UNIVERSITI PUTRA MALAYSIA

CLIMATE-SMART AGRO-HYDROLOGICAL MODEL FOR THE ASSESSMENT OF FUTURE ADAPTIVE WATER ALLOCATION FOR TANJONG KARANG RICE IRRIGATION SCHEME

HABIBU ISMAIL

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By

HABIBU ISMAIL

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

January 2020

DEDICATION

This thesis is dedicated to:

My beloved parents for their endless love and prayers,

My lovely wife Mariya who has played a significant role during the journey of my study,

My daughters Fadilah and Asma'u who endured hardships all the years without father,
and
My Supervisor, Asscoiate Professor Dr Md Rowshon Kamal who has been a source of inspiration to me throughout my study.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Agro-hydrological water management framework helps to integrate expected planned management and expedite regulation of water allocation for agricultural production. Low production is not only due to the variability of available water during the crop growing seasons, but also due to poor water management decisions, such as not considering the available water for irrigation. Climate-smart agro-hydrological model can be a robust solution for wise water management decisions in a large-scale irrigation scheme to cope with the risk of water and food security under the new realities of climate change. The Tanjung Karang Rice Irrigation Scheme has yet to model agro-hydrological systems for effective water distribution under climate change impacts. The study aimed to develop a climate-smart agro-hydrological model in the context of adaptive water allocation under the risk of climate change for a large-scale rice irrigation scheme. In this study, daily climate variables for baseline (1976-2005) and future 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) periods were extracted for ten global climate models (GCMs) under three Representative Concentration Pathways (RCPs) scenarios (RCP4.5, RCP6.0, and RCP8.5). Climate variables then downscaled to a local station using Climate-smart Decision Support System (CSDSS) in the MATLAB environment. Two hydrological models Soil Water Assessment Tool (Arc-SWAT 2012) and Hydrologic Engineering Corps Hydrologic Modeling System (HEC-HMS 4.2) simulated climate change impacts on hydrological processes in Upper Bernam River Basin (UBRB). The Hydrologic Engineering Center's River Analysis System (HEC-RAS 5.0) hydraulic model used to compute available discharges for the main water conveyance system from the Bernam River Headwork to Tengi River and at the key points in the main canal. The impact of climate change on potential basin streamflow was evaluated using the validated HEC-HMS model. Based on design parameters, the inflow and release patterns for the newly built reservoir were assessed with the need for irrigation water demand and available water for supply under future climate change. Finally, Climate-smart agro-

hydrological model was developed using Excel-based Visual Basic for Application (VBA) to analyze and visualize climate and hydrological knowledge for wise adaptive water management practices under new climate change realities.

The statistical results of the model evaluation in the watershed both during the calibration ($p = 0.014$) and validation ($p = 0.022$) indicated that HEC-HMS performed better compared to Arc-SWAT model. The R^2, NSE, PBIAS and RSR for HEC-HMS are 0.74, 0.71, 4.21 and 0.37; and 0.71, 0.69, 5.32 and 0.31 while that of SWAT are 0.67, 0.62, -5.4 and 0.64; and 0.64, 0.61, -4.2 and 0.65, respectively during the calibration and validation periods. The projected temperature will increase under scenarios with the largest changes of 1.97 ^{o}C and 2.08 ^{o}C, respectively for mean maximum and minimum temperatures during the off-season period (January-June) in the most severe scenario (RCP8.5). Projected rainfall may have normal fluctuations, increasing in the main-season and decreasing in the off-season with higher (average increase of 2.4% and decrease of -3.7%) rate in the most severe scenario (RCP8.5). The projected climate patterns indicate that the water availability for irrigation is expected in the future to be more critical during the off-season period.

