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Research article

Influence of Climate Factors on Rice Yields in Cambodia

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Abstract: Temperature and precipitation have been known as the key determinant factors to affect rice production in climate change. In this study, the relationship between climate variables and rice yields during 1993–2012 in Cambodia was analyzed and evaluated. The Ordinary Least Squares analysis was applied to examine the relationship of three climate variables (TCV) including maximum temperature, minimum temperature and rainfall against seasonal rice yields. By this period, a remarkable increasing trend of annual temperature was observed whilst rainfall was not significantly changed. The TCV explains approximately 63% and 56% of the variability of rice yields in wet and dry seasons, respectively. It is found that in Cambodia, non-climate factors such as fertilizers, water, cultivars, and soil fertility cause 40% variation to rice yields, whereas the remaining 60% can be influenced by climate variability. The levels of temperature difference (LTD) between maximum and minimum temperatures of the wet season (WS) and dry season (DS) were 7.0 and 8.6 ^{o}C, respectively. The lower value of LTD may cause the reduction of rice in WS (2.2 tons/ha) as compared to that of DS (3.0 tons/ha). Rice yield has increased 50.5% and 33.8% in DS and WS, respectively, may due to the improvement of rice cultivation practices in Cambodia such as the better use of fertilizers, pest and weed control, and irrigation, and more effective rice cultivated protocol, as the increased trend of temperature may detrimentally affect rice yield. The breeding of heat and drought tolerance rice

varieties and development of irrigation system are effective to reduce the negative influence from climate change to rice production in Cambodia.

Keywords: Cambodia; climate variables; rice yield; dry season; wet season; climate change

1. Introduction

Climate change is a cross-cutting issue, which is drawn attention to the entire world in the last several decades. Some remarkable changes are warmer air temperature, irregular rainfall and extreme weather events [1]. The significant impacts of the changes are on human health, agriculture productivity, water availability, ecosystem stability, sea level rise, and beach erosion.

Many studies reported that climate change has vulnerability on crop production [2–4]. Climate change will adversely affect crop yields in the 21st century through hotter temperature, rainfall variability and extreme events. These influences on crop agriculture would implicate to food security worldwide, particularly developing countries [5,6]. However, it was suggested that most impact studies rather focused on global and regional scales [7–10].

Cambodia is an agrarian country which is identified as one of the most vulnerable countries in the region to climate change [11]. The unpredictable changes in climatic conditions are expected to affect rice productivity. In particular, rice is the most important crop and accounts for 80% of the country's total agricultural production. However, the rice farming system is largely non-irrigated and high dependent on rainfall which enable farmers to grow only once a year. The irrigation areas are possible for cultivating rice twice a year. There are limited researches on site-specific impacts, and very few in case of Cambodia [12].

In an attempt to fulfill these limitations, this study has given a particular emphasis on location specific and its impact analysis on rice yield during the studied time of 20 years. Climate factors such as temperature and precipitation have been known to give both direct and indirect effects on rice plants. The direct effects are on the physiological processes which affect plant growth, development and grain formation, while the indirect effects are considering as the incidences of crop pests, diseases and grain yield reduction [13]. Changes in climate variables such as precipitation, temperature and humidity have significant effects on crop yield [14]. However, the impacts differ from one region to another region [15]. The warmer and wetter weather in temperate and tropical regions are likely to increase pests and diseases which will be harmful to crop production [16].

In this study, we used three major climate variables including maximum temperature, minimum temperature and precipitation to examine the relationship between rice yields and climate variables in dry and wet seasons. In Cambodia, the wet season starts from May to October and the dry season extends from November to April.

2. Material and Methods

2.1. Materials

The study was carried out in Kampot province (Figure 1), one of the coastal areas which was reported to have high vulnerable against climate change. The province is geographically located between 10°40'20.636"N and 104°17'38.497"E in the South-eastern coastal zone of Cambodia covering a total land area of 4,873km^2. Agriculture is the main sector for the province followed by fisheries. Rice is the major agricultural commodity for the province and also a key factor for economic growth with potential to reduce poverty and improve food security in the province. In the wet season, rice is transplanting from May and harvested in October. In the dry season rice is cultivated from November and harvested from January to February annually.

