Paddy, rice and food security in Malaysia: A review of climate change impacts

R. B. Radin Firdaus1*, Mou Leong Tan2, Siti Rahyla Rahmat2 and Mahinda Senevi Gunaratne2

Abstract: Malaysia has focused its self-sufficiency policy on rice and paddy production, which are the country’s primary staple food and food crop. Throughout the Eleventh Malaysian Plan (2016–2020) and National Agro-Food Policy (2011–2020), Malaysia continues its proactive and progressive measures to promote paddy and rice sector development. The impacts of climate change, however, are projected to exacerbate challenges in increasing paddy yields and achieving food security in the future. Hence, this paper attempts to discuss climate change impacts on rice production and food security in Malaysia succinctly. Using Mann–Kendall and Sen’s slope, our analysis exhibited the increased minimum (T_min) and maximum (T_max) temperature in the granary areas, ranging from 0.3°C to 0.5°C and 0.2°C to 0.3°C, respectively, in every decade. At the same time, precipitation has shown an increasing trend, ranging from 133 mm to 200 mm. Apart from the trend analysis, we conducted a literature review to substantiate our discussion. The findings signified that climate change poses a severe threat to paddy production, which eventually will affect food security as they are highly interrelated. Thus, it is high time for Malaysia to revamp its paddy and rice intervention strategies by giving due

ABOUT THE AUTHORS

R. B. Radin Firdaus is a senior lecturer at the School of Social Sciences, Universiti Sains Malaysia. His areas of research include food security, agricultural development and policy, climate change adaptation measures and sustainable development. His current research study focuses on developing a vulnerability index for the fishery community in Malaysia.

Mou Leong Tan is a senior lecturer at the School of Humanities, Universiti Sains Malaysia. His current research interests are in the areas of Hydrology, Climatology, land use and climate changes assessment, Remote Sensing and GIS.

Siti Rahyla Rahmat is a senior lecturer in economics at the School of Social Sciences, Universiti Sains Malaysia. Her research areas are environmental economics, energy and natural resource economics and science policy analysis for sustainable development.

Mahinda Senevi Gunaratne is a PhD fellow at the School of Social Sciences, Universiti Sains Malaysia. His research interest is on climate change, vulnerability assessments, sustainable development, food security, food sovereignty, public policy and participatory development.

PUBLIC INTEREST STATEMENT

Promoting the development of the paddy sector is a great concern to the Malaysian government because rice is the country’s staple food crop. Through its current development strategies, initiatives and policies, Malaysia has taken constructive measures to increase production. However, in the event of climate change, such measures may not be adequate to ameliorate the impacts. Our analysis and review echoed this fact as it was found that climate change poses significant impacts and challenges for paddy productivity in the main granary areas in Peninsular Malaysia. As these areas are regarded as the rice bowl of the country, this would certainly expose the food security of the nation to risk. Hence, in the light of climate change, it is high time for the country to revisit its intervention strategies and policies in the paddy and rice sectors.
attention to enhancing the adaptive capacity of paddy farmers to cope with climate change.

**Subjects**: Agricultural Development; Climate Change; Environment & Society; Asian Studies; Development Policy; Environment & the Developing World

**Keywords**: agriculture; climate change; food security; paddy; rice; granary areas

1. Introduction

Rice is the staple food for about half of the world’s population, which cultivates predominantly in Asia as it accounts for about 90% of world rice production. However, only 7% of rice production goes to the export market from the country of origin (Rice Almanac, 2013). Hence, rice and paddy play a pivotal role in food security, socio-culture and governments’ strategic interventions for many developing countries (Omar et al., 2019; Shah et al., 2019).

In most parts of the world, paddy fields are cultivated on a small scale, except in Australia, United States of America and several South American countries (Firdaus, 2015). Hence, paddy cultivation provides the livelihood for millions of small-scale farmer families and landless agricultural workers across Asia (Mohanty et al., 2013). Malaysia’s paddy cultivation, which has moderate plots less than two hectares (Najim et al., 2007; Terano & Mohamed, 2011) with approximately 194,000 farmers involved, hence can be distinguished as small-scale farming (Department of Agriculture, 2018). A small parcel of land contributes to low productivity and high production costs (Samberg et al., 2016). Lacks in economies of scale have placed this nation in a comparatively disadvantaged position for reaching a 100% self-sufficiency level (SSL).

There are eight main paddy granary areas in Malaysia, which can be regarded as the rice bowl and food security for the nation. The establishment of main granary areas under the National Agricultural Policy (NAP) of 1984–1991 was purposely reserved as designated wetland paddy areas (Government of Malaysia, 1984). It can be regarded as a strategic intervention to buttress the paddy and rice sectors’ development and to protect the nation’s food security.