Future streamflow at UBRB decreases in all future periods (2010-2099) during the main and off-seasons. However, the changes is more pronounced during the off-season, with a decrease of -9.14% under the worst-case scenario (RCP8.5). Projected future hydro-climatic variables show that the basin may likely to experience tremendous pressure in the late century (2070-2099) particularly during the off-season months. The analysis of water allocation in the scheme show imbalance between the scheme water demand and the available water for supply across the seasons. The scheme is under-supplied from January to March, and over-supplied from April to June during the off-season. In the main-season, there is shortage water supply from July to September, as well as excess supply from October to December, which runs as waste. Evaluation of the newly constructed reservoir in the area, to store excess water for use during water shortage shows that its capacity is inadequate. Therefore, to have effective water allocation in the scheme, provision of the additional reservoir(s) is highly recommended. The developed agro-hydrological model is user-friendly, can visualize and analyze daily, weekly, monthly and seasonal streamflows at various sections of the river, available water for supply into the scheme, scheme water demand and reservoir inflow/release/storage patterns for the baseline and future periods. The model allows water management authorities to explore water allocation alternatives under new realities of climate change.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk iazah Doktor Falsafah

MODEL AGRO-HYDROLOGI IKLIM-PINTAR BAGI PENILAIAN PENYESUAIAN PERUNTUKAN AIR MASA HADAPAN UNTUK SKIM PENGAIRAN PADI TANJONG KARANG

Oleh

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Rangka kerja pengurusan air agro-hidrologi membantu mengintegrasikan jangkaan pengurusan yang dirancang dan mempercepatkan peruntukan air untuk pengeluaran pertanian. Pengeluaran yang rendah bukan sahaja disebabkan oleh variabiliti air yang ada semasa musim tanaman, tetapi juga disebabkan oleh pengurusan keputusan air yang lemah, sebagai contoh tidak mengambil kira air tersedia untuk pengairan. Model agro-hidrologi iklim-pintar boleh menjadi penyelesaian yang teguh untuk keputusan pengurusan air yang teratur dalam skim pengairan berskala besar dalam menangani risiko keselamatan air dan makanan di bawah realiti baru perubahan iklim. Skim Pengairan Padi Tanjung Karang belum lagi memodelkan sistem agro-hidrologi untuk pengagihan air di bawah impak perubahan iklim. Kajian ini bertujuan untuk membangunkan model agro-hidrologi iklim-pintar dalam konteks penyesuaian peruntukan air di bawah risiko perubahan iklim untuk skim pengairan padi berskala besar. Dalam kajian ini, pembolehubah iklim harian untuk garis dasar (1976-2005) dan masa hadapan 2020s (2010-2039), 2050s (2040-2069) dan 2080s (2070-2099) telah diekstrak dari sepuluh model iklim global (GCMs) di bawah tiga Wakil Laluan Konsentrasi (RCPs) senario (RCP4.5, RCP6.0, dan RCP8.5). Pembolehubah iklim kemudian diturunkan skalanya kepada stesen setempat menggunakan Sistem Sokongan Keputusan Iklim-Pintar (CSDSS) menggunakan perisian MATLAB. Dua model hidrologi, Alat Penilaian Tanah dan Air (Arc-SWAT 2012) dan Sistem Pemodelan Hidrologi Kejuruteraan (HEC-HMS 4.2) mensimulasikan kesan perubahan iklim terhadap proses hidrologi di Lembangan Sungai Bernam (UBRB). Sistem Pusat Analisis Hidrologi Kejuruteraan Sungai (HEC-RAS 5.0) digunakan untuk mengira pelepasan air tersedia untuk sistem pengangkutan air utama dari Sungai Bernam ke Sungai Tengi dan pada titik utama di terusan utama. Kesan perubahan iklim ke atas aliran sungai yang mempunya potensi dinilai menggunakan model HEC-HMS yang telah disahkan. Berdasarkan rekabentuk parameter-parameter, corak masuk dan pelepasan bagi takungan yang baru dibina dinilai dengan keperluan

permintaan air pengairan dan air yang tersedia untuk bekalan di bawah perubahan iklim masa hadapan. Akhirnya, model agro-hidrologi Iklim-Pimtar telah dibangunkan menggunakan Asas-Excel Visual untuk Applikasi (VBA) untuk menganalisis dan menggambarkan pengetahuan iklim dan hidrologi untuk amalan pengurusan penyesuaian air yang bijak di bawah realiti perubahan iklim yang baru.

