

RESERVOIR SYSTEM MODELLING USING NONDOMINATED SORTING  
GENETIC ALGORITHM IN THE FRAMEWORK OF CLIMATE CHANGE

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## ABSTRAK

Sistem takungan memerlukan pembangunan model yang berterusan untuk mendapatkan operasi yang optima dalam konteks perubahan iklim pada masa akan datang. Statistik bagi variasi perubahan iklim dan percambahan kaedah evolusi telah mendorong pembangunan sistem operasi takungan mampan dan jangka panjang. Matlamat kajian ini ialah untuk membentuk dan merumuskan satu sistem operasi dan pengurusan takungan jangka panjang yang mampan bersesuaian dengan perubahan iklim menggunakan model yang bersepadu. Model ini terdiri daripada kaedah Tidak Dominasi Pengisihan Algoritma Genetik jenis II (NSGA-II), Pengaturcaraan Linear (LP), model Penurunan Skala Statistik (SDSM) dengan Kepelbagaian Linear Kolerasi Matrik (M-CM), model hidrologi dan model tanaman. Terdapat dua kumpulan model dicadangkan dikenali sebagai Model A dan Model B. Model A adalah gabungan kaedah NSGA-II dengan M-CM, model hidrologi dan model tanaman yang mengambilkira variasi iklim. Manakala, Model B pula tidak mengambilkira faktor perubahan iklim dengan menggunakan kaedah Valencia Schaake (VS) dan kaedah Thomas Fiering (TF). Kebolehpercayaan, keanjalan, dan kelemahan model tersebut telah dinilai. Model-model ini telah diaplikasikan keatas sistem takungan Pedu-Muda yang berfungsi membekalkan air untuk tujuan pertanian bagi Rancangan Pengairan Muda, Kedah, Malaysia. Kemasukkan M-CM sebagai alat penyaringan di dalam model SDSM adalah berjaya menghasilkan nilai yang rendah dalam purata ralat mutlak (MAE = 4mm/hari), purata ralat kuasa dua (MSE = 29mm/hari), and sisihan piawai (St.D = 1mm/hari). Dijangkakan hujan dan suhu masa depan akan meningkat sebanyak 4% dan 0.2°C pada setiap dekad. Keperluan isipadu air untuk penanaman padi dijangka akan menurun sebanyak 0.9 % setiap dekad. Ini kerana peningkatan kuantiti hujan dan air larian tidak terkawal ke bendang. Aliran masuk sintetik yang dijana menggunakan model VS dan TF menghasilkan perbezaan sebanyak +0.4% dan -1.3% daripada rekod sejarah. Model NSGA-II dan LP juga telah berjaya membentuk sistem operasi takungan yang mampan bagi jangka masa panjang. Tambahan lagi, model NSGA-II telah berjaya memenuhi kepelbagaian permintaan dalam objektif dan menyediakan satu set penyelesaian alternatif dalam bentuk lengkung Pareto optima dengan mengambilkira corak iklim. Pembentukan corak lengkung operasi bagi Model A adalah lebih tinggi secara konsisten daripada Model B dengan julat 1% hingga 5%. Penilaian kebolehpercayaan, keanjalan, dan kelemahan menunjukkan kaedah Model A-NSGA-II adalah baik dan berpotensi untuk dijadikan sebagai panduan operasi bagi bekalan air yang mencukupi sepanjang tahun. Model B (VS) adalah model kedua terbaik diikuti Model B (TF). Kesimpulannya, penemuan ini menyumbang kepada pembangunan model dengan menggunakan evolusi algoritma dan kaedah statistik bagi merancang dan mengurus sumber air secara mampan dalam konteks perubahan iklim masa hadapan.

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## LIST OF SYMBOLS

|                     |   |  |
|---------------------|---|--|
| $P, \eta_k$         | - | quantity of rainfall (mm)                        |
| $t_k$               | - | Temperature reading ( $^{\circ}\text{C}$ )       |
| Cov                 | - | covariance                                       |
| N                   | - | number of variable / population                  |
| $\overline{xy}$     | - | mean variables                                   |
| $s_x$               | - | standard deviation for $x$                       |
| $s_y$               | - | standard deviation for $y$                       |
| $S_k$               | - | soil moisture index                              |
| $r_{xy}$            | - | correlation matrix                               |
| $u_k, P_e, P_{eff}$ | - | effective rainfall (mm)                          |
| $\tau_w$            | - | Catchment drying time constant                   |
| $R$                 | - | reference temperature ( $^{\circ}\text{C}$ )     |
| $C$                 | - | proportion of rainfall                           |
| $f$                 | - | temperature modulation factors                   |
| $x_k$               | - | streamflow (MCM)                                 |
| $D$                 | - | Determination coefficient                        |
| $Y_t$               | - | Seasonal flow (MCM/month)                        |
| $Q_t$               | - | Annual flow (MCM/year)                           |
| $I_t$               | - | value of random deviate                          |
| $W_{irr}$           | - | irrigation water requirement                     |
| $W_{lp}$            | - | water required for land preparation              |
| $W_{ps}$            | - | persolation and seepage losses                   |
| $W_t$               | - | water required to establish standing water layer |
| $K_c$               | - | crop coefficient                                 |

|            |   |                                     |
|------------|---|-------------------------------------|
| $e_s$      | - | saturation of water vapour          |
| $e_a$      | - | actual water vapour                 |
| $\Delta$   | - | slope                               |
| $u_2$      | - | wind speed                          |
| $G$        | - | soil heat flux density              |
| $\gamma$   | - | psychrometric constant              |
| $R_n$      | - | radiation                           |
| $R_t$      | - | Water release                       |
| $S_t$      | - | reservoir storage                   |
| $D_t$      | - | Water demand                        |
| $I_t$      | - | water inflow                        |
| $Sp_t$     | - | water spill                         |
| $S_{muda}$ | - | water storage in the Muda reservoir |
| $Eva_t$    | - | Evaporation                         |
| $See_t$    | - | Evaporation                         |