Paddy farmers are settled in these main granary areas, while other small paddy fields are dotted across the country (Fahmi et al., 2013). The granary areas receive various support programmes that have alleviated poverty and strengthened the livelihoods of paddy farmers. Average production per hectare for these areas was 4.47 mt/ha (Table 1), which was above the national average yield of 4.03 mt/ha for 2017. Relatively, four granaries (MADA, KETARA, IADA Pulu Pinang and Barat Lat Selangor) of eight were above the average productivity of granaries per hectare. However, these granaries’ average productivity was in the third position, followed by Vietnam and Indonesia in comparison with other rice-producing countries in Southeast Asia (Table 2). Nonetheless, it is essential to mention that Malaysia’s total paddy cropping area is about 0.70 million hectares, which is the lowest in Southeast Asia. The top three rice producers in the region—namely Indonesia, Vietnam and Thailand—have allocated 11.50, 7.54 and 10.83 million hectares, respectively (United States Department of Agriculture [USDA], 2020).

Paddy in Malaysia is considered the most important crop under the food subsector for two reasons. First, rice is the staple food for the majority of the population. On average, Malaysian adults consumed 2.5 plates of white rice per day (Kasim et al., 2018). Second, for the paddy farming community, the crop provides the primary source of income and livelihood, particularly for small-scale farmers and landless agricultural workers. Approximately 40% of the farmers depend solely on paddy cultivation. Thus, Malaysia’s paddy and rice policies are formulated mainly to achieve three objectives: promote equitable income for farmers, ensure price stability and ensure supply security for consumers. In general, rice security predominantly reflects the nation’s food
security, in which achieving rice self-sufficiency is a crucial factor in promoting food security at the national level (Bishwajit et al., 2013; Rajamoorthy et al., 2015).

Paddy is also the staple commodity for the majority of populations in Asia. Thus, it is considered a strategic crop that ensures political stability and economic growth for many countries in this region. Likewise, paddy and rice have also been the central focus of Malaysia’s self-sufficiency agenda. The Malaysian government recognises food security as almost tantamount to rice security, rendering rice production self-sufficiency a part of the national policy goal (Omar et al., 2019). Various security programmes were developed after the nation’s independence in 1957, whereby multiple strategic interventions have taken place through the setting up of diverse government institutions and policy initiatives (Fahmi et al., 2013). These programmes, among others, include paddy stockpiles, price control, guaranteed minimum price (GMP) and stipulating production-driven targets, known as SSL.

Paddy stockpiles were introduced to provide buffer stocks to ensure price and domestic supply stabilities as well as for emergency needs (Omar et al., 2019). Although the role of price stabilisation ended when the government decided to implement the GMP, however, its role as a safeguard in times of emergency is still maintained. While the “price control” has been implemented to fix market prices charged by importers, millers, wholesalers and

### Table 1. Total paddy production and productivity of the granary areas in 2017

| Main granary areas                                             | State          | Total production (mt) | Productivity (mt/ha) |
|----------------------------------------------------------------|----------------|-----------------------|----------------------|
| Mada Agriculture Development Authority (MADA)                  | Kedah          | 974,387               | 4.841                |
| Kemubu Agricultural Development Authority (KADA)               | Kelantan       | 240,490               | 4.448                |
| Integrated Agricultural Development Authority (IADA) KETARA     | Terengganu     | 50,438                | 5.172                |
| IADA Pulau Pinang                                              | Pulau Pinang   | 146,660               | 5.737                |
| IADA Barat Laut Selangor                                       | Selangor       | 165,571               | 4.510                |
| IADA Kerian                                                   | Perak          | 171,237               | 4.087                |
| IADA Kemasin Semarak                                           | Kelantan       | 26,938                | 3.779                |
| IADA Seberang Perak                                            | Perak          | 88,198                | 3.180                |
| Total                                                         |                | 1,863,919             | -                    |
| Average                                                       |                | 232,990               | 4.469                |

Source: Department of Agriculture (2019).

### Table 2. Paddy productivity of selected countries in Southeast Asia in 2017

| Country                                         | Productivity (mt/ha) | Country     | Productivity (mt/ha) |
|------------------------------------------------|----------------------|-------------|----------------------|
| Malaysia (only eight granary areas)             | 4.47                 | Laos        | 3.24                 |
| Vietnam                                        | 5.89                 | Cambodia    | 2.78                 |
| Indonesia                                      | 4.76                 | Thailand    | 2.89                 |
| Myanmar                                        | 2.91                 | Brunei      | 2.00                 |
| Philippines                                    | 4.02                 |             |                      |

Source: IRRI World Rice Statistics Online Query Facility (2019).
retailers, and thus maintain price stability in the consumer market. Despite these intervention strategies, the rice SSL, however, plummeted significantly after the 1980s and further reduced in the mid-1990s (Table 5). The government’s concern about the high cost of production could be the reason for a particularly low target and achievement. The government realized it would be less costly to import a certain amount of rice than rely on local production. Limited arable land and attractive international market are other crucial factors for the country to import rice. The government, however, has reverted its rice SSL target to 100% in the Eleventh Malaysia Plan.

