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PREDICTION OF PADDY IRRIGATION REQUIREMENTS BY USING STATISTICAL DOWNSCALING AND CROPWAT MODELS: A CASE STUDY FROM THE KERIAN IRRIGATION SCHEME IN MALAYSIA

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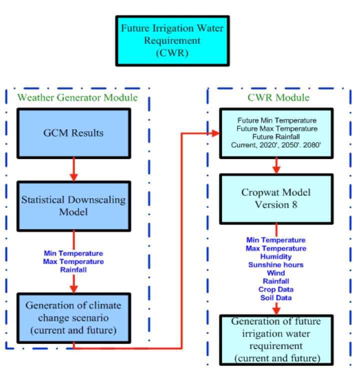
Graphical abstract



Abstract

With an average rainfall of 2500mm per year, Malaysia has abundant water resources but climate change coupled with drought, urbanisation and pollution sometimes causes water stress. Global warming has changed the local climate, threatening agricultural activities with particular impact on paddy production systems. To ensure availability of sufficient irrigation water for growing crops, there is a need to estimate future irrigation water requirements in the face of the complex dynamic resulting from global warming. The current study was therefore carried out to estimate paddy irrigation water requirements based on future climate trends by using SDSM and CROPWAT Models at the Kerian Irrigation Scheme, Perak, Malaysia. The application of the SDSM model revealed that both temperature and rainfall will increase in the future. Meanwhile the CROPWAT model predicted that the annual irrigation requirement will slightly decrease for period between 2010-2069 and increase for years 2070-2099 even though crop evapotranspiration (ETcrop) is predicted to increase in future for rise in temperature for year 2010 to 2099. This integration of SDSM and CROPWAT models produced better simulations of crop water requirement and irrigation requirement. Therefore, it can assist the reservoir's operating management team in giving effective and proficient response to climate changes in the future.

Keywords: Climate change, irrigation, water requirement, water stress

Abstrak

Dengan purata hujan sebanyak 2500mm setahun, Malaysia mempunyai sumber air yang banyak tetapi perubahan iklim ditambah pula dengan kemarau, urbanisasi dan pencemaran kadang-kadang menyebabkan kekurangan air. Pemanasan global telah mengubah iklim tempatan, mengancam aktiviti pertanian dengan memberi kesan tertentu pada sistem pengeluaran padi. Untuk memastikan bekalan air pengairan mencukupi untuk tanaman yang semakin meningkat, terdapat keperluan untuk menganggarkan keperluan air pengairan pada masa hadapan dalam menghadapi kesan yang kompleks akibat daripada pemanasan global. Oleh itu, kajian telah dijalankan untuk menganggarkan keperluan air pengairan padi berdasarkan bentuk iklim masa hadapan dengan menggunakan SDSM dan CROPWAT Model di Skim Pengairan Kerian, Perak, Malaysia. Penggunaan model SDSM mendedahkan bahawa kedua-dua suhu dan hujan akan meningkat pada masa hadapan. Sementara itu, model CROPWAT yang meramalkan bahawa keperluan pengairan tahunan akan berkurangan bagi tempoh antara 2010-2069 dan meningkat untuk tahun 2070-2099 walaupun tanaman penyejatpeluhan (ETcrop) diramalkan meningkat pada masa akan datang seiring dengan kenaikan suhu untuk tahun 2010 hingga 2099. Integrasi antara model SDSM dan CROPWAT yang dihasilkan memberikan hasil simulasi yang bagus untuk keperluan air tanaman dan keperluan pengairan. Oleh itu, ia boleh membantu pihak pengurusan operator tempangan dalam memberikan tindak balas yang berkesan dan cekap kepada perubahan iklim pada masa akan datang.

Kata kunci: Perubahan iklim, pengairan, keperluan air, kekurangan air

1.0 INTRODUCTION

Irrigation is the controlled application of water to fields for growing crops. Toriman and Mokhtar, [1] define irrigation as a science of artificial application of water to land or soil. Scientists predicte that climate variability has implications for climate-sensitive systems such as agriculture and other natural resources [2]. This climate variability has a large impact on crop yields and could trigger economic effects on agricultural production and demand [3]. As such, if ignored, climate change would cause serious disruption to the functioning of society, resulting in widespread human, material, economic and environmental losses [4].