Keputusan statistik penilaian model di dalam kawasan tadahan air semasa penentukuran ($p = 0.014$) dan pengesahan ($p = 0.022$) menunjukkan bahawa HEC-HMS berfungsi lebih baik berbanding dengan model Arc-SWAT. R^2, NSE, PBIAS dan RSR untuk HEC-HMS ialah 0.74, 0.71, 4.21 dan 0.37; dan 0.71, 0.69, 5.32 dan 0.31 manakala SWAT ialah 0.67, 0.62, -5.4 dan 0.64; dan 0.64, 0.61, -4.2 dan 0.65, masing-masing semasa tempoh penentukuran dan pengesahan. Suhu yang diunjurkan akan meningkat di bawah senario dengan perubahan terbesar 1.97 ^{o}C dan 2.08 ^{o}C, masing-masing untuk suhu maksimum dan minimum semasa tempoh musim-luar (Januari-Jun) dalam senario paling teruk (RCP8.5). Hujan yang diunjurkan mungkin mengalami turun naik yang normal, meningkat di musim-utama dan menurun di musim-luar dengan kadar yang tinggi (purata kenaikan 2.4% dan penurunan -3.7%) dalam senario paling teruk (RCP8.5). Corak iklim yang diunjurkan menunjukkan bahawa ketersediaan air untuk pengairan pada masa hadapan dijangka lebih kritikal semasa tempoh musim-luar.

Aliran sungai masa hadapan di UBRB berkurangan dalam semua tempoh masa hadapan (2010-2099) semasa musim-utama dan musim-luar. Walau bagaimanapun, perubahan ini lebih ketara semasa musim-luar, dengan penurunan sebanyak -9.14% di bawah senario terburuk (RCP8.5). Unjuran pembolehubah hidro-iklim masa hadapan menunjukkan bahawa lembangan tersebut mungkin mengalami tekanan hebat pada penghujung abad (2070-2099) terutamanya semasa bulan-bulan di musim-luar. Analisis peruntukan air dalam skim menunjukkan ketidakseimbangan antara skim permintaan air dan air yang tersedia untuk bekalan sepanjang musim. Skim ini terkurang-bekalan dari Januari hingga Mac, dan terlebih-bekalan dari April hingga Jun semasa musim-luar. Pada musim utama, terdapat kekurangan bekalan air dari Julai hingga September, serta bekalan berlebihan dari Oktober hingga Disember, yang terbuang sia-sia. Penilaian takungan yang baru dibina di kawasan tersebut, bertujuan menyimpan air yang berlebihan untuk digunakan semasa kekurangan air menunjukkan bahawa kapasitinya tidak mencukupi. Oleh itu, untuk memperolehi peruntukan air yang efektif dalam skim ini, peruntukan takungan tambahan sangat disyorkan. Model agro-hidrologi yang telah dibangunkan adalah mesra pengguna, dapat memvisualisasi dan menganalisis aliran sungai secara harian, mingguan, bulanan dan bermusim di pelbagai bahagian sungai, air yang tersedia untuk bekalan ke dalam skim, skim permintaan air dan aliran masuk takungan/pelepasan/corak simpanan untuk garis dasar dan masa hadapan. Model ini membenarkan pihak berkuasa pengurusan air untuk meneroka alternatif peruntukan air di bawah realiti baru perubahan iklim.

