UNIVERSITI PUTRA MALAYSIA

CLIMATE-SMART DECISION SUPPORT SYSTEM FOR ASSESSING WATER DEMAND PATTERNS UNDER FUTURE CLIMATE CHANGE FOR KERIAN RICE IRRIGATION SCHEME, MALAYSIA

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By

MUHAMMAD ADIB BIN MOHD NASIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master of Science

May 2019

DEDICATION

This thesis is dedicated to:

My beloved parents for their endless love and wish for their son to achieve the higher dream,

My wife Nurseha who has always played a significant role during the journey of study,

My daughter Husna who endured hardships all the years without father quality time, and

My Supervisor, Dr. Md Rowshon who has been a source of inspiration to me throughout my study.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science.

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Chairman: Md Rowshon Kamal, PhD
Faculty: Engineering

The uncertainty of water availability for irrigation supply affects the sustainable rice production under the likely evolving climate change impacts. In recent decades, the growth of populations and drastically economic development in urban areas have resulted in a severe water shortage in many countries with 70% of total global water used for the agricultural sector. Climatic changes cause an increase in temperature, changes in rainfall patterns and other hydrogeological variables. These changes will have adverse effects on hydrological systems and water resources management, which are important sources for agriculture. Therefore, analyzing the impacts of climate change on water demand and management of water resources systems to assess agricultural production, especially for rice, has become an important issue.

This study attempted to customize Climate-smart Decision Support System (Climate-smart DSS) for Kerian Rice Irrigation Scheme for irrigation water demand patterns and optimal reservoir operation policy for the best water management practices in the scheme under the impacts of future climate change. The development of mitigative measures is very crucial to reduce likely water shortages. IADA Kerian Irrigation Scheme, located in Perak, Malaysia was chosen as a study area to examine the future irrigation water demand patterns for rice scheme. The Bukit Merah Reservoir consisted of 480 km^2 of Kurau River Basin the dominant part of the reservoir, which is the main source for irrigation supply to meet the water demand of the scheme. In this study, future climate variables were generated using Climate-smart DSS, a user-friendly MATLAB interactive program. It was developed to generate future climate variables (rainfall, temperature, relative humidity, and wind speed), which were used as inputs for hydrologic and optimal reservoir operation models using MATLAB software. Statistical downscaling technique, the delta change method was used to downscale 10 GCMs under three RCPs (RCP4.5, RCP6.0, and RCP8.5) for two future periods (2021-2050 and 2051-2080) at the study area.

The Soil and Water Assessment Tool (SWAT) hydrologic model was used to evaluate the impact of climate change on future streamflow of Kurau River Basin and inflow patterns of the reservoir. The model was evaluated using 30 years of historical period streamflow records (1976-2006) to predict the future (2021-2080) hydrologic response of the Kurau River Basin. The discharge obtained from SWAT output was used as input in simulating irrigation release from Bukit Merah Reservoir for Kerian Irrigation Scheme. The projected streamflow generally indicate reduction during the off-season/first season (February to July) and main-season/second season (August to January) when compared to historical records, which could be due to high surface warming in future. Water demand patterns of the IADA Kerian Rice Irrigation Scheme were analyzed considering with evolving climate change conditions to cope with the resilience of Bukit Merah Reservoir.

Reference evapotranspiration (ET_o) was estimated using improved Climate-smart DSS from projections of temperature (maximum and minimum), relative humidity, wind speed, and solar radiation using Penman-Monteith equation. Multi-models average was used to adequate effectively express the patterns of predicted future ET_o at the Kurau River Basin. The ET_o is predicted to increase for each RCP scenario for the two periods (2021-2050 and 2051-2080) concerning with respect to the baseline period with the highest increase predicted under RCP8.5. The model outputs indicate the future is predicted to have a high demand for irrigation water, especially during the off-season compared to main-season concerning with respect to the baseline period.