In developing countries, the increase in water demand for industrial and municipal uses is expected to exceed water demand for agriculture purposes between 1995 and 2020 [5]. The Global rice demand in 2020 is projected to increase by 35% compared to the demand in 1995. With this projected increase, constraints on water resources will be further aggravated since most of the rice is produced with irrigation [6].

The Kerian Irrigation Scheme faces a problem in maintaining a water supply for irrigation due to climate change impacts. The water demand for paddy irrigation needs a flexible water supply due to spatial and temporal variations. The need to estimate future the irrigation water requirement can be a guideline for policymakers in scheduling and planning the future irrigation system.

In a previous study by Kuo *et al*. [7], the CROPWAT model was used to evaluate crop water requirements in Taiwan. The results show that the crop water requirements and deep percolation for paddy fields are respectively 962 mm and 295 mm for the first rice crop, and 1,114 mm and 296 mm for the second rice crop. Meanwhile Banik *et al*. [8] investigates the potential of CROPWAT to model the crop water assessment using a field dataset consisting of the years of 2007 to 2011 and included a comparison between plain and hilly regions for rice and wheat crops to meet the irrigation demand. Results were found that the irrigation requirements of rice and wheat crops are more for the plain region as compared to the hilly region. Neelima *et al*. [9] used the CROPWAT model to calculate the monthly net irrigation requirement (NIR) from remote sensing derived from the cropping pattern in Andhra Pradesh, India. The result from the monthly supply-demand ratio showed that the irrigation supply was more than demand.

A number of researchers have studied the impact of climate change on irrigation water demand [10-15]. Shahid [10] estimates the change of irrigation water demand in dry-season *Boro* rice fields in northwest Bangladesh in the context of global climate change. The study shows that there will be no appreciable changes in total irrigation water requirement due to climate change. However, there will be an increase in daily use of water for irrigation. Shen *et al*. [11] calculate the crop and irrigation water requirements for five main crops, including wheat, corn, cotton, oilseed and sugar beet from 1989 to 2010. The spatio-temporal variations were also analyzed. The results suggest that the demand of irrigation water in the arid region of Northwestern China showed increasing trend during the past two decades, which were mainly caused by a fast increase in cotton cultivation areas. Tukimat and Sobri [12] measured the irrigation water requirement at Pedu-muda reservoir for paddy plantations using SDSM and

CROPWAT models and found that in the future years of 2010-2099, the annual irrigation requirement is estimated to decrease slightly at each interval year. Wada *et al*. [13] used a set of seven global hydrological models (GHMs) to quantify the impact of projected global climate change on irrigation water demand (IWD) on currently irrigated areas. The resulting ensemble projections show an increasing trend in future irrigation water demand. Yoshikawa *et al*. [14] used a global water resources model H08 to estimate the time-varying dependence of irrigation water requirements from various water supply sources on a global scale, accounting for various irrigation area and meteorological forcing conditions from 1960 to 2050. The results showed that the Irrigation Requirement under Climate Change (IRCC) increased by 10% from the 1990s to the 2050s under the IPCC AR4 high emission scenario of CMIP3. Zainal *et al*. [15] applied the Providing Regional Climates for Impacts Studies (PRECIS), to estimate the potential impact of long-term changes in climate on paddy net revenue. Results show that temperature and well rainfall variability had a negative impact on paddy production. Projections based on the regional climate modeling system (PRECIS) shows that the loss in paddy production due to climate change will increase by 168.88% by the year 2099.

Modeling simulation is an analysis method based on assumptions expressed through mathematical statements [16]. Water usage needs to be interpreted in order to know how much water is lost on a crop field due to evaporation and transpiration processes. Estimation of crop water requirements is one of the main components used in irrigation planning, design and operation [17]. The objective of this research is to study the capability of the CROPWAT model to predict future irrigation water requirements for paddy fields for two seasons in the Kerian Irrigation Scheme using rainfall and temperature figures projected by the SDSM model. The long term future climate by SDSM model was divided into a 30–year period using the HadCM3 A2 scenario, 2010 to 2039 (2020s), 2040 to 2069 (2050s), and 2070 to 2099 (2080s).