Multiple strategies were designed and introduced to achieve specific self-sufficiency targets. As shown in Table 3, these strategies were institutionalized in the five-year Malaysia Plan to achieve specific rice self-sufficiency targets. Nonetheless, with the outbreak of the food crisis of 2008 linked to the fuel crisis and further aggravated by the financial crisis the same year, the food security agenda has become increasingly indispensable. The 2008 food crisis prompted the re-evaluation and reconfiguration of existing and future economic policies that could provide high priority for the development of the agricultural sector, especially the food sub-sector. Hence, under the Tenth Malaysia Plan, the government continued to strengthen the rice sector through various initiatives and strategies, where the key focus was on the improvement of research and development and the development of existing infrastructures to boost rice yield beyond the targeted SSL of 70%.

Further to that, the government promulgated the 10-year National Agro-Food Policy in 2010 to replace the National Agricultural Policy. The new policy focuses on ensuring national food security and raising the income of farmers and farm entrepreneurs. These initiatives are undoubtedly crucial for the modernization and development of the paddy and rice industries. However, the deleterious impacts of climate change would intensify the problems of sustaining the growth in production and ensuring future food security.

### 1.1. Malaysia’s climate features

Malaysia is located within the tropics of 1° N to 7° N and the equator of 99° E to 105° E (Wong et al., 2009). The climate can be classified as an equatorial or tropical rainforest or wet-humid tropical climate, and the average daily temperature is relatively uniform. The average annual temperature variability ranges from 26°C to 28°C. Due to the small temperature variations, rainfall trends considerably determine seasonal weather changes. Such rainfall variations are closely related to monsoon winds blowing at different times of the year in Peninsular Malaysia.

| Plan period                  | Self sufficiency level (%) |
|-----------------------------|---------------------------|
| First Malaysia Plan (1966–1970) | 80.0                      |
| Second Malaysia Plan (1971–1975) | 87.0                      |
| Third Malaysia Plan (1976–1980) | 92.0                      |
| Fourth Malaysia Plan (1981–1985) | 76.5                      |
| Fifth Malaysia Plan (1986–1990) | 75.0                      |
| Sixth Malaysia Plan (1991–1995) | 76.3                      |
| Seventh Malaysia Plan (1996–2000) | 71.0                      |
| Eight Malaysia Plan (2001–2005) | 71.0                      |
| Ninth Malaysia Plan (2006–2010) | 72.0                      |
| Tenth Malaysia Plan (2011–2015) | 71.4                      |
| Eleventh Malaysia Plan (2016–2020) | 100.0                     |

Source: Arshad et al. (2010), Economic Planning Unit (2015).
This monsoonal effect is mirrored in temperature variations over the year as some months are much wetter than others (Van, 1974).

The northeast monsoon from November to March will bring moisture and rain from the southern China Sea to states including Kelantan, Terengganu, Pahang, and Eastern Johor. During the Indian Ocean southwest monsoon, most states will have minimum monthly rainfall at an average of 100 mm to 150 mm, except for Sabah in eastern Malaysia. From May to September, the rainfall variations are not as intense as those delivered by the northeast monsoon. However, variations in both cycles affect the amount of sunlight in the region (Van, 1974). April and October are the wettest months in Peninsular Malaysia except for the southwest coast, owing to transitional periods during monsoon seasons. Peak rainfall for the southwest coastline takes place in October and November, with minimal rain in February.

Sunlight and rainfall are two key weather variables in a tropical country, while variations in either sunlight or rainfall have significant influences on crops and yields across the seasons (Van, 1974). Moreover, the carbon dioxide (CO₂) per capita emissions in Malaysia has risen, and it is predicted that by 2030 they will exceed 15.5 tons per capita (Ambrose et al., 2017), amid significant concerns about the potential impacts of climate change (Yii & Geetha, 2017). The production of CO₂ and other greenhouse gases in the lower atmosphere causes climate change, whereby these gases, acting as a blanket, pull energy into the air as heat, which makes the earth’s surface warmer (Jawad et al., 2018). Hence, it comes as no surprise to learn that studies have predicted the adverse impacts of climate change on agricultural productivity in warm tropical and low-latitude countries (Lobell et al., 2011; Mendelsohn et al., 2001; Rosenzweig et al., 2014).