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The member of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AR4	Assessment Report Four
AR5	Fifth Assessment Report
BRH	Bernam River Headworks
CSDSS	Climate-smart Decision Support System
CMIP5	Coupled Model Inter-comparison Project Phase-5
DCL	Deficit and Constant Loss
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
Fr	Froude number
g	gravitational acceleration
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Centre's Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Centre's River Analysis System
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
RCP	Representative Carbon Pathways
SAR	Second Assessment Report
SMA	Soil Moisture Accounting
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
TAKRIS	Tanjung Karang Rice Irrigation Scheme
TAR	Third Assessment Report
TRH	Tengi River Headworks
UBRB	Upper Bernam River Basin

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water crises is the greatest worrying global issue. Water for irrigation is susceptible to climate change that affects agricultural production (Schlenker et al., 2007). Failure of climate change mitigation and adaptation is the biggest global risk. It has become a truism of adaptation in recent years that the climate change impacts on communities, economies and environment will be weighed mainly by water. In the last two decades, the main goal of intensive research on water resource monitoring and management was to reduce the quantity of irrigation water and energy consumption. At the same time, the interests of researchers were the effects of climate change and agricultural policies. Agricultural production will be a great challenge due to population growth, dietary change, climate change and environmental decline (CGIAR, 2019). Therefore, there is an increasing focus on the assessment of irrigation performance to improve water management and to increase the sustainability of irrigated agriculture with the likely evolving climate changes and its impacts. The creative, strategy and economic advancement for food security development in the context of climate change to achieve sustainable agriculture can reduce threats (Ghosh, 2019). The agriculture therefore, must be ‘climate-smart’ to transform and reorient the systems in agriculture to promote food production in the new climate change realities.

Water becomes not only a scarce resource for agriculture but also for most sectors in almost all places across the glove. This is in efforts to meet the industrial and urbanization demands. Studies on global-scale water scarcity projections indicated that about 60% of the world’s population is projected to fall within water stressed areas by the year 2025 (Alcamo et al., 2007; Dlamini et al., 2017; Rijsberman, 2006). The competition for water is increasing in recent years to a stage of physical scarcity (Water, 2010). The improvements in the effectiveness of agricultural water use could produce sufficient water for domestic use in high-conflict watersheds. This can be a significant adaptation approach for global change (Flörke et al., 2018). In Malaysia the sector has the greatest annual water withdrawals, with the irrigated rice production accounting for more than 70% of the nation's water requirements (Amin et al., 2011). Consequently, irrigation is being criticized for wasting a lot of water due to poor performance and low efficiencies. Dlamini et al. (2017) observed shifts in the future streamflow at Bernam Basin both in off and main-seasons. The future periods indicate a declining trend in off-season streamflow. On the other side, the main-season was forecast to receive higher precipitation. Hence, the need for extensive care to the operation and management of these resources in the context of agro-hydrological basins to overcome the water related problems.

A number of studies (Amin et al., 2011; Dlamini et al., 2017; Dlamini et al., 2016; Rowshon et al., 2014) have extensively been conducted on watershed development and water resources management of the study area, Tanjung Karang Rice Irrigation Scheme (TAKRIS). However, review of literatures reveals that there was no water management study in the Scheme within the context of agro-hydrological regime for adaptive water allocation under climate change impacts. Agro-hydrological water management framework helps to integrate expected planned management and expedite regulation of water allocation for agricultural production. Climate-smart agro-hydrological models can be powerful approach for adaptive water management practices for a large-scale irrigation scheme to cope the risk on water security and to promote sustainable agriculture in the new issues in change of climate. Existing water management methods might not be sufficient to deal with climate change effects on reliable water supplies for irrigation. The goal of this research is therefore, to develop a climate-smart agro-hydrological model for adaptive water allocation in TAKRIS.

1.2 Problem Statement

Food security is the critical global challenge. The world population is projected to be about 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 (Nation, 2017). Therefore, the world will have to boost the output of crops to feed its rapidly increasing people (Godfray et al., 2010). Low production is not only due to the variability of available water during the crop growing seasons, but also due to poor water management decisions, such as not considering the available water for irrigation (Chandrasiri et al., 2020). The spatial and temporal climate variations have affected water availability in different water catchments in the world. Noticeably, TAKRIS often experiences shortage of water due to unusual spatial and temporal distributions of rainfall. It has been reported that many farmers at the scheme do not get adequate supply of irrigation water in their fields due to uneven distribution in the allocation from the upstream to downstream of the field. Consequently, this has affected the productivity in the scheme by lowering the performance of irrigation.