2.0 MATERIALS AND METHODS

2.1 Study Area

The Kerian Irrigation Scheme is divided into 2 schemes, namely Kerian Laut (137.26 km^2) and Kerian Darat (98.34 km^2) with a total area of 235.6 km^2. It is located in the North West region of Peninsular Malaysia and is one of the granary areas of Malaysia and was also the first large scheme to be constructed in the year 1892. The whole scheme is divided into 8 sub-schemes with different blocks in each sub-scheme as shown in Figure 1 and Table 1. The objective of dividing sub-schemes into blocks by the Department of Irrigation and Drainage (DID) was to improve the performance of irrigation. The main source of water is from the Bukit Merah Reservoir. Approximately sixty one percent (61%) of the irrigation supply comes from the reservoir and the rest from rainfall. The Bogak River Pumphouse, a major pumping installation, consists of four (4) pumps with 5.1 cumec capacity each, and is located at the downstream of the irrigation system, where water is pumped from the Kerian River into the main canal. The Bogak Pumphouse contributes about 14 per cent of the irrigation requirement and effective rainfall constitutes about 25 per cent.

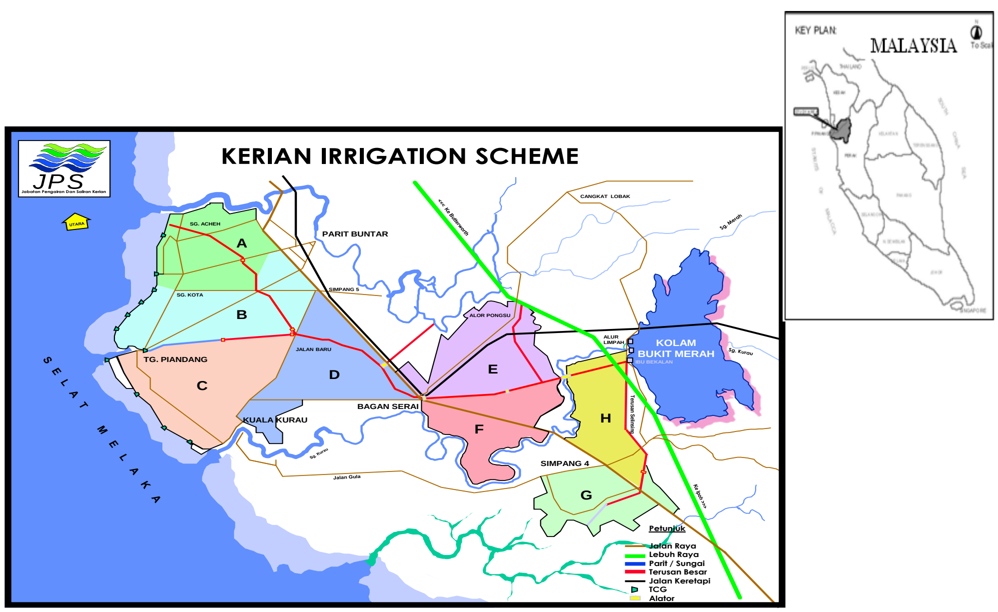


Figure 1 Location of Kerian-Sungai Manik Irrigation Scheme, Perak Malaysia (DID, Malaysia)

Table 1 Details of Kerian Irrigation Scheme (DID)

Schemes	Sub-Schemes	Block	Area (km^2)
Kerian Darat	H	1, 2, 3	26.50
	G	4,5, 6	21.45
	F	7, 8, 9	26.97
	E	10,11,12	23.44
Kerian Laut	D	13, 14, 15, 16	33.62
	C	17, 18, 19, 20	39.60
	B	21, 22, 23, 24, 25	40.02
	A	26, 27, 28	24.02
TOTAL	8	28 Block	235.60

This region is characterised by a warm and humid monsoon climate with an average rainfall of 3287 mm per year (1961-1990). The maximum and minimum temperature range between 32 to 34°C and 23 to 24^{0}C respectively. The methodology used in this study is shown in Figure 2.