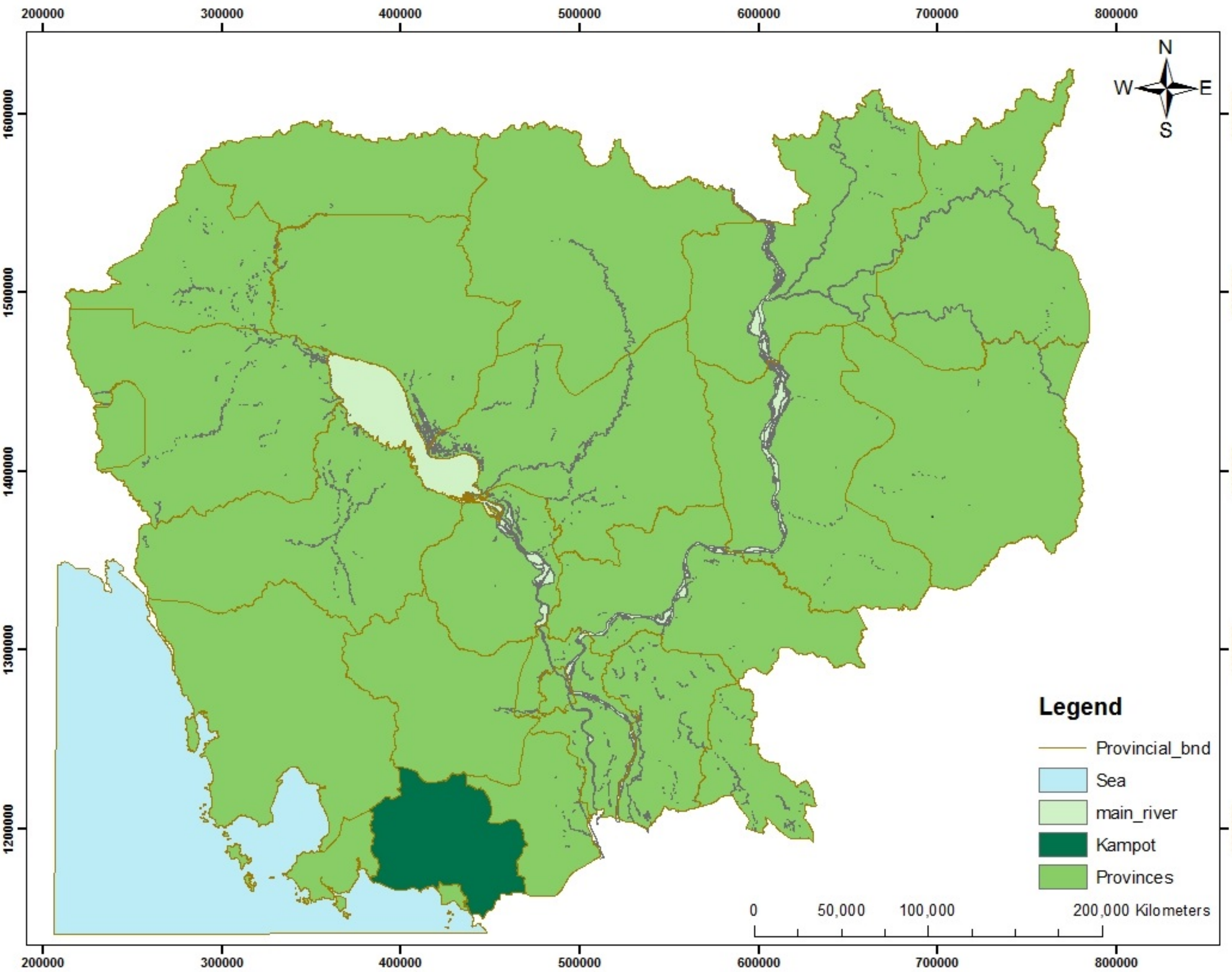


Figure 1. Study area.

The paddy area is around 140,207 ha of the total land, of which more than 98% rice is cultivated in the wet season, with average yields of 2.6 tons ha^{-1} in the wet season and 3.3 tons ha^{-1} in the dry season. Rice production in Kampot had 213,000 tons in the total 3,507,000 tons of Cambodia in 2009. However, by 2011, rice production in the province increased to 401,000 tons, whereas total rice production of the country promoted to 8,251,000 tons [17,18]. The highest temperature of Kampot province in April is 33.1 °C and the coldest month of the year is in February with an average temperature is 22.0 °C. The average annual precipitation is 1,988 mm and the highest level of rainfall recorded is 2,480 mm.