A feasibility study reports (NAWABS, 2018) and previous studies have clearly indicated that water shortage is an annual issue for the scheme. It was reported that the Bernam River Headworks (BRH) was totally closed during the period, to divert all the Sg. Bernam water into the Feeder Canal for irrigation, causing the downstream of the Sg. Bernam to almost dry up. Recently, a storage pond with capacity of 1.5 Mm^3 has been constructed in the area to overcome the issue of water shortage at the time of high demand, but it needs evaluation for in cooperation with other hydraulic structures for proper water scheduling and allocation. The amount of water diverted to the Feeder Canal from Sg. Bernam at BRH is currently unknown (NAWABS, 2018). The shortages of water can be a great risk of water allocation because of effects of future global warming.

Despite all the challenges stated above, estimation of streamflow in conveyance channel for the scheme is usually not reliable and irregular. Simulation model is needed to estimate streamflows at key locations for proper water allocation of available water for irrigation supplies. Review of the literature reveals that the previous models developed in TAKRIS were mainly for management at either upstream or downstream. They did not integrate planned management of all water systems for adaptive water allocation under climate change impacts. This study developed a climate-smart agro-hydrological model for the visualization and analysis of agro-hydrological information for water management practices for the scheme. Although the model has been customized for local application in TAKRIS, it can be extended to other locations by taking into account historical station data, GCMs and data of the location.

1.3 Hypothesis

Improved water allocation is a vital water management strategy for any irrigation system. It depends on the reliable data and appropriate simulation technique as well as the performance of the delivery and distribution of water within targeted irrigation blocks. This study hypothesizes that:

- Hydrological models can project trends of future available water resources to improve water allocation in an irrigation scheme
- The flow simulation and analysis in the Bernam/Tengi river will improve substantially the future water allocation under changing climate
- Newly developed storage reservoir will overcome the water shortage in the scheme during dry-season period
- Climate-smart agro-hydrological model will enhance the visualization and analysis of agro-hydrological information for water management practices and to cope the risk on water and food security under the new realities of climate change

1.4 Research Questions

A comprehensive review of the literature revealed that change in climate would severely affects water resources in coming decades. Climate change is worsening the water management decisions, which has affected the Malaysia's rice productivity. It is a crucial question whether the projected water resources in the agro-hydrological watershed would be adequate to meet the water demand patterns because of climate change effects. The relevant issues related the problems include:

- How would the projected trends of available water resources at Bernam River Basin be affected under evolving climate?
- How could flow simulation at crucial locations in irrigation channels improve irrigation water supply?
- Can a newly built storage reservoir in the scheme be adequate to address the problems of water shortage at period of high water demand?
- What could be the adaptive approach to integrate planned management of all water systems and to cope the risk on water and food security under the new realities of climate change?

This study tried to answer the questions listed by the results of the agro-hydrological management model developed in this research.

1.5 Aim and Objectives of Study

The aim of this study is to develop Climate-smart Agro-hydrological model for adaptive irrigation and wise water resources management towards water security in the scheme. The specific objectives are:

1. To evaluate HEC-HMS hydrologic model to project the climate change impacts on streamflow at the Upper Bernam River Basin (UBRB);
2. To predict the streamflow hydrographs at diversion (BRH) and intake (Tengi River Headworks, TRH) of the irrigation scheme;
3. To analyze the inflow and release patterns of the newly constructed reservoir for the scheme at various water management options; and
4. To develop agro-hydrological management model integrated with Climate-smart Decision Support System (CSDSS) for the adaptive water allocation strategies under climate change.

