http://dx.doi.org/10.22739/ipaid.2019.28.2.0(시작페이지)

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일반논문 「지역발전연구」 제28권 제2호: 00~00 JRSD

Climate Change Analysis to build up an Integrated Agricultural Extension Program on Sustainable Rice Production in Cambodia*

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The fluctuation in climate regimes of temperature and rainfall is a leading cause of impact on rain-fed agricultural systems overall the world. This study investigates the impact of temperature and rainfall changes on rice productivity based on long term historical data of the average rainfall and temperature in Cambodia from 1901 to 2014. Additionally, the temporal dynamics of metrological variables were determined in the context of climate change to examine the rice productivity data from 1961 to 2015. The study mainly targeted exploring, describing, and analyzing the time series data of the temperature, rainfall, and rice productivity to estimate the correlation and regression between the temperature and rainfall as predictor variables and the rice productivity as a dependent variable. The results of the time trends revealed that there are significant increases in trends of Rice growth-season Temperature Mean (RTM) and Rice growth-season Rainfall Mean (RRM) along the investigated 115-year period of the months between July and November in the years of 1901- 2015. The rice productivity also showed a similar trend along the 55-year period of 1961- 2015. The results showed that RTM and rice productivity had a significant positive regression, whereas, the RRM did not show significant correlation with rice productivity in 55-year data. Afterwards, based on the long-term analysis of climate change impact on rice productivity with practical experiences from Egyptian and Korean Agricultural Extension Research Institute, an Integrated Agricultural Extension Program (IAEP) was proposed on sustainable rice production for farmers in Cambodia.

[Key Words: Cambodia, Climate Change, Sustainable Rice Production, Rice Productivity, Integrated Agricultural Extension Program]

* This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-).

Ⅰ. Introduction

Climate change has been affecting temperature and rainfall patterns all around the world. The agricultural ecosystem which directly relates to the food security, health, and the sustainability of the human population, faces a serious problem by the climate change caused by global warming. The crops are known to suffer yield losses when temperatures rates rises. IPCC (Intergovernmental Panel on Climate Change) also predicts that billions of people, especially in developing countries, will face changes in rainfall over the coming decades, contributing to a sharp lack in water availability for irrigation or drinking, as well as contributing to more floods. The increase in temperature is influencing planting seasons of crops and having negative effects on agriculture and food production in most countries in terms of acute food shortages and the spread of pathogens, diseases, and pests affecting humans, animals, and plants, (IPCC, 2007).

The changes in rainfall may also cause a reduction in crop yields. A decrease in rainfall may cause drought in such regions that would dramatically decrease the amount that the crops will yield. The combination of climate change and population growth in many developing countries may make the problem more severe than it may seem. An interaction between food supply reduction due to climate change effects on agriculture, and demand increase from still-growing populations would result in food shortages and widespread hunger (IFPRI, 2013). Additionally, there are many social problems as effects of climate change such as the spread of human diseases and the emergence of the problem of migration from the affected areas to the less affected regions (Sakr, 2014).

Cambodia has been identified as one of the most vulnerable countries to climate change, given the predicted changes in temperature, precipitation, the share of labor in agriculture, and the country's low adaptive capacity due to widespread poverty (IFPRI, 2013). Cambodia is located in Southeast Asia in the tropical zone, just 10−13° north of the equator. It is between warm to hot year−round and the climate is dominated by the annual monsoon cycle with its alternating wet and dry seasons (Canby Publications, 2018). Particularly tropical regions in developing countries are usually characterized by poor marginal soils that cover extensive areas, making them unusable for agriculture, and leaving the developing countries particularly vulnerable to potential damage from environmental changes (Eid H, et al., 2007), (Mendelsohn and Dinar, 1999).

This study explores and analyzes the long−term time series data of temperature, rainfall (115 years), and rice productivity (55 years). Additionally, we estimate the regression effect of climate change of temperature (Rice growth−season Temperature Mean, RTM) and rainfall data (Rice growth−season Rainfall Mean, RRM) as predictor variables on the rice productivity as a dependent variable for 55 years. Based on the data from the long−term analysis of climate change's impact on rice productivity, and with the practical experiences from Egyptian and Korean Agricultural Extension Service and as programs are the heart and soul of extension work (GFRAS, 2012), an Integrated Agricultural Extension Program (IAEP) was created for sustainable rice production for the Cambodian farmers.

Ⅱ. Methodology

1. The Study Country

Cambodia is a country located in the southern portion of the Indochina Peninsula in Southeast Asia. It is 181,035 square kilometers in the area; bordered by Thailand to the northwest, Laos to the northeast, Vietnam to the east, and the Gulf of Thailand to the southwest (Wikipedia, 2018). It is considered as one of the main national development priorities as to reduce poverty within the country. Thus, efforts in addressing climate change cannot be separated from economic development and poverty alleviation of the people (National Climate Change Committee, 2013). By developing the agriculture sector, reducing poverty has been the top priority of the government's development strategies in Cambodia since 1993. Rice is considered as a main crop in Cambodia. Most rural people grow rice in addition to some other cash crops such as cassava, cashew, maize, and beans, as well as raising poultry and livestock to supplement daily subsistence and household income (IFPRI, 2013).

Cambodia has a monsoon climate, with a six-month wet season and a six-month dry season. The southwest monsoon brings the rainy season from the middle of May to the middle of September or early October. The northeast monsoon weathers dry, cooler air from early November to March, and followed up by hotter air from April until early May. The rice farming generally starts early in the wet season and the crop is harvested six months later. Cambodia has a growth in the agriculture sector especially in rice cultivation that has been increasing annually, both in terms of cultivated land and production. Recognizing that irrigation development is a significant asset to help improve rice productivity, and so the government has recently renewed efforts to promote water sector development (Ros, 2011).

The 2017 Census of United Nations Population Fund puts 79% of rural population in Cambodia's total population at 16 million (47.8 % female, 45.8 % male) (UNFPA, 2017), with an estimated growth rate of 1.54% per year and an average population density of 75 persons per Km2 (RGC, 2009), (IFPRI, 2013). In according to the formal statistics, it revealed that more than 90% of rice cultivation occurring in the wet season (July to November) and less than 10% in the dry season. Additionally, the economic role of rice production in the agriculture sector in Cambodia is proportionately smaller than its share of the cropped area of the country. Rice yields on average 1.3 ton per hectare, which is significantly lower compared with those in most other countries (Nesbitt, 1997).

2. Data Collection and Analyses

The temperature and rainfall data for a 115-year period from 1901 to 2015 were obtained from an official portal site (Climate Change Knowledge Portal http://sdwebx.worldbank.org/climateporta) and the formal historical data of the World Bank (http://sdwebx.worldbank.org). The annual average rice productivity data source came from Ricepedia Cambodia Basic Statistics (Ricepedia, 2018) for the data between 1961 to 1980, and the rest of the data was cited from the annual report for the Ministry of Agriculture Forestry and Fisheries in Japan (MAFF) Conference for the rice productivity data between 1981 to 2015 (MAFF, 2016).