Finally, Linear Programming (LP) using LINGO software was applied, used to develop programming codes and compute the optimal future release patterns of irrigation supply from the reservoir. Simulation of optimum release shows that the off-season of rice planting will suffer shortage conditions under future climate for RCP4.5, RCP6.0, and RCP8.5 scenarios. It is revealed that the excess streamflow stored during the main-season will meet the shortage of irrigation supply in the off-season irrigation periods from February to July. The filling period of the Bukit Merah Reservoir was identified for July, November, December, and January. In future, the high streamflow during the main-season will compensate the peak water demand during the off-season irrigation demand. This study provides valuable information for water demand patterns and optimal water operation policy and will help irrigation managers and policymakers for their adaptation plans for responding to climate change.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM SOKONGAN KEPUTUSAN IKLIM-PINTAR UNTUK MENILAI CORAK PERMINTAAN AIR DIBAWAH PERUBAHAN IKLIM MASA HADAPAN BAGI SKIM PENGAIRAN JELAPANG PADI KERIAN, MALAYSIA

Oleh

MUHAMMAD ADIB BIN MOHD NASIR

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Ketidakpastian dalam ketersediaan air untuk bekalan pengairan memberi kesan kepada pengeluaran padi di bawah kesan perubahan iklim yang bakal berlaku. Sejak kebelakangan ini, pertumbuhan populasi dan pembangunan ekonomi secara drastik di kawasan bandar telah mengakibatkan kekurangan air yang agak membimbangkan di kebanyakan negara dengan 70% daripada jumlah keseluruhan air dunia digunakan dalam sektor pertanian. Perubahan iklim menyebabkan peningkatan suhu, perubahan corak hujan dan juga perubahan pelbagai pembolehubah hidrogeologi. Perubahan ini akan mengakibatkan kesan negatif terhadap sistem hidrologi dan pengurusan sumber air, yang mana merupakan sumber utama untuk pengairan pertanian. Oleh itu, menganalisis impak perubahan iklim terhadap permintaan air dan pengurusan sistem sumber air untuk menilai pengeluaran pertanian, terutamanya padi, telah menjadi isu penting.

Kajian ini bertujuan menyesuaikan Sistem Sokongan Keputusan Iklim-Pintar (Climate-smart DSS) kepada Skim Pengairan IADA Kerian untuk menilai corak permintaan air pengairan dan operasi takungan secara optimum bagi amalan pengurusan air terbaik di bawah perubahan iklim masa hadapan. Pembangunan langkah mitigatif sangat penting dalam merawat masalah kekurangan bekalan air. Skim Pengairan IADA Kerian, yang terletak di Perak, Malaysia telah dipilih sebagai kawasan kajian bagi mengkaji dan meramal corak permintaan air pengairan padi pada masa hadapan. Takungan Bukit Merah adalah sebahagian daripada 480 km^2 Lembangan Sungai Kurau yang merupakan bahagian hulu yang dominan kepada takungan tersebut yang mana merupakan sumber utama bekalan air pengairan dalam memenuhi permintaan air Skim Pengairan IADA Kerian. Dalam kajian ini, pembolehubah iklim masa hadapan dijana menggunakan Sistem Sokongan Keputusan Iklim-pintar, yang merupakan program interaktif MATLAB yang mesra pengguna. Ia

dibangunkan untuk menjana pembolehubah iklim masa hadapan (hujan, suhu, kelembapan relatif, dan kelajuan angin), yang digunakan sebagai input untuk model hidrologi dan operasi takungan optimal menggunakan perisian MATLAB. Teknik penurunan skala secara statistik, kaedah perubahan delta digunakan untuk menurunkan skala sepuluh Model Iklim Global (GCM) di bawah tiga jenis senario (RCP4.5, RCP6.0, dan RCP8.5) untuk dua tempoh masa hadapan (2021-2050 dan 2051-2080) di kawasan kajian.