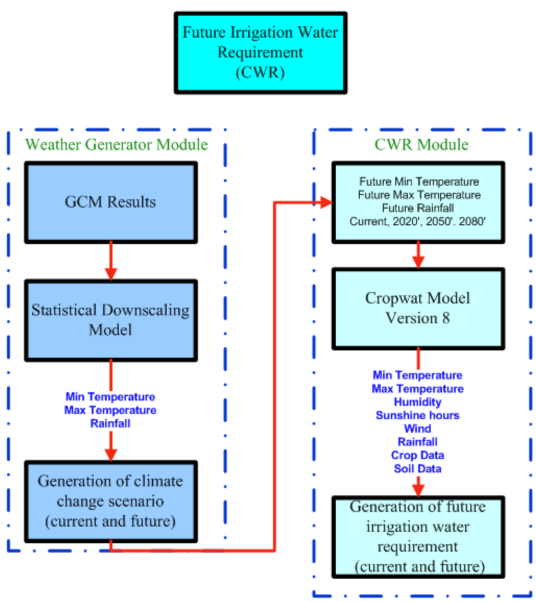


Figure 2 Methodology used in the study

2.2 Climate Simulation using SDSM

SDSM is a decision support tool that facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate [18]. It also assesses the regional impacts of global warming by allowing the process of spatial scale data reduction provided by the large-scale Global Climate Models (GCMs). GCMs are optimal tools to estimate future global climate changes resulting from continuous increase of greenhouse gas concentration in the atmosphere [19-20]. Statistical downscaling methods rely on empirical relationships between local-scale predictands and regional-scale predictors to downscale GCM scenarios.

SDSM was applied to simulate future climate trends in this region. The analysis requires two types of data, known as the predictand and predictor data. The predictand data refers to the historical temperature (1970-1990) at Ipoh station (48625) and rainfall (1961-1990) data at Bukit Merah station (5006021), which was used to represent the entire area of Kerian-Sungai Manik Irrigation Scheme as shown in Table 2.

Table 2 Detail of meteorological stations

No of Station	Type of Station	Name of Station	Location	
			Lat	Long
5006021	Rainfall	Bukit Merah, Perak	05^0 02' 00"	100^0 39' 10"
48625	Temp	Ipoh, Perak	04^0 34' 0"	101^0 06' 00"

Two climate predictors, the National Centers Environmental Prediction (NCEP) and GCMs at the grid box of 28X x 33Y were used for calibration (1961-1975), validation (1961-1990) processes. The long term future climate was divided into 30–year periods, 2010 to 2039 (2020s), 2040 to 2069 (2050s), and 2070 to 2099 (2080s). For this study, the model output of HadCM3 Global Circulation Model GCM was used for the A2 (medium-high) emission scenarios as shown in Table 3. Hundred (100) ensembles of synthetic daily time series were produced for HadCM3 A2, 139 years (1961 to 2099). HadCM3A2 is the emission scenario from GCM output files. HadCM3 was chosen because of its wide application in many climate-change impact studies [21-23].

Table 3 The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)

Class	Emission Scenario Detail
A1	A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter with rapid introduction of new and more efficient technologies.
A2	A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines
B1	A convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in materials intensity, and the introduction of clean and resources efficient technologies
B2	A world in which the emphasis is on local solutions to economic, social and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development

2.3 CROPWAT Model

CROPWAT 8.0 is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Center, Egypt. The model calculates crop water requirements using existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. The estimated water demand can be measured and arranged using the CROPWAT model beginning from 80% of CWR, with the remaining CWR assumed to be contributed by the uncontrolled flow in the crop field. The measurement of CWR is as follows;

$$W_{irr} = ET_{crop} + W_{lp} + W_{ps} + W_{l} - P_{e} \qquad 2.1$$

where;
W_{irr} is the irrigation water requirement;
ET_{crop} is the crop evapotranspiration;
W_{lp} is the water required for land preparation;
W_{ps} is the percolation and seepage losses of water from paddy field;
W_{l} is the water required to establish standing water layer;
P_e is the effective precipitation.