The data sets were used for historical time series analysis of climate change and other regression analyses for long-term rice productivity with climate factors. The climate data in this research are expressed as the average of monthly temperature and rainfall, as well as RTM and RRM during the rice growth period from July till November in Cambodia.

Some abbreviations were used for suitable interpretation as following: Rice growth-season Temperature Mean (RTM) and Rice growth-season Rainfall Mean (RRM) refer to the mean of the temperature and rainfall during the five months of rice growth (July to November) during 1901 to 2015. Decadal Temperature Annual (DTA) refers to the mean of the temperature for a 10-year-period. Decadal Temperature Rice-growth season (DTR) refers to the mean of the temperature in the five months of rice growth season for a 10-year period. Rice growth-season Rainfall Summation (RRS) is calculated by the summation of the rainfall during the rice growth period from July till November. Decadal Annual Rainfall Summation (DARS) is calculated by the summation of the rainfall for the whole year for a-10-year period. Decadal Rice growth-season Rainfall Summation (DRRS) is calculated by the rainfall summation for the rice growth season for a 10-year period. Some of the data was divided into eleven clusters in according to the time series into eleven decades, and five more years of data for temperature and rainfall, as well as five decades and five more years of data for rice productivity. To analyze the trends of climate change and its effects on rice productivity, the temperature and rainfall mean, standard deviation, variability of monthly, rice-growth-period and its annual data were calculated. Furthermore, the years in according to the drought index were classified to understand anomalies of rainfall by calculating the standardized precipitation index by the time (Patel, 2017).

Trend detection of climate change and its effects on rice productivity were analyzed by calculating the temperature and rainfall mean, standard deviation, and variability of monthly, rice-growth-period and annual data. Furthermore, the years were classified according to the drought index to understand anomalies of rainfall by calculating the standardized precipitation index by the time (Patel, 2017).

3. Temperature, Rainfall and Rice Productivity Measurements

1) Temperature

The temperature data expressed as the mean, standard deviation (S.D), coefficient of variations (C.V), and changes (Ti) were measured between each year and the previous year as a slope by this equation:

where Xj and Xi are considered as data values at time j and i (j > i) correspondingly, that measured Ti between any two values of a time series X can be estimated from and between each year and decade as it increases or decreases, the trend detection by Mann Kendall's test (Yilma and Z., 2004), (Asfaw et al., 2017). The trend was calculated using the linear of Kendall test expressed in °C for each year during rice growth period for 115 years to find out if there was a significant trend and if the direction indicated a positive or negative trend.

The regression linear or quadratic models were used as a parametric measurement between the temperature and the time series, and as well be used in the future prediction. Afterward, the Man Kendall's test was used to determine the trend for each month of growth period, in addition to the trend of the temperature changes.

2) Rainfall

The rainfall data expressed as the mean, S.D, C.V, the changes of the rainfall annually and decadal, and the trends were detected by Mann Kendall's test. Regression linear and quadratic model were used as a parametric measurement as well as between the rainfall and the time series, standardized rainfall anomalies (Z) (Woldeamlak, 2007), by calculating this equation:

where, Z is standardized rainfall anomaly; Xi is the annual or inter-growth rainfall of particular year, is the long term mean of rainfall over the period of observation, s is the standard deviation of the observed period. The Z value of rainfall have been computed to examine the nature of the trend to classify the historical values according to the rainfall for inter-annual and inter-growth to classify into four levels of drought: 1- extreme drought, 2- severe drought, 3- moderate, and 4- no drought (Agnew, 1999), (Asfaw et al., 2017).

3) Rice Productivity

The rice productivity was analyzed by measuring the mean, S.D, C.V, the annual and decadal changes, and the trends were detected by Mann Kendall's test. Regression linear and quadratic model were used as a parametric measurement as well between the rice productivity over time.

Ⅲ. Results and Discussions

1. Temperature Analysis

1) Temperature Statistics

Table 1 reveals the temperature statistics (mean, S.D, C.V) of the month, season, RTM, and year average (°C) for 115 years from 1901 to 2015 in Cambodia. The year average was 27 ℃, the warmest month was April (29.05 ℃), and the coolest month was December (24.87 ℃) with the highest variation of 4.3% C.V. The RTM during July to November (26.9 ℃) appeared slightly lower than the year average temperature (27.01 ℃) and the standard deviation was 2.85% of the mean (C.V).

<Table 1> Temperature statistics of the monthly, seasonal, rice growth−period temperature mean (RTM), and year average for 115 years from 1901 to 2015 in Cambodia (°C)

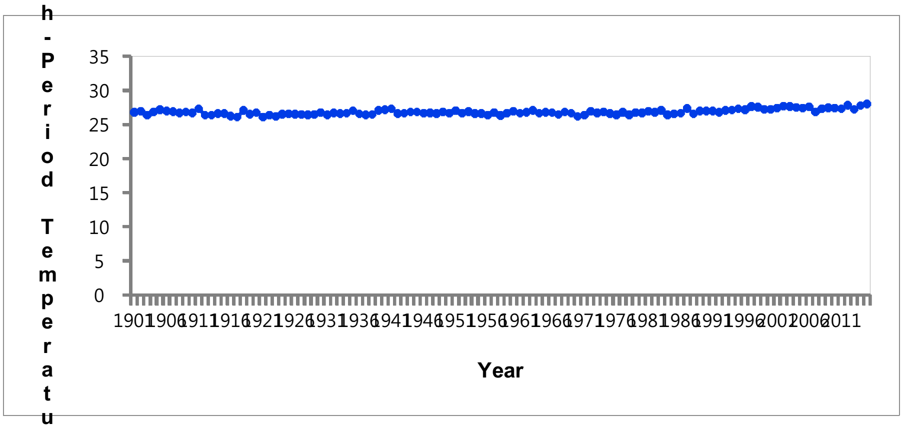
Month and Seasonal Climate	Mean (Co)	Standard Deviation (S.D)	Coefficient of Variation (C.V)
January	24.989	1.070	4.283
February	26.511	0.769	2.902
March	27.959	0.687	2.458
April	29.046	0.648	2.230
May	28.595	0.551	1.929
June	27.870	0.432	1.552
July	27.340	0.395	1.448
August	27.358	0.383	1.400

September	27.047	0.432	1.599
October	26.621	0.543	2.040
November	25.893	0.807	3.118
December	24.867	1.068	4.298
Nov – Feb: Cool and dry	25.565	1.154	4.517
Mar – May: Hot and dry	28.533	0.772	2.705
June–Aug: Hot and wet	27.523	0.472	1.716
Sep–early Nov: Cool and wet	26.834	0.534	1.990
RTM (July - Nov)	26.852	0.766	2.853
115 Year Average	27.008	1.429	5.293

2) Trend Detection

Through the 115–year period, 5 months of RTM showed a significant linear increase of the temperature anomaly by the non–parametric Mann–Kendall test with α = 0.05, and Kendall's tau value = 0.387 (Figure1).