Satu model hidrologi, Alat Penilaian Tanah dan Air (SWAT) digunakan untuk menilai kesan perubahan iklim pada aliran sungai masa hadapan di Lembangan Sungai Kurau dan corak aliran air masuk ke takungan. Model ini dinilai menggunakan 30 tahun rekod aliran sungai masa lampau (1976-2006) untuk meramalkan tindak balas hidrologi di Lembangan Sungai Kurau masa hadapan (2021-2080). Pelepasan yang diperolehi daripada output SWAT digunakan sebagai input dalam simulasi pelepasan air pengairan dari Takungan Bukit Merah untuk Skim Pengairan Sawah Padi Kerian. Aliran air sungai yang diunjurkan secara amnya menunjukkan pengurangan bagi kedua-dua musim-utama/musim pertama (Februari hingga Julai) dan di musim-luar/musim kedua (Ogos hingga Januari) berbanding rekod masa lampau, yang mungkin disebabkan oleh pemanasan permukaan yang tinggi pada masa hadapan. Corak permintaan air Skim Pengairan IADA Kerian telah dianalisis dengan mengambil kira perubahan keadaan iklim yang tidak menentu sesuai dengan daya tahan Takungan Bukit Merah.

Evapotranspirasi rujukan (ET_o) dianggarkan menggunakan Sistem Sokongan Keputusan Iklim-pintar daripada unjuran suhu (maksimum dan minimum), kelembapan relatif, kelajuan angin dan sinaran suria dengan menggunakan persamaan Penman-Monteith. Purata pelbagai-model GCM digunakan untuk mengekspresikan corak ET_o di Lembangan Sungai Kurau bagi masa hadapan. ET_o diramalkan meningkat bagi setiap scenario RCP untuk kedua-dua tempoh masa hadapan tersebut (2021-2050 dan 2051-2080) dibandingkan dengan masa lampau dengan peningkatan tertinggi diramalkan dibawah senario RCP8.5. Hasil model menunjukkan masa hadapan diramalkan bakal beradapan dengan permintaan air pengairan yang tinggi terutamanya semasa musim-luar berbanding dengan musim-utama jika dibandingkan dengan masa lampau.

Akhirnya, Pemrograman Linear (LP) menggunakan perisian LINGO digunakan bagi membangunkan kod pengaturcaraan dan meramal corak pelepasan bekalan air pengairan secara optimum masa hadapan dari takungan untuk amalan pengurusan sumber air yang berkesan di bawah impak perubahan iklim masa hadapan. Simulasi pelepasan optimum menunjukkan bahawa musim penanaman padi di musim-luar akan mengalami keadaan kekurangan di bawah iklim masa hadapan bagi senario RCP4.5, RCP6.0, dan RCP8.5. Telah dirungkaikan bahawa lebihan aliran sungai yang disimpan semasa musim-utama akan menampung kekurangan bekalan pengairan dalam tempoh pengairan di musim-luar dari bulan Februari hingga Julai. Tempoh pengisian Takungan Bukit Merah telah dikenal pasti dalam bulan Julai, November, Disember, dan Januari. Pada masa hadapan, aliran tinggi semasa musim-utama akan mengimbangi permintaan air puncak ketika musim-luar. Kajian ini menyediakan maklumat penting bagi corak permintaan air dan dasar operasi air secara optimum yang mampu membantu pengurus pengairan dan penggubal dasar dalam rancangan penyesuaian dalam menanggapi perubahan iklim.

ACKNOWLEDGEMENT

Completion of this work would not have been possible without the help I received from many supporters. It has been a hard two years journey, but a most enlightening one too. Grateful to Allah for granting me an opportunity, strength, and wisdom to accomplish this great work.

I would like to express my sincere gratitude and regards to my supervisor, Dr. Md Rowshon Kamal, for his guidance, support, and suggestions through the journey of my research. His patience with me makes my research life more exciting, meaningful and less painful. I consider myself fortunate to have him as my guide. I am equally grateful to my committee member, Dr. Aimrun Wayayok, without the extraordinary help, I would not have been able to accomplish the task.

Heartfelt thanks are extended to the Universiti Putra Malaysia for financial support through *Skim Tenaga Akademik Muda*. Sincere appreciation is poured to the Department Irrigation and Drainage (DID), Malaysian Meteorological Department (MMD) and IADA Kerian for providing the necessary data. I am also grateful to Dr. Dlamini for his efforts in giving me training about the process to downscale Global Climate Models and MATLAB Programming. I also would like to thank all the staff of the Department of Biological and Agricultural Engineering for their hospitability and cooperation whenever required during my work.