For Malaysia, the impacts of climate change certainly troubling its agricultural sector, and especially rice, a staple food of the nation. Such an assertion corresponds with the results of various studies which signified that impacts of climate change would significantly affect Malaysian paddy yield (Firdaus, Ibrahim et al., 2014; Firdaus, 2015; Tang, 2019a; Vaghefi et al., 2016). Therefore, the future development of the rice sector in Malaysia is prophesied to face multiple challenges, including complex shifts in climatic conditions and impacts of climate change, scarce arable farmland, social and economic transformations, the influx of low-priced rice from neighbouring countries, insufficient property assets and dependency on smallholder agriculture.

Consequently, the purpose of this paper is to review the interplay of climate change on rice and food security by reviewing existing literature related to climate change impacts on paddy productions and food security. In particular, it aims to understand the relationships between above-mentioned themes and their pragmatic implications. To substantiate the review and discussion, we analysed the 34-year trend of precipitation and temperature in main granary areas in Malaysia using Mann–Kendall and Sen’s slope test. In addition, we also looked at links and connections between rice productions and food security to synthesise current understanding and identify future research priorities in East Asia, particularly Malaysia. This will help to understand the possible areas of integration in concepts, future researches, strategical interventions and policy reforms.

2. Method and study area
This paper is primarily based on reviewing the literature, which limited to the articles published from 2000 to 2020. The search of literature mainly focused on themes such as food security, climate change, rice and paddy policies, and sustainability of paddy farming, within the Malaysian context as well as global perspectives to some extent. Several databases were used for the search, including Science Direct, PubMed, ProQuest and Google Scholar. We also conducted a review of grey literature published by numerous reputable international and local agencies that were subjected to the similar aforementioned themes.
Apart from the literature review, we also used secondary data to provide analysis through statistical lenses. We used observed daily temperature and precipitation data from the Malaysian Meteorological Department to examine trends for the past 34 years, from 1985 to 2018. Two widely applied approaches—the Mann–Kendall and Sen’s slope—were used to analyse the magnitude of the climate variables over the granary areas. Meanwhile, Sen’s slope is used to understand the magnitude changes of climate trend for a particular period (i.e. year or decade). Detailed calculations of the Mann–Kendall and Sens’ slope are available in several hydro-climatic trends analysis manuscripts, for instance, in Tan et al. (2015). The mathematical equations for Mann–Kendall Statistics, $S$, is calculated as:

\[
S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \text{sgn}(x_i - x_k)
\]

where

\[
\text{sgn}(x_i - x_k) = \begin{cases} 
+1, & \text{if } (x_i - x_k) > 0 \\
0, & \text{if } (x_i - x_k) = 0 \\
-1, & \text{if } (x_i - x_k) < 0 
\end{cases}
\]

$X_i$ and $X_k$ are the data values at times $i$ and $k$, and the length of the data set is represented by $n$. Variance $S$ is estimated as:

\[
\text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)}{18}
\]

where $q$ denoted the number of tied groups, while $t_p$ is the number of ties for $p$th. The standard normal variate $Z$ is denoted by:

\[
Z = \begin{cases} 
\frac{S - 1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 
\end{cases}
\]

A Mann–Kendall value greater or lower than 1.96 indicates that the climate trend is classified as significant at 95% significance level, showing that the climate system experienced dramatic changes (Tan, 2019).

The Sen’s slope estimator is calculated as

\[
Q_i = \frac{X_j - X_k}{j-k} \quad \text{for } i = 1, \ldots, N,
\]

where $X_j$ and $X_k$ are the data values at times $j$ and $k$ ($j > k$), respectively. $N = [n(n-1)]/2$ if it only has one observation in each time period, and $N < [n(n-1)]/2$ if there are multiple observations in one or more time periods, where $n$ represents the total number of observations. The median of slope or Sen’s slope estimator is computed as

\[
Q_{med} = \begin{cases} 
Q_{\lceil N/2 \rceil} & \text{if } N \text{ is odd} \\
\frac{Q_{\lceil N/2 \rceil} + Q_{\lfloor N/2 \rfloor}}{2} & \text{if } N \text{ is even}
\end{cases}
\]

In this study, Mann–Kendall and Sen’s slopes were calculated using the MAKESENS programme developed by the Finnish Meteorological Institute. Table 4 details the necessary information on the five meteorological stations. The location of each station can be considered as the closest main meteorological station to the granary areas, as shown in Figure 1. Some of these stations are within the granary areas, such as MADA, IADA Pulau Pinang, Seberang Perak, KADA and Kemasin Semarak. Data for paddy yield were obtained from the World Rice Statistics Online Query Facility of International Rice Research Institute (IRRI) and the Department of Agriculture, Malaysia.
3. Results and discussion
The primary purpose of this review is to discourse succinctly the impacts of climate change on food security and paddy in Malaysia. The discussion in this paper is, therefore, divided into two parts to achieve this objective. The first section reviews the impacts of climate change on paddy crop based on findings from various studies. The review is also supported with trend analysis using the Mann–Kendall and Sen’s slope test to examine the trends of maximum and minimum temperatures and precipitation. The second section reviews various policies developed by the Malaysian government to improve the level of self-sufficiency and promote food security. It also discusses several implications on rice self-sufficiency and food security from the looming impacts of climate change.