<Figure 1> Trend of the rice growth–period temperature mean (RTM) in Cambodia by Mann–Kendall test during time series between 1901–2015



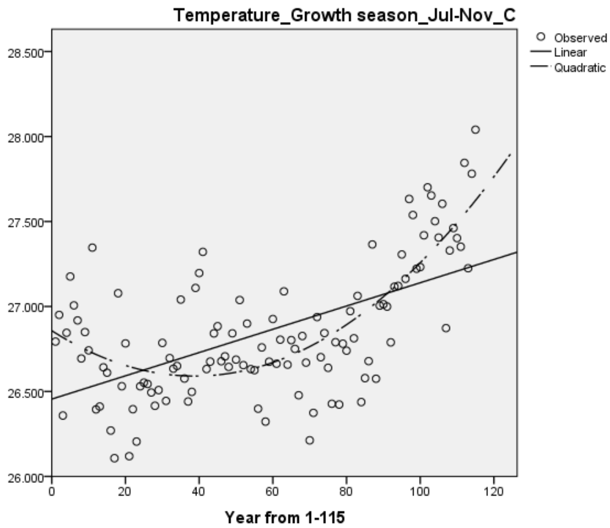
The regression model (Table2) reveals that there is a significant positive trend between the RTM as a dependent variable and the time by number of years (1–115) as predictor variable in two equations of linear and quadratic regression with two equations as (Y1=26.455+0.007X1, R2 = 0.337), and (Y2=26.857−0.014X1+0.0001X12, R2 = 0.537), respectively. Those two equations are useful for predicting the temperature in the future, in addition to Figure 2 that describes the estimation linear and quadratic curve to show the increase of the temperature over the time.

<Table 2> Regression analysis of the rice growth−period temperature means (RTM) and the time in Cambodia during (1901−2015)

Dependent Variable: RTM (July−Nov) °C, independent variable is Year from 1^{st}−115^{th}

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	.337	57.363	1	114	.000	26.455	.007	
Quadratic	.537	64.918	2	113	.000	26.857	−.014	.000

<Figure 2> The linear and quadratic regression analysis of the rice growth−period temperature mean (RTM, Co) and the time by years 1−115 (1901−2015)



The results of the DTA, and DTR in the Table 3 were revealed that there were ups and downs of the temperature among the first seven decades; on the other hand, it found significant increases of the temperature changes for the last 4 decades and last five years. Concerning the changes of the DTR, it obviously noted a significant increase in the last 4 decades and last five years that may give an expected trend for more increases in the future, more than the suitable temperature level for the rice cultivation in Cambodia. Consequently, the changes of the temperature of each month in the period 1901 to 2015 in Table 4 reported increases for whole months for 115 years, in addition to the increase of the temperature for the whole 115 years of the total annual changes and the total growth changes are 1.121℃, 1.247℃. That gave an increase to future trends, especially the sensitive period of flowering and heading during September and October of which the temperature is increased within 115 years to be 1.31°C and 1.12°C respectively.

<Table 3> The changes of the decadal temperature annual (DTAs) and decadal temperature rice−growth season (DTRs) for 115 years (1901−2015), changes of DTAs and DTRs were calculated by the average of 10−year differences between each year and the previous value for each decade

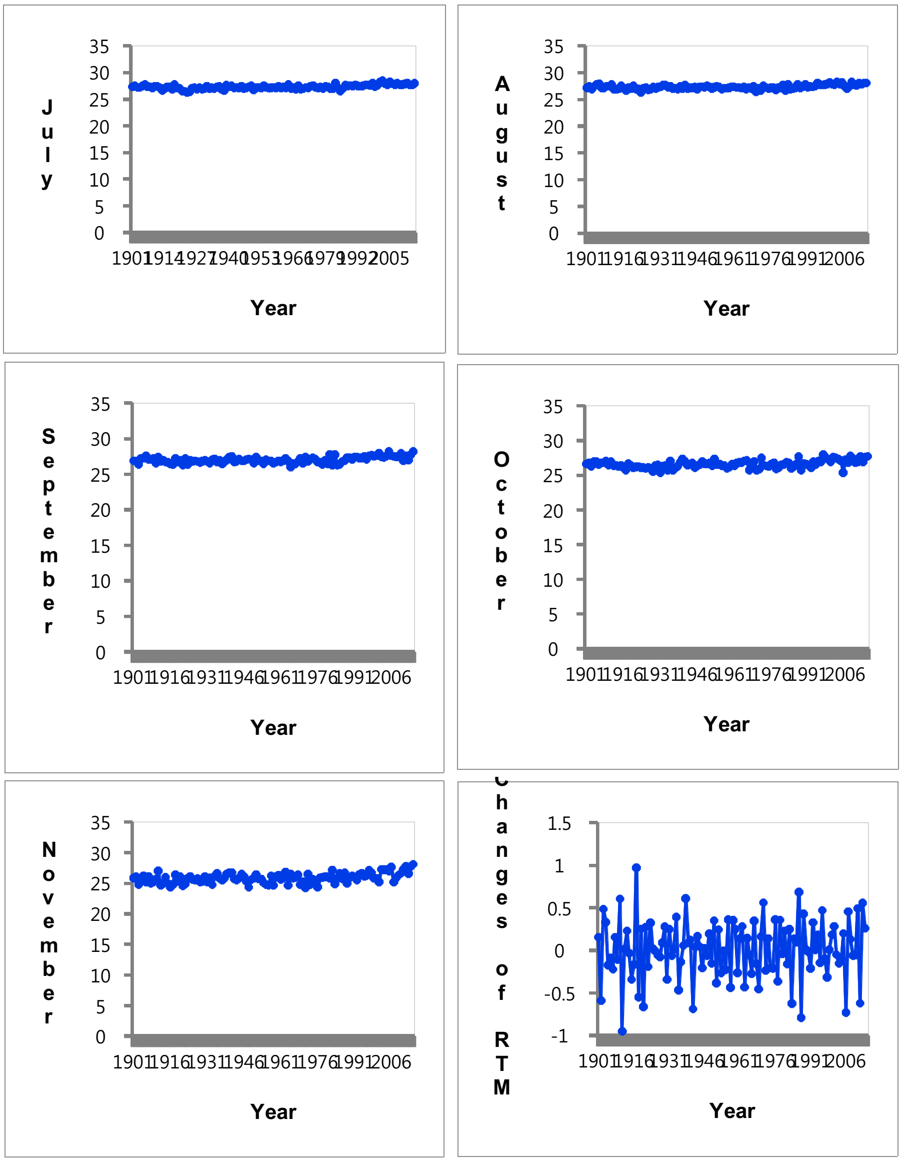
Decades	DTAs change (°C)	S.D of DTA change	DTGs change (°C)	S.D of DTGS change
1901−1910 (1st)	−0.239	0.446	−0.052	0.325
1911−1920 (2nd)	0.154	0.323	0.041	0.555
1921− 1930 (3rd)	−0.009	0.340	0.003	0.289
1931−1940 (4th)	0.338	0.407	0.411	0.323
1941−1950 (5th)	−0.354	0.419	−0.509	0.259
1951−1960 (6th)	0.176	0.207	0.239	0.326
1961−1970 (7th)	−0.329	0.316	−0.714	0.290
1971−1980 (8th)	0.487	0.346	0.527	0.312
1981−1990 (9th)	0.072	0.423	0.273	0.452
1991−2000 (10th)	0.055	0.524	0.219	0.243
2001−2010 (11th) +last 5 years	0.771	0.439	0.808	0.370