It would not have been easy for me to achieve this great work without my wife and daughter support. It is through their love and sacrifice of numerous days without quality time with husband and father busy to accomplish the master’s study. Sincere gratitude goes to my parents, siblings, and friends for their love, affection, and encouragement.

Declaration by graduate student

I hereby confirm that:

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Signature: ______________________________________

Name of Member of Supervisory Committee: Dr. Aimrun Wayayok

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LIST OF ABBREVIATIONS

AR4	Assessment Report Four
AR5	Fifth Assessment Report
CSDSS	Climate-smart Decision Support System
CMIP5	Coupled Model Inter-comparison Project Phase-5
DEM	Digital Elevation Model
DID	Drainage and Irrigation Department
DOA	Department of Agriculture
DSS	Decision Support System
ET_c	Crop Evapotranspiration
ET_o	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FAR	First Assessment Report
GCM	Global Climate Model
GHG	Greenhouse Gas
HRU	Hydrologic Response Unit
IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use/Land Cover
MMD	Malaysian Meteorological Department
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent Bias
R^2	Coefficient of Determination
SAR	Second Assessment Report
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
SUFI-2	Sequential Uncertainty Fitting
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT - Calibration and Uncertainty Procedures
TAR	Third Assessment Report
WG	Weather Generator

CHAPTER 1

INTRODUCTION

1.1 Background

Water is the basic natural resources and a key element of life for everyone on earth. It is also a crucial resource and vital for both agriculture and industry. In recent years, competition for water to satisfy the daily requirements of the world's growing population has been on the increase to the point of physical scarcity of the resources (UN-Water, 2010). According to global-scale water scarcity projection studies, more than half of the world's population is likely to be living in countries facing high water stress by the year 2025 (Rijsberman, 2006). The significant driving of water scarcity is associated with the increasing demand for different land, water uses, and climate change phenomena (Gregory et al., 2005). Climate change is expected to cause long term water shortages which would worsen soil condition, rise of sea level, disease on crops, and greenhouse gas emissions are now at their highest levels in history (Siwar et al., 2009).

Irrigation still has significant potential for economic growth, food security, and poverty reduction. Agricultural irrigation remains the largest consumer of the world's water, accounting for about 70% of total water withdrawals in the world (FAO 2010). Crop production critically depends on plant roots taking up water from the soil, transporting it up to the leaves to balance transpiration losses during the intake of carbon dioxide process associated with photosynthesis. The agricultural sector was faced with the challenge of encountering future food requirements with limited water resources. Moreover, according to FAO (2010), agricultural production would have to be increased by 60% due to the increase in the world population by 2025. In addition, more water is needed for environmental concern such as wildlife refuges, aquatic life, scene values, recreation and riparian habitats (Bouwer, 2000). However, irrigation is criticized for the huge amount of water losses due to low efficiencies system and poor performance.

Rice is the most common staple diet and currently sustains more than half of the world population, which rich in protein and energy sources. More than 90% of the world's rice is produced and consumed in Asia (IRRI, 2002). The Malaysian scenario shows, rice production cannot accommodate the rapid increase in the country's population (Sarwar & Khanif, 2005). In order to meet the demand, about RM501 million has been spent per year to import rice from neighboring countries (Sarwar & Khanif, 2005). Alam et al. (2010) reported Malaysia to have more than 300,000 rice farmers encompassing over 322,000 hectares under irrigation. Rice is cultivated during the off-season (first season) and main-season (second season) also synonym with double cropping under irrigation schemes. Water is the primary inputs for rice production, while irrigation and drainage facilities are the keys for rice-growing areas (Agriculture Statistical Handbook, 2008). Rice production systems in Malaysia use 80% of available freshwater and its a higher quantity of water compared to other countries.

Irrigation requirement for rice production in the country is 1000 to 1500 mm (DID & JICA, 1998; Rowshon et al., 2009).