Table 1. Seasonal climate and rice data of study area (1993–2012).

Year	Wet Season Rice				Dry Season Rice			
	Maxt (°C)	Mint (°C)	Train (mm)	Yield (ton/ha)	Maxt (°C)	Mint (°C)	Train (mm)	Yield (ton/ha)
1993	31.22	24.17	1404.90	1.11	31.68	23.13	392.20	2.13
1994	30.90	24.33	1664.00	1.14	31.58	22.92	344.20	2.54
1995	31.58	24.28	1355.30	1.65	31.30	22.88	292.60	2.69
1996	31.48	24.05	1299.10	1.60	31.27	22.55	411.30	1.92
1997	31.87	24.27	1795.60	1.86	32.25	23.12	647.20	2.99
1998	32.02	23.72	1160.50	1.62	32.08	22.95	800.90	2.50
1999	31.97	24.80	1750.20	2.26	31.17	22.85	545.40	3.19
2000	31.33	23.75	1788.90	2.16	31.48	23.50	541.40	3.30
2001	31.27	24.33	1752.50	1.95	31.77	22.90	421.80	2.50
2002	31.58	25.13	1278.00	1.74	31.98	23.27	298.20	2.48
2003	31.45	24.88	2041.90	2.31	32.07	23.27	222.10	2.44
2004	31.57	24.55	1320.00	1.59	32.22	23.13	185.10	2.82
2005	31.80	24.85	1814.00	2.39	32.02	23.73	464.30	3.25
2006	31.37	24.80	2139.60	2.40	32.47	23.73	333.50	3.25
2007	31.67	24.68	1465.60	2.56	31.63	23.32	536.80	2.90
2008	31.55	24.87	1453.60	2.75	31.62	24.53	477.00	3.80
2009	31.53	24.97	1880.30	2.97	32.55	24.13	331.70	3.16
2010	32.87	25.28	1059.30	3.03	31.78	23.42	409.40	3.33
2011	31.82	24.67	1546.10	3.07	32.30	23.95	374.00	3.90
2012	32.07	25.18	1509.70	3.04	32.29	23.69	379.25	4.33

Maxt: maximum temperature Mint: minimum temperature Train: total rainfall

Due to data limitation collected from the study area, only twenty years of time series data covers the period of 1993–2012 at an aggregate provincial level was obtained (Table 1). The climate data were obtained from the Ministry of Water Resources and Meteorology (MoWRAM) (Table 1). The data were collected in the daily basis, and were then converted as monthly mean of the growing periods, from different locations throughout the eight districts of the Kampot province. The climate data are represented by maximum temperature, minimum temperature and total rainfall in the growing seasons of rice crops. Similar to Lobell et al. [7], this study does not estimate the direct effect of elevated CO_2 on rice yields. The rice yield data of both wet and dry seasons were given by the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Cambodia. This average rice yield data was collected from the eight districts of Kampot.

2.2. Methods

Before running the regression, the authors draw the histograms to check the distribution of the dependent variables. The histogram revealed that both the rainy season and dry season rice have normal distribution. Therefore, the Ordinary Least Square was employed to examine the effect of historical variation in average growing temperature and rainfall on rice yields. Regression analysis approach is useful in providing a practical estimation of crop yield, which affected by temperature and rainfall [18]. According to Sarker et al. [4] this study used maximum temperature, minimum temperature and rainfall as independent variables for examining the statistical relationship with rice yields.

The study used an average growing seasonal temperature parameters together with total growing season rainfall parameter since seasonal climate can capture net effect of the entire range of the development process by which yields are affected by climate [20]. Therefore, regression analysis of the two rice crops follows the below models:

$$Ywet\ season_t = \alpha + \beta_1 maxt_t + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t \quad (1)$$

Where $Ywet\ season_t$ is the yields of wet (ton per hectare); $maxt$ is the average maximum temperature (°C) from May to October; $mint$ is the average minimum temperature (°C) from May to October; $train$ is the total rainfall (mm) from May to October; $\boldsymbol{\varepsilon_t}$ is the error term; and $\boldsymbol{t}$ is the time.

$$Ydry\ season_t = \alpha + \beta_1 maxt_t + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t \quad (2)$$

Where $Ydry\ season_t$ is the yields dry season rice (ton per hectare); $maxt$ is the average maximum temperature (°C) from November to April; $mint$ is the average minimum temperature (°C) from November to April; $train$ is the total rainfall (mm) from November to April; $\boldsymbol{\varepsilon_t}$ is the error term; and $\boldsymbol{t}$ is the time.