<Table 4> Changes of the temperature (°C) for each month in 115 years from 1901 to 2015 in Cambodia

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug.	Sep	Oct	Nov	Dec	Total Annual Changes	Total Growth Changes
Changes (°C)	0.25	0.20	0.20	0.33	1.65	1.65	1.10	0.83	1.31	1.12	2.25	2.90	1.121	1.247

The Mann-Kendall test confirmed that the positive trend is statistically significant for the mean of the temperature of each month of the rice growth period. The positive trends were shown to be significant at 0.05, it appears that in Figure 3 that Kendall's tau values of the five months (July to November) are 0.335, 0.275, 0.283, 0.258, 0.290 respectively, and the Kendall test reveals a positive increase with significance levels with $P<0.0001$. On the other hand, for the trend of the changes of RTM over the years, the Mann Kendall figure explained almost no changes in these changes of the temperature. The test was giving an insignificant relationship between the changes and the years, which means, in spite of increasing significantly, the temperature during the growth period, and the changes during the inter-growth period is almost stabled and insignificantly related with the years.

<Figure 3> Trends of the temperature during the months and the changes in the rice growth period (RTM) in Cambodia by Mann–Kendall test during time series between 1901 and 2015



2. Rainfall Analysis

1) Rainfall Statistics

Table 5 reveals the rainfall statistics of the monthly, seasonal, annual and Rice Growth-period. Changes of Rainfall means (mm) for 115 years from 1901 to 2015. The highest three months during the monthly means of the rainfall in descending order were, September, August, and July with a 310.346 mm, 303.984 mm, and 264.839 mm, respectively. The highest amount of rainfall matched the duration of the rice growth period especially in the first three months of the rice growth period that may attribute in increasing the

<Table 5> Rainfall statistics of the monthly, seasonal, rice growth-period rainfall mean (RRM), and year average for 115 years from 1901 to 2015 in Cambodia (mm)

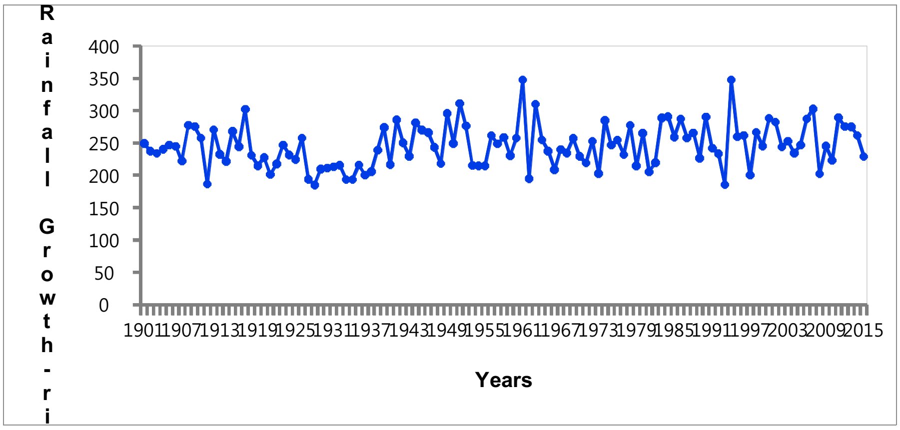
Time	Min	Max	Mean	Standard Deviation (S.D)
January	0.44	53.80	12.230	9.773
February	0.59	56.95	18.734	12.576
March	3.90	187.10	46.644	35.424
April	23.23	159.74	79.4395	29.007
May	58.29	373.57	169.882	67.795
June	127.77	786.38	247.474	74.505
July	121.82	521.47	264.839	101.164
August	113.24	513.93	303.984	79.388
September	185.59	510.45	310.346	66.228
October	101.34	580.38	244.647	90.125
November	27.60	291.72	105.005	50.021
December	9.30	185.21	12.231	27.088
Nov - Feb: Cool and dry			37.050	45.406
Mar - May: Hot and dry			98.655	63.826
June-Aug: Hot and wet			272.099	28.946
Sep - Early Nov: Cool and wet			277.496	46.456
RRM (July - Nov)	927.12	1739.19	245.764	108.733
115 Year Average	1394.41	2671.25	152.792	127.190

productivity. Additionally, the RRM is higher by 92.972 mm than the general mean of the whole period of 115 years.

2) Trend Detection

The RRM were reported to be significantly increased as (Figure 4), that in the years of investigation (1901 to 2015). Statistically, the straight line showed the linear trend of the rainfall anomalies. Trend calculations based on mean annual values of the rice growth period for 5 months (July, August, September, October, November) by the non-parametric Mann-Kendall test for trend was applied to refer to a positive significant value that indicated upward trend with Kendall's tau value = 0.157, and P-value is 0.006.

<Figure 4> Trend of the mean of rainfall in rice growth-period in Cambodia by Mann-Kendall test during time series between 1901-2015.



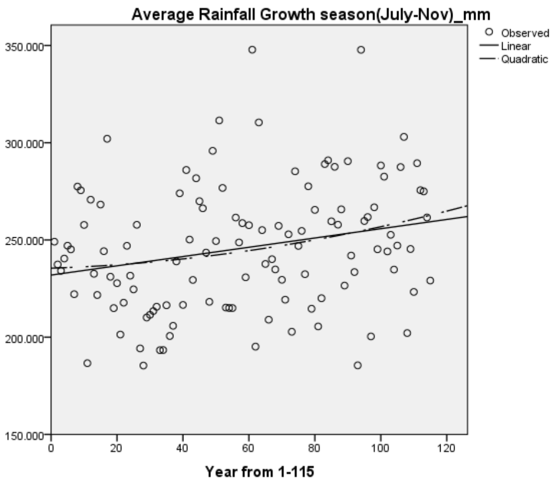
The regression model revealed that there was a significant regression between the RRS as a dependent variable and the time by years number (1-115) as an independent variable, (Table 6) with two equations of linear and quadratic regression with $R2$ = 0.566 and 0.657 that refer to very small values of R2 that means the increasing trend of the rainfall over the 115-year period. It had been expressed about this regression by two equations of linear and quadratic as (Y1=231.942+0.238X1, R2 = 0.058), and (Y2=235.487+ 0.002X1+0.002 X12, R2= 0.060), respectively. Figure (2) describes the estimation linear and quadratic curve to show that the increase of the rainfall does not show a big difference over a long time.

<Table 6> Regression analysis of rice growth-period rainfall mean (RRM) in Cambodia during 1901-2015.