Although Malaysia is blessed with an average rainfall of 2500 mm per year with abundant water resources, climate change coupled with drought, pollution and urbanization would cause water stress to the country (Nuramidah et al., 2015). The concept of water security and drought resilience has received increased attention due to ever-increasing water demand. Chartres and Varma (2011) stated that the world faces an emerging water crisis due to the worsening water shortage and scarcity. Cook and Bakker (2012) indicated that water security is an integrative approach to bring issues of good governance to the fore, hence holds promise as a new approach to water management. Drought is well known for declining and varying crop yield drastically. Increased evaporation due to climate change is thought to augment irrigation requirement in Southeast Asia by 15% (Doll et al., 2003). Several recent studies highlighted that climate change causes potential changes in global and regional agricultural water demand for irrigation (Chiang & Liu, 2013; Chung, et al., 2011; Chung & Temba, 2012; Hanjra & Qureshi, 2010; Hugh et al., 2013; NAHRIM, 2011; Tyagi, 2012; Yoo et al., 2012). Sufficient irrigation water availability can be ensured by estimating future irrigation water demands based on future climate trends by using appropriate decision support tools. Estimation of future irrigation water requirements coupled with irrigation scheduling able to optimize production and minimize the adverse impact on the environment (Nuramidah et al., 2015; Shah et al., 2015). Good irrigation scheduling will apply water at the right time and in the right quantity to conserve water.

Climate change is now disrupting every country on every continent in the world and affecting national economies and lives, costing people, communities, and countries dearly today and even more tomorrow (IPCC, 2013). Many researchers have revealed the impacts of climate change that the experiencing extreme drought at any time is expected to increase and major flooding events will become more frequent. Agriculture is vulnerable to climatic conditions and change in temperature, precipitation, solar radiation, and carbon dioxide concentration. (Kaiser, 1991). Rice is very sensitive to water stress, which caused by climate change. Hydrologic changes are the most affected processes due to the impact of climate change in the Southeast Asia Region where Malaysia is part of it (IPCC, 2007; Christenen et al., 2007). Water availability, risk, and resilience greatly incorporate hydrological and hydrogeological assessments at basin scale under current and future climate scenarios. IPCC (2013) reported Peninsular Malaysia would experience an increase in rainfall intensity during the southwest monsoon season while during the northeast monsoon, total rainfall, rainfall intensity and frequency of extreme rainfall event will increase. Thus, this also causes an increase in temperatures, which requires a high demand for irrigation water requirements for the crop. That is why the adaptation strategies to climate risk have become an important technique at the basin scale.

In Malaysia, the irrigation sector has the highest annual water withdrawals, and consequently, it has been criticized for wasting a lot of water due to poor performance and low efficiencies (Akinbile et al., 2011). These are associated issues of climate change and water management uncertainty. Therefore, improvement of the water requirement through simulations and predictions of the changes in water flows within a catchment and along the river through the incorporation of the fluctuating available water resources and crop water demand is paramount. However, there is often an imbalance between water supply from the basin and the water demand patterns in the scheme, which consequently results in either water shortage at high demand or water wastage at the period of low demand (Rodríguez Díaz et al., 2007). Additionally, continuous measurement of stream discharge is difficult to obtain, time-consuming and is a costly procedure.

Reservoir (dam) is built mainly to supply water for agricultural sector (49%), hydropower production (20%), industrial and domestic (13%) and flood mitigation (9%). In Malaysia, approximately 17% of dams are built to execute multi-objective to meet more than two of these purposes (ICOLD, 2018). The extension of irrigated agricultural land is essential to meet future food demands, which in turn advocates further dam construction (Nüsser & Baghel, 2017). Reservoir plays a vital role in storing available excess water during wet period (main-season) for use during deficient water availability during the dry period (off-season) to sustain the crop production. However, predicted increases in the frequency of extreme weather caused by climate change impact would in turn, alter streamflow patterns affecting the water inflow to the reservoir and the operations and downstream hydrologic impacts of the existing water infrastructure (Ehsani et al., 2017). Performance of the reservoir normally depends on the operational decisions of the release volume. The irrigation schedule based on the water supply from the basin, the irrigation demand and the availability of the water in the reservoir needs to be studied and simulated, to be able to project the future demand and supply of the irrigation water for the scheme. Therefore, a quantitative assessment of the different water management components needs to be integrated under the spatial and temporal variations of climate change impacts and changes in land use using simulation tools. The optimization of the reservoir involves determining a set of optimal release decisions for consecutive periods to maximize long-term operations.