3.1. The impacts of climate change on paddy
Looking back at the Green Revolution, which was initiated at the beginning of the 1970s to revitalise the agriculture industry, it seemed that this transformation was environmentally unsustainable. Fossil fuels for fertilisers, chemicals, intensive irrigation and modern machineries adapted to the special circumstances have assisted the Green Revolution in Malaysian rice field intensively (Vasar et al., 2015). The technological advances made, however, have come with a price to pay. They triggered the contamination of groundwater and surface water, degraded land and biodiversity, and intensified chemical usage, resulting in harmful environmental effects. Muazu et al. (2015) reported that paddy farmers in granary areas in Malaysia depend on non-renewable fossil-based fuel, forming around 84% of the total energy input. Herman et al. (2015) implicated that over the years, paddy yield in Malaysia has been able to record a slight increase due to an intensification of the usage of nitrogen fertilisers despite a stagnant harvested area.

Various studies have shown that nitrogen fertilisers cause environmental problems through soil, water and atmosphere pollution. These nitrogen fertilisers leave toxic residuals and release harmful gases such as nitrous oxide, other oxides of nitrogen and ammonia, where these gases potentially contribute to global warming (Vashisht et al., 2015; Wang et al., 2017). Perhaps, for this

| Table 4. Meteorological stations information |
|---------------------------------------------|
| No. | Station | Name                  | Granary area |
|-----|---------|-----------------------|--------------|
| 1   | 48603   | Alor Setar            | MADA         |
| 2   | 41529   | Perai                 | IADA Pulau Pinang |
| 3   | 41529   | Perai                 | IADA Kerian  |
| 4   | 43402   | Hospital Teluk Intan  | Seberang Perak |
| 5   | 43402   | Hospital Teluk Intan  | Barat Laut Selangor |
| 6   | 48615   | Kota Bharu            | KADA         |
| 7   | 48615   | Kota Bharu            | Kemasin Semarak |
| 8   | 48615   | Kota Bharu            | Ketara       |

| Table 5. Trend and magnitude changes of precipitation, maximum and minimum temperature from 1985 to 2018 |
|-----------------------------------------------------------------------------------------------|
| Station                  | Tmin (°C/year) | Tmax (°C/year) | Precipitation (mm/year) |
|--------------------------|----------------|---------------|-------------------------|
| Alor Setar               | 0.03*          | 0.02*         | 13.32*                  |
| Perai                    | 0.05*          | 0.03*         | 20.03*                  |
| Hospital Teluk Intan     | 0.04*          | 0.03*         | 8.18                    |
| Kota Bharu              | 0.03*          | 0.00          | 16.80                   |

*Significant trend at 95% significance level.
reason, ecosystem productivity in the Malaysian agricultural sector was ranked 124 out of 178 in the 2014 Environmental Performance Index (Firdaus, 2015). A study by Mohamed et al. (2016) echoed this fact: about 80% of paddy farming practices in Kedah are unsustainable due to the excessive use of agrochemicals, fertilisers and non-compliance with Malaysia Rice Check Guideline. Nevertheless, the impact of environmental externalities, such as climate change, degradation of soil and water quality, will undoubtedly affect crop productivity. Studies have indicated the disruptive effects of climate change on the crop (Firdaus, Samsurijan et al., 2018). Paddy yield is expected to record a decline of up to 5% by 2030 in Southeast Asia, Central America and Brazil (Lobell et al., 2008).

Located in the tropical climate countries of Southeast Asia, Malaysia’s paddy crop will encounter constraints in productivity as the temperature increase (Candradijaya et al., 2014; Ngoc Thuy & Ha Anh, 2015; Poudel & Kotani, 2013; Vaghefi et al., 2016). The variability of precipitation volume and distribution is a significant factor that could limit rain-fed rice crops (Candradijaya et al., 2014; Ngoc Thuy & Ha Anh, 2015), particularly in low-altitude countries (Poudel & Kotani, 2013) such as Malaysia (Vaghefi et al., 2016). Unfavourable climate conditions are expected to occur in Peninsular Malaysia in future. This climate scenario is supported by the fact that temperature and precipitation have shown a rising trend in every decade (Table 4). In Peninsular Malaysia,

![Granary areas in Peninsular Malaysia.](https://doi.org/10.1080/23311886.2020.1818373)
a study by Vaghefi et al. (2016) has shown that the increase in precipitation might not be able to offset the negative impacts on paddy yield caused by the temperature increase predicted in 2030.