Dependent Variable: Rainfall mean mm (July-Nov.), Independent variable is Year from $1^{st}-115^{th}$

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	0.058	6.944	1	114	0.010	231.942	0.238	
Quadratic	0.060	3.581	2	113	0.031	235.487	0.002	0.002

<Figure 5> The linear and quadratic regression model between the mean of the rainfall during the rice growth period (RRM) by years 1st-115th during 1901-2015



The decadal changes in the rainfall during the annual and the rice growth period as shown in table (7) is revealed that the changes that had happened for both of DARS, and DRRS fluctuated between increases and decreases trend of the changes for each decade, but the biggest lowering in the rainfall in the 11th decade with the last five years with decreases by −533.21mm and −295.93 mm in the annual and the rice growth period respectively. On the other hand, the trend of DRRS over the decades was shows decrease in the amount of rainfall.

Rainfall changes of each month in the period 1901 to 2015 table (8) reported decreases and increases, but these changes are insignificantly decreased from April until December which means that within the rice growth period, it may affect the rice production in the future if it would be assumed that the same trend of rainfall decreases in the future.

<Table 7> The changes of the decadal rainfall annual (DARs), and decadal rainfall rice−growth season (DRRs) for 115 years during 1901− 2015 in Cambodia, changes of DARs and DRRs were calculated by the average in 10−year of differences between each year and the previous value for each decade

Decades	DARs Change (mm)	S.D. of Changes of DARS (mm)	Changes of DRRs (mm)	S.D. of Changes of DRRS (mm)
1901−1910 (1st)	221.07	136.50	43.26	113.75
1911−1920 (2nd)	−410.81	249.56	−149.87	264.30
1921− 1930 (3rd)	−41.39	193.77	−81.22	148.22
1931−1940 (4th)	−26.33	150.91	25.34	138.76
1941−1950 (5th)	186.15	215.31	164.09	227.55
1951−1960 (6th)	237.73	224.68	40.88	188.20
1961−1970 (7th)	−141.11	373.50	−140.31	376.87
1971−1980 (8th)	55.51	303.69	179.75	241.76
1981−1990 (9th)	34.97	275.20	125.25	216.37
1991−2000 (10th)	207.11	396.98	−11.15	370.13
2001−2010 (11th) +last 5 years	−533.21	414.11	−295.93	198.34

<Table 8> Monthly rainfall changes for 115 years during 1901− 2015 in Cambodia

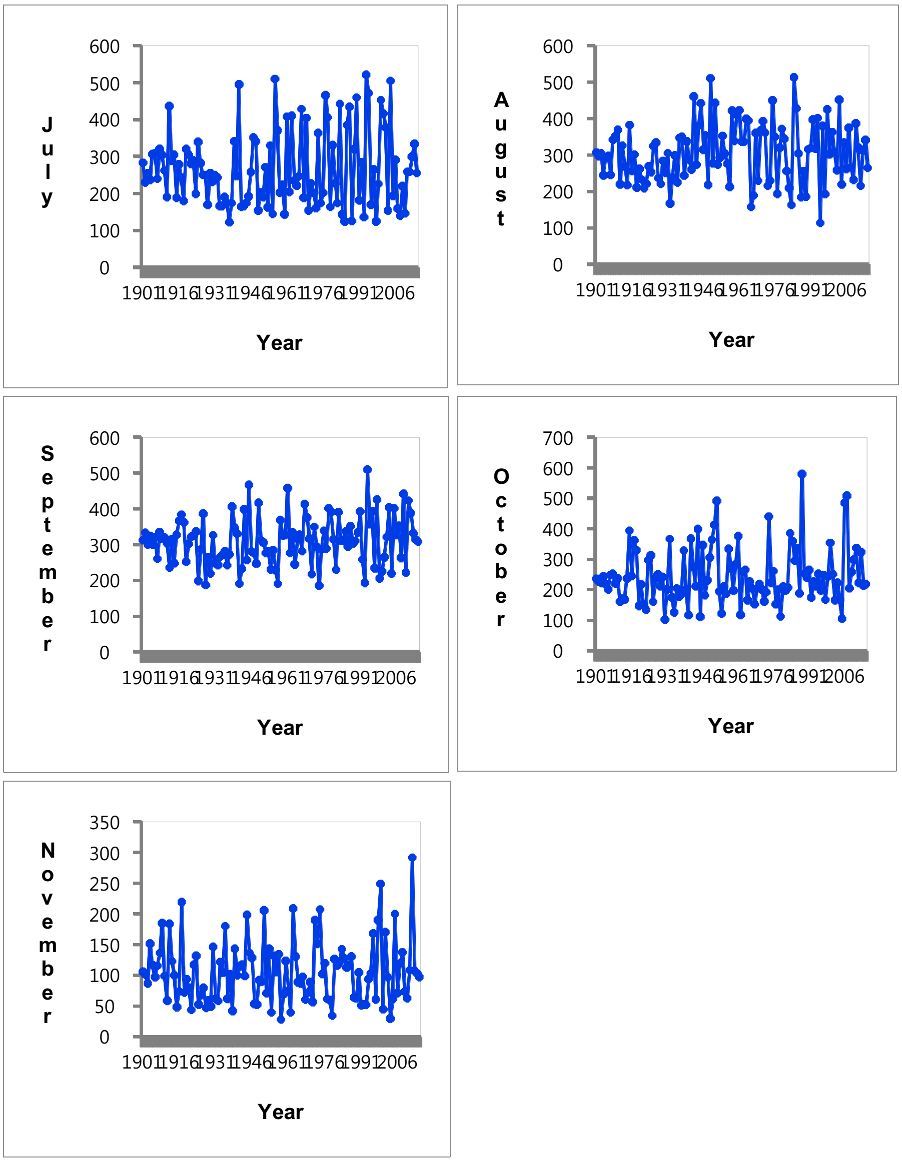
Months (1901−2015)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Rainfall change (mm)	2.34	6.128	2.20	−31.37	−71.14	−16.88	−27.57	−41.87	−3.39	−18.88	−8.21	−1.66

The Mann−Kendall test confirmed that the positive and negative trends were statistically insignificant for the mean of the rainfall of each month of the rice growth. As it is shown in the figure (6) that Kendall's tau values of the five months (July to November) are −0.029, 0.081, 0.095, 0.059, and 0.008 with p−values are 0.6, 0.1, 0.06, 0.1, and 0.4, respectively.

Independent samples t−test was conducted to compare the difference of the mean growth months rainfall from 1901−1960, and 1961−2015. Statistically significant mean difference was resulted t (−2.480; $p < .05$) at 95% level of significance. The RRM for the period 1901-1960 (Mean 238.61; S.D 29.72) was statistically lower than the RRM for the period 1961-2015 (Mean 253.57; S.D 34.91). The result revealed that rainfall has been increased since the 1960s. The rainfall anomaly also observed for the presence of inter−annual and inter−growth months variability and the trend being sometimes below the linear long−term average and sometimes above the linear long−term average (Figure 6). The rainfall anomaly for both of annual and growth months rainfall monitored and their values were located between a long range of extreme drought, severe drought, moderate, and no drought that by calculating the standardized rainfall anomaly.