1.2 Problem Statement

Climatic changes are expected to cause an increase in temperature, changes in rainfall patterns and other hydrogeological variables. These impacts result uncertainty in water availability for irrigation. In many impact assessment studies, many researchers have highlighted the sensitivity of water resources to climatic variations due to future climate change (Chiang & Liu, 2013; Chung, et al., 2011; Chung & Temba, 2012; Hanjra & Qureshi, 2010; Hugh et al., 2013; NAHRIM, 2011; Tyagi, 2012; Yoo et al., 2012). Streamflow fluctuations, groundwater recharge, reservoir levels, and crop irrigation water demands would change because soil moisture is associated with precipitation, which has been influenced by global climate change. This impact of climate risk will first affect sustainable agricultural production, which is related to food security for the country.

Computer models such as decision support systems (DSS) are powerful tools that can be integrated with outputs from Global Climate Models (GCMs) to simulate crop irrigation water demands under climate scenarios. However, the impacts of likely evolved future climate change were not accounted for existing DSS (RWM-DSS, RIMIS, PIM, and SWAMP) in modeling irrigation and water resources (Deepak, 2011; Haque, 2004; Rowshon, 2006; Maina, 2014). Dlamini (2017) has recently developed CSDSS-RIMIS a decision support system for water allocation in rice irrigation scheme under climate change scenarios. However, this DSS limits to downscaling the future climate variables for three rainfall stations within the Tanjung Karang Irrigation Scheme only. Therefore, this study attempts to customize the DSS developed by Dlamini (2017) to model rice water demand for the IADA Kerian Irrigation Scheme.

Paddy rice requires a large amount of water to grow. However, the rainfall is characterized by uneven distribution and variable intensity. In addition, the amount of rainfall with uneven distribution is a common issue that affects crop productivity. The future population rises may hamper rice production due to the uncertainty of water for irrigation supplies, which is likely exacerbated by the climatic change. Climate change may introduce high uncertainty on irrigation water availability, and streamflow discharge or reservoir storage may decrease in the dry period. On the other hand, reservoir inflow mostly depends on the fluctuation of incoming streamflow, which significantly varies for two planting seasons (off-season and main-season) and could be affected by future climate forcing. Therefore, the adaptive solution for satisfying irrigation demand for rice production is needed under the likely evolving climate change impacts. This study hypothesizes that the quantification of uncertainty level and identification of the appropriate GCM model(s) integrated with a field investigation will ease to develop the adaptation strategies related to the future risk in rice production under the evolving climate change impacts.

1.3 Aim and Objectives

The main aim of this study is to customize Climate-smart DSS for assessing irrigation water demand patterns and optimal reservoir operation for Kerian Rice Irrigation Scheme with adaptation strategies under future climate change. The specific objectives are:

1. to customize the Climate-smart DSS framework for downscaling rainfall and climate variables under ensemble GCMs and multi-scenarios realizations;
2. to simulate the hydrologic response using ArcSWAT model of the catchment of Bukit Merah Reservoir under climate change conditions;
3. to assess the irrigation water demand of the scheme to cope with the resilience of Bukit Merah Reservoir; and
4. to simulate the optimum reservoir operation policy for the best management practices of water resources under the impacts of climate change.

1.4 Justification of the Study

Climate-smart DSS for irrigation water demand patterns is a model to facilitate applying future rice irrigation demand at the right time and in the right quantity under climate forcing. Climate-smart DSS model able to reduce uncertainty issues of a number of GCMs that used to project future climate scenarios which it considers up to 10 GCMs. The outputs of downscaled GCMs are used to simulate future streamflow of Kurau River Basin using the SWAT model and to assess future water demand patterns of Kerian Irrigation Scheme. The future streamflow and future rice water demand used as inputs to simulate irrigation release from Bukit Merah Reservoir for Kerian Irrigation Scheme using Optimal Operating Policy. This enables the reservoir operator to release water from the reservoir optimally, thus maintaining or maximizing rice yields. In the long-term, periodic comparisons of actual and simulated deliveries could be used to monitor climate change signals as season advance and thereby allowing the users to propose adaptation strategies that lead to improve water and management in the rice schemes.