Nonetheless, more studies need to be commissioned to project the long-term impact of climate change on paddy yield in Malaysia. A review paper by Tang (2019) used temperature and precipitation data from Malacca, Kuantan and Subang Jaya stations to exhibit the past trends (1956–2016) of climate parameters and link the rising trend with the impacts of climate change on agricultural sectors in Malaysia including paddy. However, the stations used in Tang (2019) were not the ones that can be considered as the closest to the main granary areas in Peninsular Malaysia. Hence, we selected four stations, which are within and closer to the granary areas, as shown in Figure 2 (Temperature minimum, T_{\text{min}}; Temperature maximum, T_{\text{max}}) and Figure 3 (precipitation).

Based on the data from the Malaysian Meteorological Department, Figure 2 presents the spatial and temporal trends of minimum and maximum temperature over the last 34 years (1985 to 2015). To understand the patterns of climate variables trends, Mann–Kendall and Sens’ slope test were performed to examine the magnitude, as shown in Table 4. Results from the Mann–Kendall test indicated an increase in both minimum (T_{\text{min}}) and maximum (T_{\text{max}}) temperature in all stations. All four stations recorded a significant increasing trend of minimum temperature with changing rates from 0.3°C to 0.5°C per decade. The significant increment of the temperature is considered high risk because many countries have considered global warming of 2°C as a high-risk level (Masson-Delmotte et al., 2018). Various studies have shown that grain yield in paddy reduced
with a higher minimum temperature (Shrestha et al., 2016; Welch et al., 2010). Most of the stations within the granary areas also exhibited an increasing trend in maximum temperature, except Kota Bharu. Welch et al. (2010) found that maximum temperature could decrease yields if it was close to the upper threshold limit. Shrestha et al. (2016) implied that an increase in minimum temperature would reduce the grain-filling period during the flowering stage, which eventually causes drops in yield.

Similarly, other crops like wheat and corn are likely to be affected in South Asia and Southern Africa, as well. Rosenzweig et al. (2014), in their study to determine the impacts of climate change on various types of crops worldwide, found that the impacts of climate change in tropical areas would be severe (or less favourable). Particularly for annual C3 crops, such as paddy, the rate of plant development is profoundly affected by temperature (Hatfield & Prueger, 2015). Mohammed and Tarpley (2011) found that high night temperature would cause damage to paddy spikelet sterility and reduced width, length, and height of the grain. Excessive exposure to temperature or exceeding threshold level will impede crop growth and reproductive processes. Generally, paddy is sensitive to hot temperature. Therefore, exposure to a temperature of more or less than its threshold levels for several hours will damage the crop (Wheeler et al., 2000). Consequently, physiological responses of crops towards changes in climate variability can occur on a short-term timescale (Wollenweber et al., 2003).

Earlier studies on the effects of CO₂ fertilisation postulated that such fertilisation produces positive impacts on plant growth (Darwin & Kennedy, 2000; Long et al., 2004; Wheeler et al., 2000). In fact, Firdaus, Gunaratne et al. (2019) argued that some studies are sceptical of such
effects. In Malaysia, it was found that an increase of CO$_2$ level from 383 ppm to 574 ppm would reduce paddy yield by 0.69 per hectare if it is accompanied by rising temperature (Vaghefi et al., 2011). Hence, CO$_2$ fertilisation might not be able to impact yields positively and offset the increase in minimum and maximum temperature, as shown in Figure 2. This also corresponds with the assessments of a crop simulation model of East Asian monsoon climate by Kim et al. (2013) for 2050 and 2100. The model predicted that rice production will increase due to CO$_2$ fertilisation. However, rice yield declined drastically to 22.1% and 35.0%, respectively, when the increased CO$_2$ levels are adjusted with high temperature.

Given that the spatial variability of precipitation lacks regularity, we used annual precipitation anomaly to understand the precipitation changes. As shown in Figure 3, reductions in precipitation were mainly recorded from 1985 to 2000 in Alor Setar and Perai. Dry years observed within this period were more frequent and intense as compared with the period of 2000–2018.

Nevertheless, such patterns differ with the condition at the Hospital Teluk Intan and Kota Bharu stations as the intensity and frequency of dry years and wet years were relatively equal. Studies have indicated that variability in temperature and precipitation would significantly affect agricultural productivity (Kattelus et al., 2016; Porter & Semenov, 2005; Poudel & Kotani, 2013). In Nepal, for instance, year-to-year weather variability is deemed as the main factor that causes instability of paddy and wheat production (Poudel & Kotani, 2013). Similarly, Kattelus et al. (2016) found that variability in precipitation significantly impacts paddy yields. In Malaysia, Vaghefi et al. (2016) observed that rising temperature and high variability in precipitation will reduce rice yield during main and off seasons in 2030 by 12% and 31.3% respectively. Tang (2019a) also found that a 1% increase in temperature reduces the paddy yield by 3.44% in Malaysia. However, Tang (2019a) predicted that a 1% increase in rainfall will cause a marginal decrease in rice production by 0.12%. Therefore, changes in temperature are likely to impact rice yield significantly compared with the changes in precipitation.