The classification of the years in according to the drought index by the historical values that referred to the anomalies of rainfall revealed that the “extreme drought” years of the annual time series rainfall were the Z value of “standardized rainfall anomaly” ranges from −1.66 to −2.08 in 1932, 1933, 1934, and 1993. The “severe drought” years were 1922, 1928, 1935, 1936, 1937, 1962, and 2008, while the moderate drought had been in 1911, 1919,

<Figure 6> Trends of the rainfall during the five months of rice growth period (RRM) in Cambodia by Mann–Kendall test during time series between 1901 to 2015



1927, 1930, 1931, 1940, 1954, 1959, 1968, 1973, 1977, 1982, 1991, 1992, 1997, and 2010, then the remaining 88 years were in the "no drought" range.

On the other side, the Z values ranges for the rice growth months in the whole period were divided to "extreme drought" range was in 1911, 1928, 1993, while "severe drought" range was in 1921, 1927, 1933, 1934, 1936, 1962, 1973, 1997, 2008. The third range of "moderate drought" was in 1919, 1922, 1929, 1930, 1931, 1932, 1935, 1937, 1940, 1953, 1954, 1955, 1966, 1975, and 1981. The remaining 88 years were in the "no drought" range.

3. Rice Productivity Analysis

1) Rice Productivity Statistics

The mean, standard deviation (S.D), standard error (S.E), and coefficient of variance (C.V) have been statistically calculated of the rice productivity (ton/hectare) and the changes for the productivity computed for each decade of five decades between (1961 to 2015) and for the last five years (2011 to 2015). These data are given in Table 9, the general mean of the rice productivity and its standard deviation values are 1.485, and 0.606 respectively. It is clear from the table that the mean rice productivity was higher in the last decade and last 5 years to be 2.435 ton/h, but it has been decreased just in one decade within the 2nd decade by 0.052 ton/h. Additionally, coefficient of variation values were high within four decades are ordered downward the following, the second, the fourth, the fifth, and the first decade with values, 18.787%, 17.161%, 16.956%, and 16.243% respectively. These values express that there were big changes of the rice productivity in these mentioned decades from year to year, that which may have been affected by the climatic condition or by some production conditions.

The changes values of the rice productivity for each decade is giving a real calculation for the real state of the productivity over time. The highest two decades were the fifth plus last five years and the first decades in their changes of the increase of the productivity by increases with 0.880 and 0.500 ton per hectare, respectively.

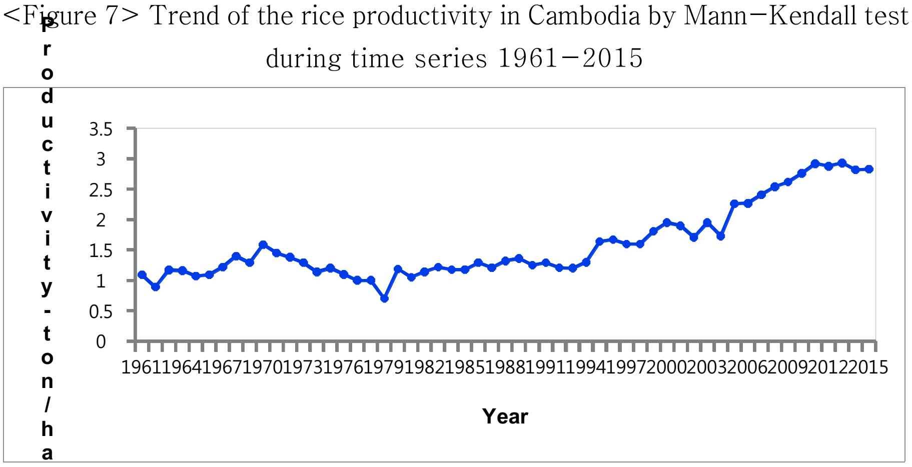
<Table 9> Statistics of the rice productivity (ton/per ha) in the period extended for 55 years (1961 to 2015) for each decade

Decades	Mean	S.D	S.E	C.V (%)	Productivity Changes (ton/ha)	S.D Changes (ton/ha)	S.E Changes (ton/ha)
1961−1970 (1st)	1.197	0.194	0.062	16.243	0.500	0.177	0.056
1971−1980 (2nd)	1.145	0.215	0.068	18.787	−0.400	0.209	0.066
1981−1990 (3rd)	1.220	0.091	0.029	7.432	0.060	0.171	0.054
1991−2000 (4th)	1.527	0.262	0.083	17.161	0.280	0.131	0.041
2001−2015 (5th)	2.435	0.442	0.140	18.152	0.880	0.217	0.069
55−year period	1.485	0.606	0.082	38.132	1.32	0.165	0.022

2) Trend Detection

The rice productivity trend during the time series between 1961 and 2015 were reported to be statistically significant increased as in (Figure 3). The straight line showed the linear trend of the productivity anomalies. The trend was computed based on annual values of the rice productivity the Mann−Kendall test for measuring the trend that was applied to refer to a positive significant value that had been indicated an upward trend with Kendall's tau value = 0.669, and P−value is less than 0.0001. It was observed through the graph that there was a decreasing trend in the productivity from 1970 to 2000 that almost thirty years of decreases that less than the average linear trend. On the other hand, it had been tested the trend by Mann−Kendall test between the decadal rice productivity changes and the time series that were revealed an insignificant increase in the productivity.

<Figure 7> Trend of the rice productivity in Cambodia by Mann-Kendall test during time series 1961-2015



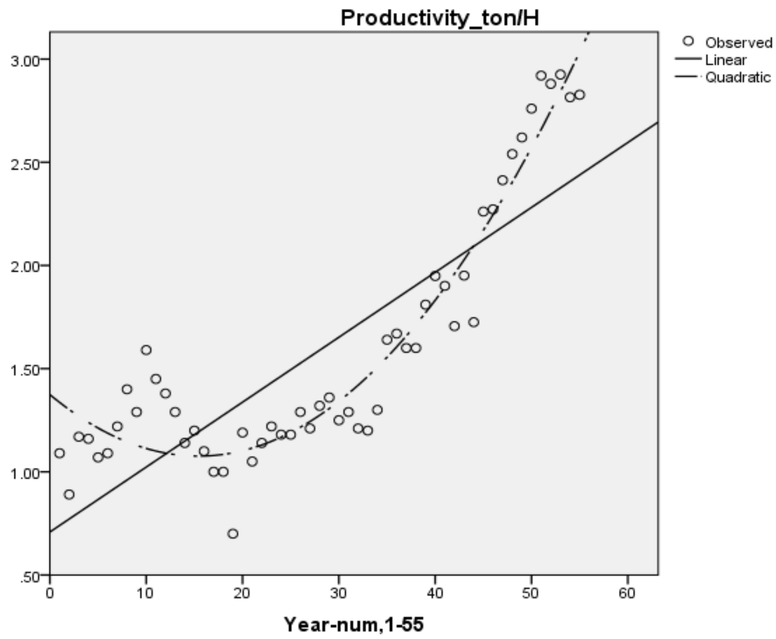
The regression model showed that there was a significant relationship between the rice productivity as a dependent variable and the time by number of years (1-55) as an independent variable as mentioned in (Table 10) with two equations of linear and quadratic regression with R2 = 0.692 and 0.913 with two equations as (Y1=0.708+0.031X1), and (Y2=1.374-0.039X1+ 0.001 X12) respectively. Those two equations were used to predict the rice productivity in the future, in addition to Figure (8) that describes the estimation linear and quadratic curve to show the increase of the productivity over the time.