1.5 Scope of the Study

The scope of work includes the following:

- Collection of relevant information on history, operation and management of reservoir and the irrigation scheme.
- Collection of spatial maps (land use, soils, and DEM) and meteorological data from different stations within the study area for calibration and validation of a hydrological model.
- Downscaling and extraction of GCMs data from '.nc' file format to '.mat' file format using MATLAB software.
- Downscaling the climate variables through a specified downscaling domain with coordinates.
- Simulation of future streamflow of the Kurau River Basin considering the effects of climate change on the hydrology using 10 GCMs.
- Simulation of future water demand for Kerian Irrigation Scheme using 10 GCMs under three future periods (RCP4.5, RCP6.0, and RCP8.5).
- Simulation of irrigation release for Kerian Irrigation Scheme using Optimal Operating Policy of the reservoir.

1.6 Outline of the Thesis

The thesis is organized into five chapters as follows: Chapter 1 provide the overview of crucial role of water in rice production, highlighting the problem faced by the agriculture sector on having to increase production with limited water resources, and the need for the sector to develop an irrigation scheduling model for optimizing the use of irrigation water. The specific objectives of the study and its contribution to water management are also highlighted in this chapter.

Chapter 2 provides relevant literature review to methods, technique, and approach used in the study. The chapter includes detail discussion of the irrigation and water resources management, concept of climate change, downscaling methods and their application to irrigation scheduling model for future irrigation water demand. Reservoir operation system and various reservoir optimization model and application of decision support systems as related to rice irrigation, water resources, and agriculture are also further reviewed in this chapter.

Chapter 3 presents the methodology with background information on the study area, data collection and a summary of the methods used to downscale future climate data, determination of future rainfall projection, models applied in assessing future streamflow, projection of future rice irrigation demands and simulation of optimal reservoir operation together with adaptation strategies and policy options.

Chapter 4 provides the results of the study including downscaled climate parameters, climate change impact on the future rice water demand, the optimal operating policy of reservoir and application of climate-smart decision support system in modeling water demand projections for IADA Kerian Rice Irrigation Scheme. This will be useful to farmer and water authorities for implementing irrigation water release from Bukit Merah Reservoir during climate change conditions.

Chapter 5 concludes the study by highlighting its contribution and methodological limitation and suggests some recommendations for future work.

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BIODATA OF STUDENT

Muhammad Adib bin Mohd Nasir is a native of Johor, a state located in the southern of Peninsular Malaysia. Adib is a Master Candidate in Soil and Water Engineering at Universiti Putra Malaysia (UPM). He received Certificate and Diploma in Mechanical Engineering (Agriculture) from Politeknik Kota Bharu, Kelantan, Malaysia. He obtained a Polytechnic Director Award in 2009 for being excellence in academic and co-curriculum. Upon obtaining the Public Service Department (Jabatan Perkhidmatan Awam - JPA) scholarship, he further obtained his Bachelor of Engineering (Agricultural and Biosystem) with first-class honors in 2015 from Universiti Putra Malaysia. He also obtained an award from the Malaysian Society of Agricultural Engineers (MSAE) for being the best student in the program.

Immediate after his graduation Adib begin his career as a design engineer at a construction company. He involved in designing a security system for high-end building developed in the area of Selangor, Malaysia. He also has a role to do research on new developments and innovation and turn those research ideas into technical plans, consider cost, effectiveness, and safety of the new design.

Adib has received an offer to become one of the researchers in irrigation and drainage engineering at Department of Biological and Agricultural Engineering, Universiti Putra Malaysia where it requires him to further study in Master and Doctor of Philosophy (PhD). He researches interests include irrigation and drainage, irrigation and water resources management, climate change impact on water resources for irrigation, decision support system in irrigation water management and optimization of reservoir operations.

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