1.6 Relevance and Scope of the Study

The study location, Tanjung Karang, is one of the largest rice irrigation schemes in Malaysia, which contributes immensely not only to the rice food for large population but also to youth's employment, standard of living and economic development of the country. General issues such as regular water shortage during dry season months and poor water management practices are some of the problems reported by the local water managers and previous feasibility studies. Hence, the needs to invest tremendous efforts and resources in both management of water sector demand and improvement on the supply side to improve the system.

The scope of the work includes the following:

- Collection of relevant information on history, operation and maintenance of the irrigation scheme
- Collection of spatial maps, which include land use, soils, digital elevation models, etc. from various government agencies and generating new maps
- Collection of observed hydro-meteorological data from different stations within the study area and the watershed for models evaluation
- Extraction of future climatic data based on GCMs and RCPs realization, correcting/downscaling the data using a statistical (change factor) method developed in CSDSS program
- Predicting Bernam river basin future streamflow by considering spatial and temporal variations in rainfall and some climatic data within the catchment
- Collection/generation of river geometry data, which include river width, length, bed slope, Manning's n, etc. for calibration and validation of hydraulic model
- Design and development of Bernam/Tengi river system on a reach-by-reach basis. Flow routing and flow analysis at various reaches along the rivers
- Assessing inflow and release patterns of the newly constructed reservoir
- Estimation of periodic water demand, water allocation and
- Integrating all resources to develop an agro-hydrological management model for planning and decision making

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LIST OF PUBLICATIONS

Adib Nasir, Rowshon Kamal, Mojid Abdul, and Habibu Ismail (2020) Predicted Streamflow in the Kurau River Basin of Western Malaysia by Climate-smart DSS (Scientific Report, Q1 Journal. Accepted)

Habibu Ismail, Md Rowshon Kamal, Ahmad Fikri b. Abdullah and Mohd Syazwan Faisal bin Mohd (2020) Climate-smart Agro-hydrological Model for a Large Scale Rice Irrigation Scheme in Malaysia (Applied Sciences, Q2 Journal. Accepted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2019) Modeling Future Streamflow for Adaptive Water Allocation under Climate Change at Tanjung Karang Rice Irrigation Scheme Malaysia. (Applied Sciences, Q2 Journal. Accepted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2020) Performance of HEC-HMS and ArcSWAT Models for Assessing Climate Change Impacts on Streamflow at Bernam River Basin in Malaysia (Journal of Science and Technology, Scopus indexed. Accepted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri bin Abdullah (2019) HEC-HMS for Streamflow Projection under Climate Change: A Review. International Journal of Hydrology and Technology (Scopus Indexed. Under review)

Habibu Ismail, Md Rowshon Kamal, Deepak T.J., Lai Sai Hin, Ahmad Fikri Bin Abdullah (2019) Hydrological Modelling for Evaluating Climate Change Impacts on Streamflow Regime in the Bernam River Basin of Malaysia. (International Journal of Water, Scopus Indexed. Under review)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2019) A Comparison of Selected Hydrological Models for Prediction of Streamflow at Bernam River Basin Malaysia. International Conference of Universal Wellbeing (Accepted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2020) Assessment of Climate Change Impacts on Future Streamflow in the Bernam River Basin Malaysia. International Conference on Geospatial & Remote Sensing (Accepted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2019) Application of HEC-RAS Model for Hydraulic Analysis of a Run-of River at Tanjung Karang Rice Irrigation Scheme Malaysia. (To be submitted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2020) Evaluation of Hydraulic Model for Water Allocation in Large Rice Irrigation Scheme, Malaysia. Malaysia Society of Agricultural Engineers Conference (To be submitted)

Habibu Ismail, Md Rowshon Kamal, Lai Sai Hin and Ahmad Fikri Bin Abdullah (2020) Prediction of Climate Change Impacts on Water Demand at Large Rice Irrigation Scheme, Malaysia. International Conference on Agricultural and Food Engineering, CAFEi2020 (To be submitted)

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