<Table 10> Regression analysis of the rice productivity in Cambodia during 1961-2015

Dependent Variable: Rice Productivity (ton/ha), Independent variable is year from 1st-55th

Equation	Model summary					Parameter estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Linear	0.692	119.277	1	54	0.000	0.708	0.031	
Quadratic	0.913	272.491	2	53	0.000	1.374	-0.039	0.001

<Figure 8> The linear and quadratic regression model between the Rice Productivity in Cambodia and the time by years 1st−55th during 1961−2015



4. Correlation and Regression

The results of the linear simple regression between the rice productivity, average temperature during rice growth season, and average rainfall during rice growth season listed in Table 11. At the 0.05 level, it was observed that the rice productivity, and average temperature during the growth season significantly correlated at 0.69 on the other side. It was observed that the correlation was insignificant between the rice productivity and the average rainfall during growth season correlated at 0.09. The R2 of the model is equal 0.48 by the enter method was found that the temperature has a significant relationship with the rice productivity in a positive direction but with the rainfall revealed an insignificant relationship with the rice productivity.

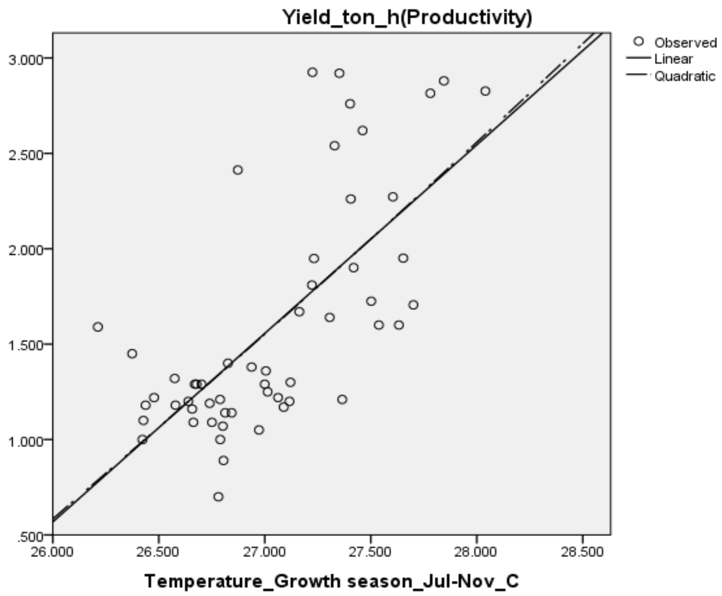
Due to the results, it was so clear that positive relationship between the temperature RTM and the rice productivity, that was logically interpreting by the minimum and maximum of the temperature during 55 years during the rice growth period was 26 and 28 °C respectively. This range of degrees is a perfect condition for the whole life cycle of rice especially during its sensitive stages of heading and flowering so the rice productivity didn't decrease, but it was increased by that suitable climatic condition in addition to other factors like fertilizer amount that had a positive significant correlation and regression with the rice productivity. Additionally, there were many non-climatic factors that may affect the rice productivity e.g. the dates of sowing, varieties, pesticides, irrigation and drainage system, machinery using etc. In the same context, the expected trend of the temperature would be increasing in the future that may affect the productivity, in addition to the expected trend of the rainfall especially in RRM that may change to be decreased in the future as an effect of climate change that may cause lowering in rice productivity in the future.

<Table 11> Model summary and parameter estimates of the rice productivity, RTM, and RRM from 1961-2015

Independent Variable	Unstandardized Values		t-Value	P-Value
	B	S.E		
Constant	-25.473	3.861	-6.597	0.001
Temperature °C	0.987	0.142	6.945	0.001
Rainfall (mm)	0.002	0.002	0.882	0.382
R^2	0.486			
F-Value	24.581			0.001

Dependent Variable: Rice Productivity (ton/ha)

<Figure 9> Regression model between the rice productivity and RTM in Cambodia during 1961-2015



5. Discussion and Conclusion

In this study we used the methodology of the historical long-term analysis of the temperature and rainfall in addition to the rice productivity to find out the trend of the temperature, rainfall, and rice productivity during the time series. We also used it to figure out if there were any significant correlation and regression between each one of them and the time series by some statistical techniques e.g. Mann Kendall, regression, and graphs. The results revealed that the temperature ranges were in the ideal ranges for the rice crop growth, especially in its first life cycle and in the flowering and heading stages in September and October which was recorded as mean of temperature during the Rice inter-Growth-period in July, August, September, October, November, and was 27.340, 27.358, 27.047, 26.621, and 25.893, respectively. On the other hand, the results of the annual averages of the temperature reported a significant increase trend. In the investigated period of years 1901 to 2015, the results gave a foresight of more temperature increases in the future that had been confirmed by climate change scenarios. This requires readiness for further efforts in Cambodia regarding the rice adaptation options program, in according to the correlation and regression estimation which showed significant relationships between the temperature and the rice productivity. It was interpreted as the temperature ranges were in the suitable ranges for the rice growth to give a higher productivity. Concerning the results of rainfall trend, it revealed positive significant value that indicated upward trend of rainfall by time. Additionally, there were decadal increases and decreases changes and anomalies values of rainfall. The highest decreases were in the last decade and last five years by −295.9 mm in the rice growth period, which may affect the rice production in the future if it would be assumed the same trend of rainfall decreases changes in the future. There was an insignificant correlation between the rainfall and the rice productivity. For the rice productivity trend results, it revealed a significant increase trend by time, but regarding the result of the trend of the changes as increases and decreases of rice productivity by time, it revealed an insignificant correlation, which may be interpreted as rice productivity in Cambodia was increasing at a decreasing rate.

Ⅳ. Suggested Integrated Agricultural Extension Program

The extension program is an all−inclusive set of activities designed with a target client base in mind that focuses on the continuous education and development of clients. The educational component is meant to generate specific outcomes for the client base. These programs are usually made available to farmers by government extension service providers or other private consultants as a way to increase their farming knowledge and production potential. This knowledge can be shared through informative lecture, workshops, presentations, training program and field days (GFRAS, 2012).