Global climate change is linked to parameters such as temperature, precipitation, sea-level rise, solar radiation and humidity (Bickford et al., 2010; Hamzah et al., 2017). Other parameters related to climate change include the occurrence of extreme weather events such as droughts and floods. The extreme prevalence of droughts and floods could produce significant impacts on paddy and rice production. Table 5 shows that the amount of precipitation has increased in all areas, with a significant increasing trend observed in Alor Setar and Perai.

Within these stations, there is a major river basin—the Muda River Basin—that is located in northwestern Peninsular Malaysia. The river basin supplies freshwater resources for domestic, industrial, and agricultural uses in Kedah and Pulau Pinang. Tan et al. (2019) reported monthly
precipitation decreased significantly in May but increased significantly in January and December. Flood hits the basin almost every year during the wet seasons (Ghani et al., 2010). These extreme events may reduce paddy yields over the northern region of Peninsular Malaysia.

Such increase in precipitation would intensify the occurrence of floods. Over the years, floods have caused considerable losses to paddy farmers, particularly farmers in MADA Kedah, which is the largest granary in Malaysia. As shown in Figure 4, paddy yield in the subsequent year was impaired by several flood events in 2003 and 2005. In 2017, flooding in Kedah and its neighbouring state Pulau Pinang caused a significant decline in rice production in the country from the preceding year. These have affected not only farmers’ productions, livelihoods and income but also have severe impacts on the country’s food security. During the main cropping season of 2005/06, floods impaired the yield of paddy over 50,000 tons, affecting 18,250 ha of paddy fields and 10,580 farmers in MADA area (MADA, 2010). As a consequence, total rice imports soared by 45% in 2006 (Firdaus, Siwar et al., 2015; Firdaus, 2015). In addition to climate change and its related parameters, efforts to increase paddy productivity would face daunting challenges, both endogenous (e.g., changes in demography and consumption patterns) and exogenous (e.g., scarcity of lands and water) (Bishwjait et al., 2013; Shah et al., 2019).

3.2. Climate change, rice and food security in Malaysia

Food security at the domestic level reflects the country’s ability to guarantee consistent, sufficient, healthy and nutritious supply, either through local production, import or through international assistance. In Malaysia, the formation of eight main granaries for paddy with various interventions has indeed been set up as strategic food security plans. The impact of climate change could be the main obstacle in achieving desired outcomes of the ten year National Agro-Food Policy (Rajamoorthy et al., 2015; Tang, 2019; Vaghefi et al., 2016). A number of studies have indicated that the impact of climate change would bring substantial pressures to achieving food security in most Asian countries (Gregory & Ingram, 2000; Parry et al., 2001; Rosegrant & Cline, 2003). An integrated assessment model to assess climate change impacts on rice in East Asia found that extreme weather patterns would reduce rice production by 50% by 2100 in the region (Sekhar, 2018). According to the International Food Policy Research Institute (IFPRI), climate change could impact paddy productivity throughout Asia and the Pacific. The consequences could put millions of people in Asia at risk and food insecure (IFPRI, 2009). This is because paddy is the predominant food crop of the poor compared to wheat, where the people in upper-income countries mostly consumed (Rice Almanac, 2013). According to the Asian Development Bank (ADB), increased food prices will affect food accessibility and utilisation of the poor while pushing about 38 million people into hunger in Asia and the Pacific (Asian Development Bank [ADB], 2019).

A meta-analysis on yields of wheat, rice, maize and soybeans found that different climatic conditions under climate change would reduce crop yields significantly (FAO, 2017). In Malaysia, Solyamani (2018) found that an excessive increase in temperature and precipitation affect multiple agricultural products, which consequently affect food availability and accessibility in the market. Such unfavourable conditions will create fragile structures despite encouraging socio-economic progress achieved over the years. Sundaram and Gen (2019) implied that food access is no more a problem in Malaysia. Nevertheless, food affordability is still an issue due to increased food prices, price fluctuations, income inequalities, and consumption patterns and food preferences. Moreover, lack of policy coherence, complicated administrative structures and institutions, and high dependency on imported food products and raw materials challenge the food supply chains and stability of food systems in Malaysia (Yap, 2019).