To investigate the changes in climate variables, descriptive statistics such as moving average, standard deviation and coefficient of variation were computed. Moreover, simple linear regression method was used to access the statistical change of climate variability in both rice-growing seasons.

3. Results

3.1. *Climate change and its variability*

Temperature and rainfall are a straightforward way to measure climate change. The means of both average annual maximum temperature and minimum temperature have gradually increased (Table 2). Absolute variability measured by standard deviation was the highest in the first period (1993–1997) and the lowest in the second period (1998–2002). However, this standard deviation was risen in the third (2003–2007) and fourth (2008–2012) periods. The relative variability of CV (Table 2) was higher in the average minimum temperature than the average maximum temperature. Mean for the average annual rainfall was the highest in the second period, but it had shown a declining trend in the period third and fourth. A similar trend was found in absolute variability. The relative variability had fluctuated over the four periods. There was an evidence of changing in climate over the last 20 years in Kampot province.

Table 2. Climate variability in Kampot province (1993–2012).

Climate variables	Statistical tools	1993–1997	1998–2002	2003–2007	2008–2012
Average annual maximum temperature	Mean	31.50	31.70	31.90	32.00
	SD	1.04	0.70	0.88	0.90
	CV (%)	3.31	2.22	2.78	2.80
Average annual minimum temperature	Mean	23.6	23.6	24.1	24.40
	SD	1.15	0.97	1.13	1.01
	CV (%)	4.88	4.09	4.67	4.13
Average annual total rainfall	Mean	1944.60	2067.90	2035.90	1903.40
	SD	323.10	462.70	338.66	346.47
	CV (%)	16.62	22.38	16.63	18.20

Data were collected from MoWRAM (Ministry of Water Resources and Meteorology)

Simple linear regression method was used to access the statistical change of climate variability in both rice-growing seasons. Regression results are shown in Table 3. The equations represent the mean of variation for maximum temperature, minimum temperature and rainfall, both seasonally and annually. The maximum temperature and minimum temperature of annual model, wet season model and dry season model show a strong time trend in mean with statistically significant and explanatory power. However, explanatory power of minimum temperature is higher than maximum temperature for all models. Meanwhile, rainfall is statistically insignificant for all models. The estimates for these equations are also weak in terms of R^2 and t-Statistic. Overall, both annual maximum and annual minimum temperatures show an upward trend with the increasing rate of 0.038 ^{o}C and 0.058 ^{o}C per year, respectively.

Table 3. Trends in the variability of three major climate variables in 1993–2012.

Dependent variables	*Intercept*	*Coefficient*	R^2	*t-Statistic*	*P-value*	*F-value*	*Prob. > F*
Annual maxt	-45.666	0.039**	0.469	3.985	0.000	15.887	0.000
Annual mint	-93.390	0.058**	0.618	5.400	0.000	29.160	0.000
Annual train	6840.469	-2.423	0.002	-0.174	0.863	0.030	0.863
WS maxt	-34.474	0.033*	0.229	2.309	0.033	5.332	0.033
WS mint	-90.696	0.058**	0.467	3.971	0.000	15.771	0.000
WS train	52.143	0.755	0.000	0.062	0.951	0.003	0.951
DS maxt	-43.076	0.037*	0.299	2.750	0.013	7.563	0.013
DS mint	-102.466	0.063**	0.567	-3.957	0.000	23.608	0.000
DS train	9343.505	-4.456	0.033	-0.787	0.441	0.619	0.442

* and ** represent 5% and 1% levels of significance, respectively

Maxt: maximum temperature, Mint: minimum temperature, Train: total rainfall; WS: west season, DS: dry season

The temperature during the dry season is higher than wet season in terms of both maximum and minimum temperatures. The annual rainfall has shown a downward trend with a decreasing rate of 2.423mm per year. The decrease in rainfall is more pronounced during dry season. The rate of decrease for dry season is 4.456mm per year. In contrary, wet season rainfall has a slight increase trend. To summarize, maximum temperature and minimum temperature variables have a high tendency to increase over the last 20 years for both seasons, while total rainfall has a slightly increase trend in wet season, but in contrast, it is decreased during dry season. It provides a clear evidence of an increasing temperature and decrease of rainfall in Kampot.