Based on the recent needs and problems related to the rice production and climate change in Cambodia, in accordance to the results of this study and in addition to the observed problems that related to the rice smallholder farmers in Cambodia, it could be summarized as the following:

1. Lowering in the rice productivity compared with the global ranges in the highest yield countries from 6 to 10 ton/ha (Ricepedia, 2018) and the highest rice yield 2.4 ton/ha in Cambodia was in the last decade of our investigation research period.
2. The traditional practice was applied in all stages of rice cultivation.
3. Irrigation and drainage facilities have not been applied on the rice farming system.
4. Lack of knowledge and skills of the farmers' practices concerned the appropriate rice cultivation methods.
5. Single culture practice once a year results on rice production and farms' income.
6. Insufficiency of rice storage and processing facilities for smallholder farmers.
7. Absence of rice breeding research programs for heat and drought-tolerance varieties.
8. Lack of the empirical studies on farmers' perception level of the climate change impacts and how to adapt with climate change.

<Table 12> Suggested integrated agricultural extension program to develop rice production in Cambodia

Developmental and Learning Objectives	Implementers	Extension Methods	Extension Aids	Place of Implementation	Time	Expected Feedback
1. To investigate the recent situation of the rice farmers by conducting the following studies: - Measurement of perception concerning climate change and sustainability concept - Measurement of knowledge level of climate change adaptation options - Measurement of attitude towards adoption of heat and drought tolerant varieties	- Researchers - Rice crop specialists	- Social survey - Discussion groups - Brain storming	- Questionnaire - Question index (for discussion groups& brain storming)	-Rice cultivation villages	-As soon as possible	Future training programs for rice farmers with the following goals: - To raise the perception and awareness level for the climate change impacts on the rice cultivation and productivity and how they would be facing in the future in according to the climate change scenarios. - Change the negative attitudes regarding to adopt the new varieties. - The farm practical schools. - Promote the sustainability concept.

2. To build training programs to improve: − the knowledge, skills level and change the attitudes of the rice farmers to raise their awareness and perception. − To increase their recent and future productivity due to the sustainability rules.	− Professors − Researchers − Specialists	− Lectures − Field (harvest day practical explanation) − Mindset change programs	− Videos − Photos − Real successful stories of pioneer farmers	− Research Centers − Universities − Visiting the pioneer farmers' farm − Public media	− After finding out the results of studying the recent situation	− Rice farmers would be conscious farmers regarding the climate change and its impacts on the rice productivity. − To increase their knowledge about the adaptation options to face climate change impacts. − To be aware practically with the sustainability concept as a life style generally and for their rice cultivation activities specially.
3. Establishment of the farmers' associations (unions).	− Farmers' self−help − Government − Private sector	− Conferences − National meetings between rice farmers leaders (representatives) with government officials, and	− Magazines − Posters − Info−graphics − Newspapers to declare about important events	− In the central villages − Public media	− After finishing the perception and awareness training programs	By the fund of these farmers' unions would be: − Providing the agricultural technology as farmers' properties e.g. machinery, and tractors to save the money, efforts,

		entrepreneurs	− Incentives for participation			and time. − Providing the production supplies, and to unify the whole efforts to solve the problems and crisis.
4. Establishment irrigation and drainage systems.	− Private sector − Government − Farmers' Unions	− Symposiums − Rural leaders to be a practical pacemaker for all farmers −Personal communication − TV	− Videos − Practical activities and work	− Rice villages − Public media	− After doing a feasibility study and inventory for the available resources	− Increasing the rice productivity − Possibility of recycling for the drainage water to use it again in the dry season − To solve the problem of the changes of rainfall − To adapt to the expected drought that may happen
5. Promote the farmers' awareness to cultivate the rice crop two seasons a year instead of one season.	− Specialists − Pioneer − Farmers − Rural leaders − Private sector	− Field schools − lectures − TV − Radio, − Newspaper − Internet	− Posters − Videos − Photos − Diagrams − Info− graphics	− Public places and media − In the farms	− After training program of the perfect practices of rice cultivation − After	− To increase the rice production during the year, and then increase their income by export their production

					recycling the drainage water.	
6. Establishment stores and research centers as the following: - Establishment healthy and appropriate rice stores, with purifying and packing system. - To develop new varieties to be adapted for the climate change impacts in the future and giving higher yield by breeding programs hence achieving the sustainability for their rice productivity to be higher.	- Government - Private sector - self-help and farmers' diligences - Researchers	- Lectures - Symposiums meetings - Practical training programs - Diffusion programs for the new varieties to be adoptable - Farm schools (practical explanation)	- Videos - Photos - Posters - Info-graphics - Machines of packing and purifying - Research farms - Laboratories of breeding programs	- Rice Experimental research farms - Public media	- Before the harvest time - After the breeding program and experiment phase	- To reduce the rice losses - To keep appropriate prices - Achieve higher profits - Increase the productivity and the production (by cultivating it two times a year) - Improving the sustainable rice production.

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■□□□□□ 국문초록

캄보디아의 지속적 쌀생산을 목표로 한 통합적 농업extension 프로그램을 구축하기 위한 기후변화 분석

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전 세계적으로 온도와 강우량의 기후 요인 변동은 강우에 의지하는 농업 시스템에 영향을 미치는 주요한 원인 중 하나이다. 이 연구는 캄보디아의1901 년부터 2014 년까지의 장기간의 자료를 바탕으로 벼 생산성 (단위면적당 생산량)에 미치는 평균 온도와 강우량 변화 의 영향을 연구 분석하였다. 또한 1961 년부터 2015 년까지의 벼 생산성 자료를 분석하기 위해 기후 변화의 관점에서 시간을 계량 변수화하였다. 이 연구는 주로 온도, 강수량 및 쌀 생산성의 시계열 데이터를 탐색, 기술 및 분석하는 것을 목표로 하였는데, 예측 변수로서 기온과 강수량 간의 상관 관계와 쌀 생산성을 종속 변수로 회귀 분석을 실시 하였다. 시계열 분석 결과에 따르면 1901 년부터 2015 년까지 11 월까지 조사 된 115 년 동안의 쌀 성장계절 평균기온 (RTM)과 쌀 성장계절 강우평균 (RRM)은 시간에 따라 증가하는 유의 한 상관관계가 있었다. 쌀 생산성은 1961년 ~ 2015 년 (55 년간) 시간에 따라 증가하는 같은 경향을 보였는데, RTM이 쌀 생산량에 유의 한 양의 회귀를 보인 반면 RRM은 55 년 자료에서 쌀 생산성과 유의 한 상관 관계가 없었다. 이러한 장기적인 기후 변화 분석에 기초한 분석 결과를 바탕으로 캄보디아 농민의 지속 가능한 쌀 생산을 위한 종합적 농업기술계획 (Integrated Agricultural Extension Programmer)이 이집트와 한국 농업 기술센터 (Agricultural Extension Research Institute)의 경험을 바탕으로 본 연구에서 제안되었다.

[주제어: 캄보디아, 기후변화, 지속적 쌀 생산, 쌀 수확성, 종합적 농업기술프로그램]

논문접수일: 2019년 1월 18일
논문수정일: 1차: 2019년 3월 5일 / 2차: 2019년 월 일
게재확정일: 2019년 8월 27일

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