unit area
μ	Hydraulic diffusivity
U, V, W	Covariant velocities in vertical and horizontal direction
x	Distance at downstream
X	Predicted value
Y	Dependent value

LIST OF ABBREVIATIONS

AMC	Antecedent Moisture Condition
ANN	Artificial Neural Network
ASCII	American Standard Code for Information Interchange
ARW	Advance Research WRF
AVHRR	Advance Very High-Resolution Radiometer
B	Bias
BMJ	Betts Miller Janjic
CMORPH	Climatic prediction centre and Morphing Technique
CN	Curve Number
CU	Cumulus
CuP	Cumulus Potential
CUH	Calrk’s Unit Hydrograph
CRED	Centre for Research on the Epidemiology of Disaster
D8	Deterministic 8
DA	Data Assimilation
DEM	Digital Elevation Model
DHI	Danish Hydrological Institute
DID	Drainage and Irrigation Department
DOA	Department of Agriculture
DSM	Digital Surface Model
DVAR	Dimensional Variation
ECMWF	European Centre for Medium-range Weather Forecast
ENIAC	Electronic Numerical Integrator and Computer
EPIC	Environmental Policy Integrated Climate
ERA	ECMWF Re Analysis
ESRI	Environmental Systems Research Institute
FAR	False Alarm Ratio
FEST	Fully Vegetated Slab of Soil and Transpiring Plants
FNL	Final Analysis Data
G3D	Grell 3D
GCM	Global Circulation Model
GDEM	Global Digital Elevation Model
GEOREX	Geo-Spatial Data Exchange System

GF	Grell Freitas
GFS	Global Forecasting System
GIS	Geographic Information System
GoM	Goddard Microphysics
GPS	Global Positioning System
GRIB	General Regularly distributed Information in Binary form
GUI	Graphical User Interphase
HadCM3	Hadley Centre Coupled Model
HEC	Hydrologic Engineering Centre
HEC-HMS	Hydrologic Engineering Centre- Hydrologic Modelling System
HMS	Hydrologic Modelling System
HR	Hit Rate
HSG	Hydrological Soil Group
IR	Infra-Red
KF	Kain Fritsch
KMC	Kuantan Municipal Council
KRB	Kuantan River Basin
KS	Kessler
LBC	Lateral Boundary Condition
LC	Lambert Conformal
LiDAR	Light Detection and Ranging
Lin	Lin et al scheme
LLP	Lat-Long Projection
LSM	Land Surface Model
LU	Land Use
LW	Long Waves
MACRES	Malaysian Centre for Remote Sensing
MAE	Mean Absolute Error
MLC	Maximum Likelihood Classifier
Me	Mercator
MM5	Fifth-generation Mesoscale Model
MMD	Malaysian Meteorological Department
MDM	Morrison Double Moment
MP	Microphysics
MPI- ECHAM5	Max Planck Institute- European Centre Hamberg Model

MSE	Mean Square Error
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NCAR	National Centre of Atmospheric Research
NCEP	National Centre of Environmental Prediction
NCL	NCAR Command Language
NDVI	Normalized Difference Vegetation Index
NEM	Northeast Monsoon
NGIA	National Geospatial-Intelligence Agency
NIR	Near Infra-Red
NMM	Non- hydrostatic Mesoscale Model
NSE	Nash-Sutcliff Efficiency
Nth	New Thompson et al.
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OKF	Old Kain Fritsch
PC	Percentage Correct
PE	Percentage Error
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network
PS	Polar Stereographic
PBL	Planetary Boundary Layer
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
R	Reservoir /Storage Coefficient
RCM	Regional Climatic Model
RMSE	Root Mean Square Error
RRTM	Rapid Radiative Transfer Model
RS	Remote Sensing
RSM	Regional Scale Model
RZ	Relax Zone
SAR	Synthetic Aperture Radar
SBU	Stony Brook University
SHE	System Hydrologique European
SCS	Soil Conversation Service

SL	Scripting language
SMA	Soil Moisture Accounting/Algorithm
SP	Specified Zone
SPOT	Satellite Probatoire d' Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
SW	Short Waves
SWAT	Soil & Water Assessment Tool
SWM	Southwest Monsoon
Ti	Tiedtke
TM	Thematic Mapper
TOPMODEL	Topographic based Hydrological Model
TMPA	TRMM Multisatellite Precipitation Analysis
TS	Threat Score
TRMM	Tropical Rainfall Measuring Mission
USDA	US Department of Agriculture
Var	Variational
WPS	WRF Pre-Processing System
WRF	Weather Research Forecasting
WSM3	WRF Single Moment 3 class
WSM6	WRF Single Moment 6 class
YSU	Yousei University PBL

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