Descriptive statistics of data for period 1993–2012 are presented in Table 4. The mean value of dry season rice yield was higher than the value of wet season rice yield. The mean value of total rainfall in wet season was almost four times higher than that in the dry season period. Mean maximum temperature was higher in the dry season and, surprisingly, the lower mean minimum temperature was also recorded in the dry season.

Table 4. Descriptive statistics of data for period 1993–2012.

Statistics	*Variables*							
	Yield (ton/ha)		*Maximum temperature (℃)*		*Minimum temperature (℃)*		*Rainfall (mm)*	
	WS	*DS*	*WS*	*DS*	*WS*	*DS*	*WS*	*DS*
Mean	2.159	2.971	31.6	31.9	24.6	23.3	1574.0	420.4

Standard deviation.	0.620	0.604	0.409	0.407	0.451	0.493	292.7	144.6
Standard Error	0.139	0.135	0.091	0.091	0.101	0.110	65.4	32.3
Maximum	3.070	4.327	32.9	32.6	25.3	24.5	2139.6	800.9
Minimum	1.111	1.920	30.9	31.2	23.7	22.6	1059.3	185.1
Range	1.959	2.407	2.0	1.4	1.6	2.0	1180.3	615.8
Skewness	-0.017	0.441	1.192	-0.106	-0.389	0.739	0.163	0.882
Kurtosis	-1.030	0.062	3.393	-0.996	-0.624	0.309	-0.690	1.341

WS: wet season; DS: dry season.

3.2. Result for wet season model and dry season model

The impact of climate variables on rice yield of wet season is shown in Table 5. The climate variables (maximum temperature, minimum temperature and rainfall) were able to explain variations in rice production of wet season. The R^2 value indicates that model can explain 63% (Table 5) of the variation in wet season against rice yield. The t-Statistics associated with P-value for the three climate variables indicate that these climate variables are highly significant.

Table 5. Regression result for wet season rice model

Independent variables	***Coefficient***	***Standard***	***t-Statistic***	***P-value***
Constant	-38.847**	8.459	-4.592	0.000
Maxt	0.839*	0.296	2.833	0.012
Mint	0.535*	0.243	2.204	0.043
Train	0.001*	0.000	2.166	0.046
R Square = 0.63				

* and ** represent 5% and 1% levels of significance, respectively

Maxt: maximum temperature; Mint: minimum temperature; Train: total rain fall

The dry season rice in Kampot province is generally grown with irrigation. Therefore, Table 6 showed that only minimum temperature was statistically significant for dry season model. The dry season rice yield was found to have a positive association with rainfall but it was negative with maximum temperature. The R^2 value suggests that 56% (Table 6) of the variation in dry season rice yield was explained by climate variability. In general, rice yield in wet season (WS) should be greater than in dry season (DS). However, in this study, it is observed that rice yield in WS (2.2 tons/ha) was lower than that of DS (3.0 tons/ha). The levels of temperature difference (LTD) between maximum temperature and minimum temperature of WS was 7°C, whereas that of DW was 8.6°C. The lower value of LTD in WS than DS was proposed to cause the reduction of rice yield in WS, as compared with DS (Table 4).