**LIST OF ABBREVIATIONS**

|      |   |   |
|------|---|---|
| MADA | - | Muda Agriculture Development Authority        |
| NSGA | - | Nondominated sorting genetic algorithm        |
| LP   | - | Linear Programming                            |
| NLP  | - | Non-linear Programming                        |
| TF   | - | Thomas Fiering                                |
| GCM  | - | General circulation model                     |
| RCM  | - | Regional Climate Model                        |
| NCEP | - | National Centers for Environmental Prediction |
| SWG  | - | Stochastic Weather Generator                  |
| WT   | - | Weather Typing                                |
| DP   | - | Dynamical programming                         |
| SD   | - | Statistical Downscaling                       |
| CLS  | - | Classical Least Square                        |
| MLR  | - | Multiple Linear Relationship                  |
| AR   | - | Autoregression                                |
| ARMA | - | Autoregression Moving Average                 |
| CWR  | - | Crop Water Requirement                        |
| CWD  | - | Crop Water Demand                             |
| ET   | - | Evapotranspiration                            |
| ETc  | - | Evapotranspiration of crop                    |
| MOEA | - | Multi-objective evolutionary algorithm        |
| MSL  | - | Mean sea level                                |
| KOD  | - | Kodiang                                       |
| JIT  | - | Jitra   |
| LTP  | - | Ladang Tanjung Pauh                           |

|       |   |                             |
|-------|---|-----------------------------|
| KN    | - | Kuala Nerang                |
| AP    | - | Ampang Pedu                 |
| GM    | - | Gajah Mati                  |
| TC    | - | Teluk Chengai               |
| KT    | - | Keretapi Tokai              |
| KS    | - | Kuala Sala                  |
| Kg.LB | - | Kampung Lubuk Badak         |
| LH    | - | Ladang Henrietta            |
| SL    | - | Sungai Limau                |
| KP    | - | Kedah Peak                  |
| SG    | - | Sungai Gurun                |
| SIK   | - | Sik                         |
| Kg.LS | - | Kampung Lubuk Segintah      |
| PEN   | - | Pendang                     |
| IBT   | - | Ibu Bekalan Tupah           |
| KSS   | - | Kota Sarang Semut           |
| Kg.T  | - | Kampung Terabak             |
| mlsp  | - | mean sea level pressure     |
| p_f   | - | surface airflow strength    |
| p_u   | - | surface zonal velocity      |
| p_v   | - | surface meridional velocity |
| p_z   | - | surface vorticity           |
| p_th  | - | surface wind direction      |
| p_zh  | - | surface divergence          |
| p5_f  | - | 500hpa airflow strength     |
| p5_u  | - | 500hpa zonal velocity       |
| p5_v  | - | 500hpa meridional velocity  |
| p5_z  | - | 500hpa vorticity            |
| p500  | - | 500hpa geopotential height  |
| p5th  | - | 500hpa wind direction       |
| p5zh  | - | 500hpa divergence           |
| p8_f  | - | 850hpa airflow strength     |
| p8_u  | - | 850hpa zonal velocity       |

|      |   |                                      |
|------|---|--------------------------------------|
| p8_v | - | 850hpa meridional velocity           |
| p8_z | - | 850hpa vorticity                     |
| p850 | - | 850hpa geopotential height           |
| p8th | - | 850hpa wind direction                |
| p8zh | - | 850hpa divergence                    |
| r500 | - | relative humidity at 500hpa          |
| r850 | - | relative humidity at 850hpa          |
| rhum | - | near surface relative humidity       |
| shum | - | surface specific humidity            |
| temp | - | mean temperature                     |
| MCM  | - | $\times 10^6$ cubic meter            |
| MAE  | - | Mean absolute error                  |
| MSE  | - | Mean square error                    |
| StD  | - | Standard deviation                   |
| N-E  | - | North-East monsoon                   |
| S-W  | - | South-West monsoon                   |
| M-CM | - | multi-correlation matrix             |
| ARPE | - | Average Relative Parameter Error (%) |

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction and Background

Global climate change is a pressing issue that needs an aggressive attention and action from the global authorities. Karl *et al.* (2009) classified the climate warm as unequivocal and had become greater than over the last century. Increment of the greenhouse gases emission such as carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, CFC, and water vapor into the atmosphere could ruin the earth's life year by year. A major contaminant is carbon dioxide (CO<sub>2</sub>) that comes from human activities such as burning of fossil fuel, clearing forest, animal husbandry and agricultural practices at least 5 times greater than natural effects from the sunrise. A report by United States Environmental Protection Agency (EPA) stated that the electricity is the largest single source of CO<sub>2</sub> in range 38 % followed by transportation (31 %), industry (14 %), residential & commercial (10 %) and others (6 %) during year 1990 to 2011. This is supported by a report from National Oceanic and Atmospheric Administration (NOAA) which stated that the increment of monthly CO<sub>2</sub> achieved 395 ppm in August 2013, 45 ppm higher than CO<sub>2</sub> safety limit while an annual reading of year 2012 is 394 ppm (+0.6 % than year 2011).

Intergovernmental Panel on Climate Change AR4 (IPCC, 2007) reported that the global average surface temperature for the past 100 years had increased from 0.6 °C (1901 - 2000) to 0.74 °C (1906 - 2005). The World Meteorological Organization (WMO) claimed that the year of 2010 is the warmest year achieved with temperature of 1.2 °C to 1.4 °C especially in Africa, parts of Asia and parts of the Arctic.