3.0 RESULTS AND DISCUSSION

3.1 Future Climate Scenarios

SDSM results for maximum and minimum temperature are shown in Figure 3 and 4. It reveals that the maximum temperature from year 2010 to 2039 is expected to be within the range of 32 to 34°C and the minimum temperature will be in the range of 23 to 25°C. A similar trend is expected from the year 2040 to 2069 and the temperature is expected to reach up to 35°C (about 9 % more than the historical data) and 36°C for year 2070-2099 (about a 12.5% increase compared to the historical data).

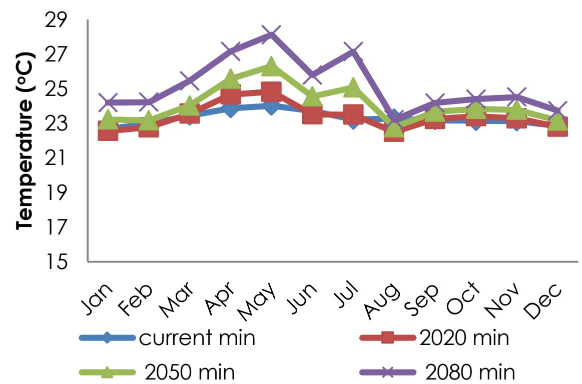


Figure 3 Minimum Temperature at Ipoh Station for the year 1961-2099

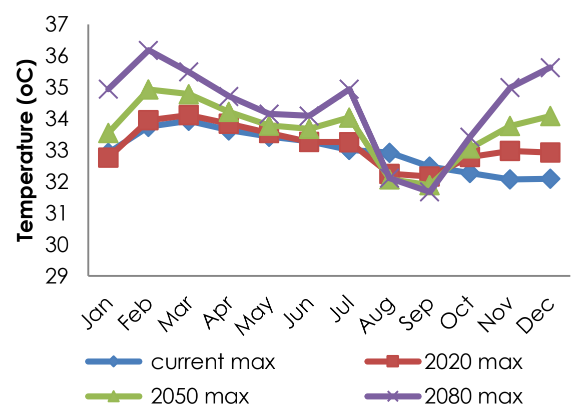


Figure 4 Maximum Temperature at Ipoh Station for the year 1961-2099

In the future, the average pattern of rainfall is expected to increase with a small difference from the historical data, as shown in Figure 5. However, the rainfall intensity is estimated to increase every year. From the year 2010 to 2039, the average annual rainfall is expected to be 3949 mm/year. The highest rainfall is expected to occur in April (488 mm) and the least rainfall in January (173 mm). Rainfall pattern from year 2040 to 2069 is predicted to increase continuously reaching 4006 mm. From year 2070-2099, the average annual rainfall is increase continuously reaching 5700mm/year. The highest rainfall is expected to occur in August (978 mm) and the least rainfall in January (263 mm). This is supported by Meteorological Department Malaysia Scientific Report [24] higher increase in rainfall is simulated for Peninsular Malaysia compare to Sabah and Sarawak for period 2010-2099. This trend of increment also agree with Hassan *et al*. [25] and Kabiri *et al*. [26] in which their studies found an increment of rainfall and temperature for the West-North of Peninsular Malaysia.

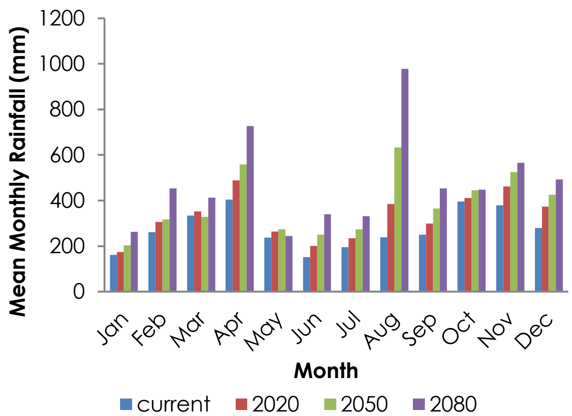


Figure 5 Rainfall pattern for the year 1961-2099 at Bukit Merah station (5006021)

3.2 Future Irrigation Water Requirements

The total water requirement was measured using CROPWAT Model version 8.0. In this region, the required irrigation water supply is twice a year for double crop cultivations during the main season (August-February) and off season (February-July).