In its 2017 sustainable development goals review, the Government of Malaysia (2017) reported that absolute poverty (SDG 1) in Malaysia reduced to 0.6% in 2014 compared to 49.3% in 1970. Referring to food security, end hunger and improve nutrition (SDG2), 90% of the reduction in hunger is reported during the 1990–2014 period, yet the prevalence of underweight children and stunting and wasting children under five years of age in 2016 was still considerably high; 13.7%;
20.7%; and 11.5%, respectively. Hence, food security and hunger still require particular attention, specifically in Asia and the Pacific, as proposed by the Asian Development Bank (ADB, 2019). In 2017, the number of people suffering from hunger increased to 821 million from 804 million in 2016 globally. In Asia, the same trend has experienced as the number of people are suffering from hunger increased by one million. Under the climate change scenario, ADB (2019) projects that the prevalence of hunger incidence in 2030 in Asia and the Pacific will be 38 million. Therefore, Sekhar (2018) argued that climate change adaptation practices in Southeast Asia require going beyond agronomical solutions by linking them with poverty reduction and sustainable development policies while bringing different stakeholders together.

With such a daunting future scenario, it is indispensable to link the impacts of climate change with the underlying principles of food security. According to FAO (2008), “Food security exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life”. FAO (2008) also emphasises that “Food security depends more on socioeconomic conditions than on agroclimatic ones and access to food rather than the production or physical availability of food”. However, Wheeler and Von Braun (2013) argued that future studies need to shift their focus to other dimensions of food security, particularly to food accessibility, utilisation and stability. According to them, the underlying concept of food security also emphasises the ability of a household to obtain consistent, sufficient, healthy and nutritious food. In contrast, a vast majority of studies and their climate models tend to focus on the availability or supply of food (Firdaus, Gunaratne et al., 2019). Likewise, in Malaysia, based on our review, we can conclude there are limited number of studies that focus on food accessibility, utilisation and stability, which are crucial in order to understand the impact of climate change on food security and hunger. Thus, we end our discussion with the opinion that the impact of climate change across all four dimensions of food security is still less understood, particularly within the context of paddy and rice in Malaysia.

4. Conclusion
Observing the trends of climate change parameters will enable meteorologists, policymakers and researchers to develop proper planning and comprehensive policy formulation to deal with the climate change phenomenon. Hence, we performed a trend analysis of climate change-related factors (temperature, precipitation) that could affect a country’s ability to improve SSL levels and promote food security. The findings of this study discovered that the granary areas in Peninsular Malaysia had experienced increased temperature and precipitation ranging from 0.3°C to 0.5°C (maximum temperature, T_{max}); 0.2°C to 0.3°C (minimum temperature, T_{min}); and 133 mm to 200 mm (precipitation) in every decade. For precipitation, further analysis showed a high variability of precipitation in the granary areas. According to our review, it is evident that the impacts of climate change pose significant challenges for paddy productivity in the main granary areas in Peninsular Malaysia. These areas are considered the rice bowl of the country and therefore expose the food security of the nation to risk. However, this review undoubtedly found that various granary assistance programmes have been able to improve the welfare of farmers and reduce poverty. Furthermore, such interventions help maintain the interests of paddy farmers to continue to cultivate their paddy lands.

In the event of climate change, the existing strategies and initiatives, however, might not be adequate to ameliorate the impacts. Hence, it is high time for the country to revamp its paddy and rice intervention strategies. First, the country needs to concentrate on enhancing the adaptive capacity of paddy farmers to cope with climate change in any of such future agricultural programmes and policy interventions. As most climate change adaptations executed are typical types of farm-based and agronomic responses (changes in plant variant and crop management), promoting policy responses should be a key priority for the paddy and rice sectors in Malaysia. Policy-based adaptations through agricultural research, for instance, may leverage the speed and scale of adaptation to create synergy with farmers’ responses. For many tropical developing countries, including Malaysia, in which the impacts of climate change will surpass the rates of agricultural technological advancements, policy-based adaptations appear to be the best measures. Presently, there is no national policy on agriculture adaptation plan yet, heralded as the key to improving the
climate change adaptation of agriculture sector in Malaysia. Secondly, specific strategies and programmes need to be revised. For instance, using SSL as an indicator to measure food security in the current policy might be insufficient due to the multidimensional nature of food security.

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Author details
R. B. Radin Firdaus1
E-mail: radin@usm.my
ORCID ID: http://orcid.org/0000-0001-7022-0576
Mou Leong Tan2
E-mail: mouleong@usm.my
ORCID ID: http://orcid.org/0000-0003-3939-0336
Siti Rahyla Rahmat2
E-mail: rahyla@usm.my
ORCID ID: http://orcid.org/0000-0002-6121-7604

1 School of Social Sciences, Universiti Sains Malaysia, Pulau Pinang 11800, Malaysia.
2 Geography Section, School of Humanities, Universiti Sains Malaysia, Pulau Pinang 11800, Malaysia.

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