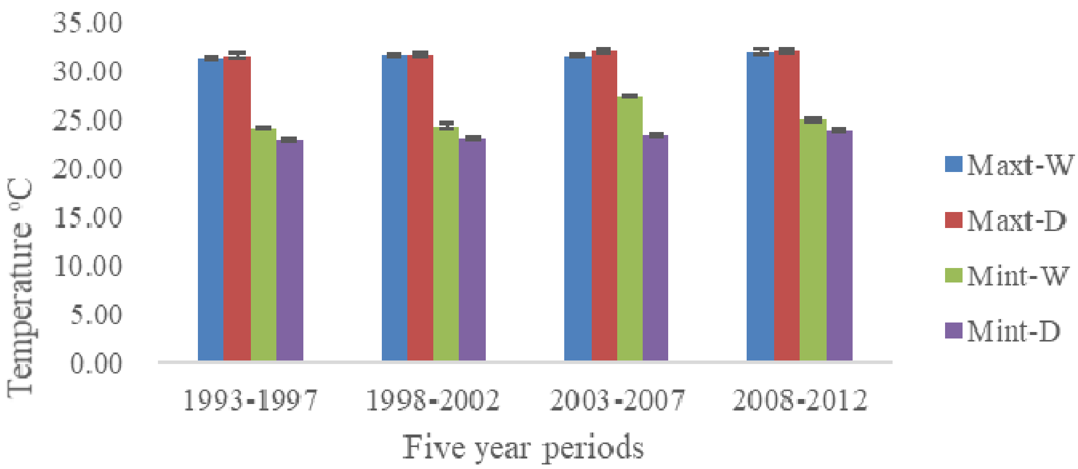
Table 6. Regression result for dry season rice model.

Independent variables	*Coefficient*	*Standard*	*t-Statistic*	*P-value*
Constant	-18.409*	8.068	-2.282	0.037
Maxt	-0.012	0.286	-0.041	0.968
Mint	0.922**	0.234	3.938	0.001
Train	0.001	0.001	0.791	0.440
R Square = 0.56				

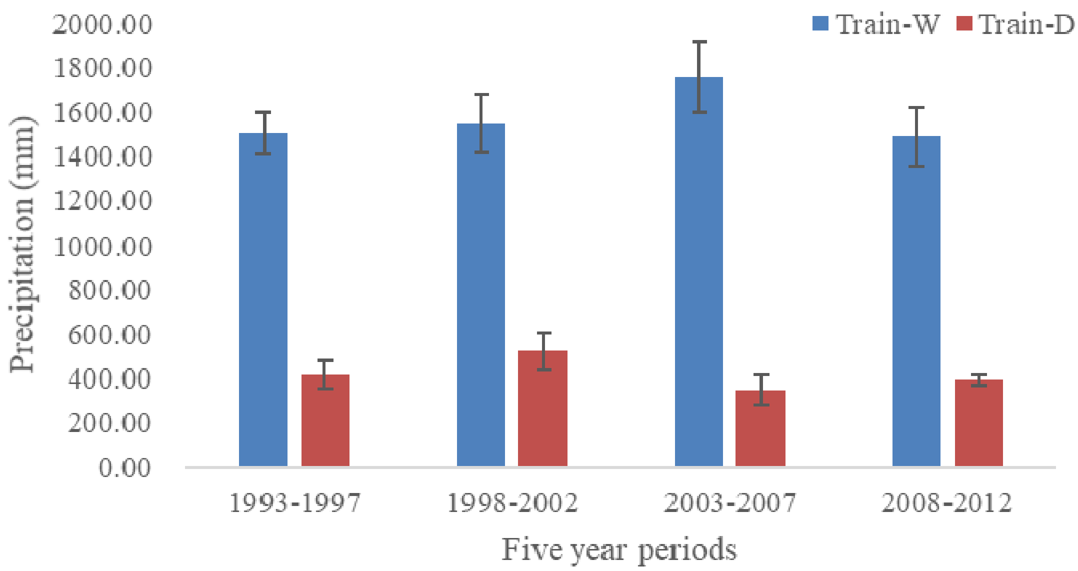
* and ** represent 5% and 1% levels of significance, respectively