CROPWAT model simulations showed that the reference crop ET (Et_o) (Figure 6) value varies between 0.88 mm/day and 4.76 mm/day for December and April, respectively. The historical Et_o showed the highest value in April with 4.76 mm/day compare to Et_o 2020's with a value of 4.39mm/day (May), Et_o 2050's with a value of 4.42 mm/day (May) and Et_o 2080's with a value of 4.45 mm/day (May). It showed that the lowest Et_o occurred during rainy season and the highest during the dry season. The result is similar with [12] findings, temperature increases during the years 2010-2099; the value of Et_o will decreases even though the future temperature increase.

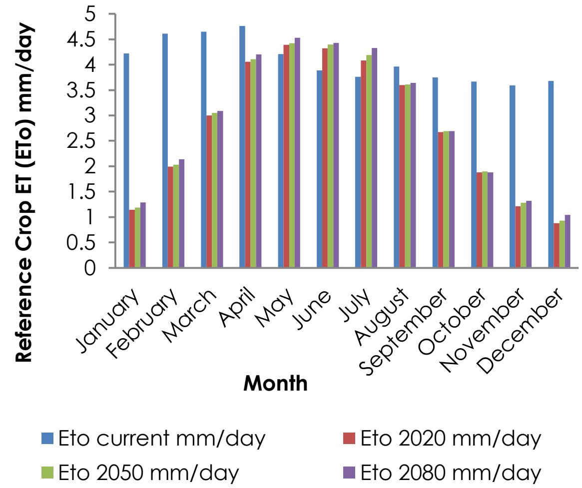


Figure 6 Block diagram of the processes of the system

The simulations of irrigation requirements using the CROPWAT model for the historical period (year 1961-1990) gives 1446.2 mm, and for future periods 2020's 992.1mm, for 2050's 845.2mm and 2080's 893.4mm. The overall annual irrigation requirement was estimated to slightly decrease at each interval year from 2010-2069 and increase 5.76% (compared to 2050's) in years 2070-2099 (Figure 7). This is reliable because the amount of effective rainfall was predicted to increase every month except in October, when the rainfall would slightly decrease between the years 2040 to 2069 and increase between the years 2070-2099. Karanja [27] and Khan [28] revealed that the increment/decrement of irrigation need is dependent on the temperature rate and rainfall intensity. The summary of the total water requirement in Kerian Irrigation Scheme is illustrated in Table 4.

Table 4 Summary of total water requirement for Kerian Irrigation Scheme

Season	Irrigation Req. current	Irrigation Req. 2020	Irrigation Req. 2050	Irrigation Req. 2080
Main Season	678.4	280.7	205.5	295.2
Off Season	767.8	711.4	639.7	518.2
TOTAL (mm)	1446.2	992.1	845.2	893.4

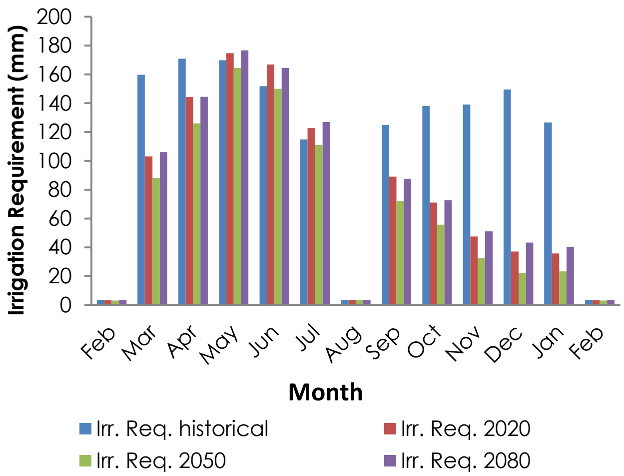


Figure 7 Irrigation water requirements for the years 1961-2099 at Kerian Irrigation Scheme

4.0 CONCLUSION

The SDSM simulations show that in the future, rainfall and temperature will increase more than 50% compared to the historical period. As a result of the increment of rainfall and temperature, the future irrigation water for Kerian irrigation Scheme will decrease between the years 2010-2069 and increase between the years 2070-2099. The study findings have important implications for Malaysia's agricultural policy and the country's strategies in adapting to climate variability.

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