Maxt: maximum temperature; Mint: minimum temperature; Train: total rain fall

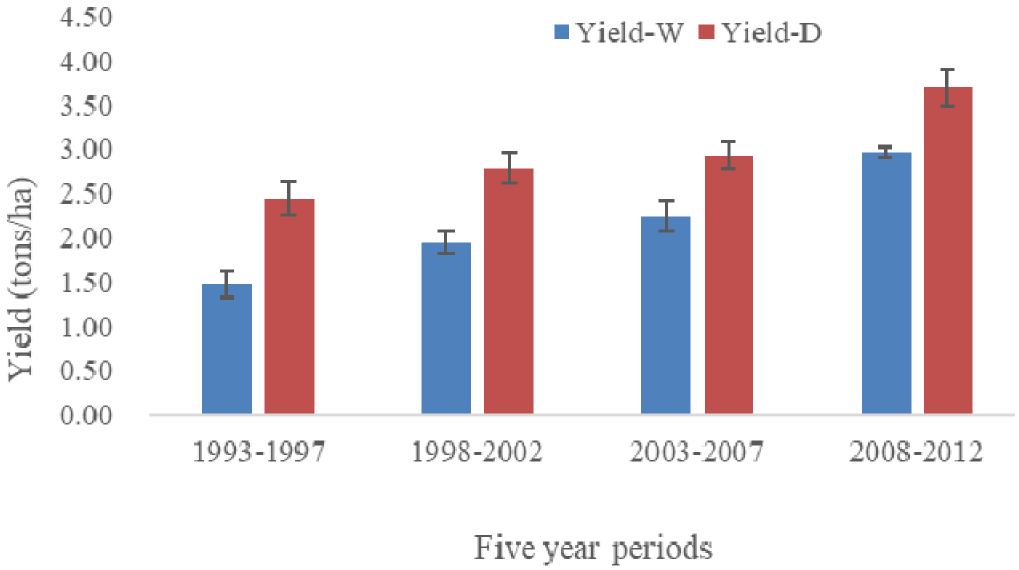
Figure 2 showed the evolution change of temperatures, total rainfall, and rice yield between the wet and dry seasons in five year periods from 1993–2012. In general, there was an increasing trend of maximum and minimum temperatures of both seasons between the two periods 1993–1997 and 2008–2012. In contrast, total rainfalls of the both seasons have been declined constantly in every five year period, with the exception of the period 2003–2007, although the values of total rain fall among these periods are not significanly different. In the period 2003–2007, the total rain in wet season was increased significantly but that of the dry season was reduced remarkably. However, in the period 2008–2012, total rain fall of both seasons were reduced as compared with the periods 1993–1997 and 1998–2002 (Figure 2).



(a)



(b)



(c)

Figure 2. Evolution of temperatures (a), rainfall (b), and rice yied (c) in five year periods from 1992–2013

Maxt-W and Maxt-D: maximum temperature in wet and dry seasons, respectively; Mint-W and Mint-D: minimum temperature in wet and dry seasons, respectively; Train-W and Train-D: total rain in wet and dry seasons, respectively; Yield-W and Yield-D: yield in wet and dry seasons, respectively. Values in bars are means ± SE (standard errors) (n = 5)

Rice yield in the dry season was markedly higher than the wet season. Comparing among periods, rice yield in Kampot province has significantly improved. It is observed that during 1993–1997 and 2008–2012, there was 50.5% increase of rice yield in the wet season, whilst it was 33.8% growth in the dry seasons. Combining with the results obtained from Tables 5 and 6, and Figure 2, the improvement of rice yield may be explained from application of better agricultural practice in rice cultivation in Cambodia such as fertilizers, irrigation, use of new cultivars, and more appropriate culivation prococol of rice.

4. Discussion

4.1. Climate change and its variability

Findings of this study indicate that maximum and minimum temperature show an increase over the studied period of 20 years. The coefficients of maximum and minimum temperatures for both seasons were positive. Maximum temperature of the wet season was increasing at lower rate compared to that of the dry season. Wet season and dry season maximum temperatures were increasing at the rate of 0.033 °C and 0.037 °C per year in the period of 1993–2012, respectively. Similarly, minimum temperature in the wet season was increased with its annual increase rate of 0.058 °C. Dry season minimum temperature was also rising but slightly higher than wet season. The increased rate of the dry season minimum temperature is 0.063 °C every year.

Rainfall for all seasons showed an insignificant relation with time variables. Rainfall fluctuated over the years with lower degrees of predictability. However, rainfall for wet season indicated an upward trend but, in contrast, there was a dramatic decline trend for dry season. The coefficients suggest that wet season rainfall is increased by 0.76 mm every year, while dry season rainfall has an annual decrease of 4.46 mm. Rainfall in Cambodia is predominately in the wet season to account for approximately 70% of total annual rainfall. The positive coefficient for wet season rainfall and negative coefficient for dry season rainfall indicate that the rain in the wet season returns more intense. According to Hughes et al. [21], by the late 19th century, the global temperature has increased by about 0.6 °C, and by 0.2–0.3 °C over the past 40 years. However, under the occurrence of civil war in Cambodia until 1998 [22], the data on climate change can be collected within 20 years only. The temperature tends to get warmer, particularly during dry season. Rainfall has shown some deviations, which has a negligible increase in the wet season but is declined during dry season.

4.2. Relationship between historical climate variables and rice yields

The results of wet season model suggest that it can be useful to describe the variation in wet season yield by 63% (Table 5). An increase in wet season rainfall and temperatures contributed strongly in increase in rice yields. The coefficient can be used to analyze the actual effect of climate variables in the change of crop yields. The dry season model indicates that the increase in dry season yield is markedly associated with an increase in minimum temperature. Climate variability can explain about 56% (Table 6) of the variation of dry season rice yield. Therefore, about 44% of variation in dry season rice yield could be influenced by non-climate factors such as fertilizers, water, and soil fertility.

The current trends in climate variables may not affect rice yield in both seasons. The average maximum temperature of Kampot province particularly during the dry season is between 30 °C and 32 °C. According to Pheav et al. [23], the high temperature, which exceeds 38 °C, can harmfully reduce crop production in Cambodia. However, in this study, rice yield in WS (2.2 ton/ha) and was lower than that of DS (3.0 tons/ha) that may be due to the lower value of levels of temperature difference (LTD) between WS (7 ^{o}C) than DS (8.6 ^{o}C). Meehl et al. [25] reported that the increase of minimum temperature as compared with the maximum temperature may result in severe reduction on crop grain. It can also affect to crop pollination that also induce the decrease of crop yield [25]. Therefore, it is suggested the temperature did not influence to rice yield in both seasons, but the lower value of LTD in WS than DS may attribute to the reduction of rice yield in WS than DS. When comparing the rice yields in WS and DS in five year periods from 1993–2012, it was found that rice yield has increased 50.5% in the WS and 33.8% in DS (Figure 2), may due to improvement of practices on rice cultivation in Cambodia such as fertilizers, weed and pest controls, irrigation, and cultivating protocols. As reported in literature, the increase of temperature apparently causes negative impact on rice yield [26].

The development of heat and drought tolerance rice varieties is thus effective to reduce the influence of climate change to rice production in future. Although the total rain did not show any correlation with rice yields in both WS and DS, as the survey was conducted in areas where have good irrigation system. Similar research should be conducted in different areas in Cambodia where the irrigation system has not well developed, to understand the correlation of total rain on rice yield of Cambodia in a greater extent.

5. Conclusion

Findings of this study reveal that during the recent two decades, about 60% of rice yield can be explained by three climate variables. In this study, it is found that high temperature did not correlate to rice yield, but the LTD values showed negative effects to rice yield. Time period of twenty years is short to measure the impacts of climate change. This data limitation, to a certain extent, may lead to some biases in the results computed. To be more accurate, Rosenzweig et al. [1] suggested using 30 years of data for climate change may provide more persuasive estimation. However, the civil war in Cambodia prevents from data collection before 1993. A more accuracy result can be obtained if these factors can be included in a period of 30 years that needs further elaboration in future research.

In this study, linear regression on time series data was applied to estimate the influence of climate variables to rice production in Cambodia. However, the investigation on issues that might arise with time-series data, such as auto-correlation should also be considered, when further data in a period of more than 30 years in different locations of the country can be provided. With time series data, it is highly likely that the value of a variable climate factors observed in the current time period will be influenced by its value in the previous period, therefore the finding of auto-correlation should provide a larger prediction.

Finding of this research showed that climate variables including temperature and precipitation may cause up to 60% effect on rice yield production in Cambodia. Therefore, the development of irrigation system, and improvement of management and practices in rice cultivation, such as appropriate use of fertilizers and pest and weed control may help to reduce the detrimental effects which may cause by climate change. The breeding of rice cultivars tolerance to drought and submergence is also useful to reduce the dependence on climate variables of rice production in Cambodia. However, the decrease of levels of temperature difference (LTD) values may strongly affect the reduction of rice yield in Cambodia.

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Conflict of interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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