Temporal Analysis of Rice Yield and Climatic Trends in Pakistan

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Abstract: Climate in its spatial and temporal inconsistency is one of the chief causes for determining agricultural productivity in a region. Climatic impacts should be kept into mind while developing long term agricultural policies. This study aimed at investigating the change in rice production in Pakistan from 1989-2009 using the GIS techniques and the impacts of climate change on rice production. Pakistan is very rich in the production of rice and a lot of foreign exchange is earned through exporting rice. The results showed that rice production increased in Pakistan in all the four provinces of Pakistan. The highest percentage increase was observed in Punjab. However, when the country faced a drought after 2000, the production in KPK and Sindh was decreased which again attained its increasing level in the following years. The correlation of climatic variables with rice production variables indicated a significant relation and the regression analysis revealed that high level of variance in rice production could be explained by climatic parameters under study. This aspect could be linked with some other possible best options to increase the rice production to a higher level in order to ensure sustainable rice production.

Key words: Pakistan • Climate Change • Rice Production • GIS

INTRODUCTION

Climate Change is chiefly caused by different economic actions called as an externality and many developing countries are located at such geographical position that they are most susceptible to climate change. The IPCC predicted that if there is no strategy to decrease the emissions of GHG’s, then they can increase from 550 ppm to 700 ppm at the middle of this present century and due to this, the temperature can increase from 3°C to 6°C [1]. The effects of climate change can appear in the form of recurrent floods, drought and famine, shortage of food, non supporting weather events, newly discovered diseases, rise of sea level and many other factors [2].

The most exposed and susceptible sector to climate change is evidently, agriculture. A number of factors associated with climate change like the precipitation pattern, change in temperature etc. greatly impacts agriculture which includes reduction in agricultural productivity and the growth time for different crops are also restricted [3]. Every country is fretful about the costs and profits that may arise in the future from the effects of climate change, regionally as well as globally. It has been confirmed that when there is no climate change, the crops would react positively to increased CO₂ concentration while when it is coupled with elevated temperatures, variability in precipitation patterns and the likelihood of increased occurrence of severe events like drought and floods, then all these factors merged together will decrease yields and will raise the risks of production in many areas of the world [4].

Pakistan resides in the South Asian section between 24-37°N of latitude and 61-76°E of longitude. The most significant area of Pakistan’s economy is agriculture, accountable for providing income to 70% of the inhabitants which are directly or indirectly associated with agriculture. The population of Pakistan is approximately 160 million out of which 32% people are existing under the poverty level and they have to face many grave challenges [6]. Due to indirect effect of diminishing crop’s yields, the susceptibility of the poor to food insecurity will particularly increase. During the present decade, the strength and occurrence of intense climate events have increased in Pakistan. The geographical setting and socio-
economic setup of Pakistan is the main reason behind climate change. It is the country which has been ranked as the 12th most country, which is prone to the consequences of climate change.

Rice is the staple food for more than half of the present world population. South and South East Asia are the biggest consumers of rice and they are going to require a 2.5% yearly increase in the production of rice. The positive weather and environmental conditions should be there for constant increase in rice production whereas; unfavorable conditions could put the food security of world in danger. Rice is the second main food crop in Pakistan and 6% of daily ingestion of calories is attributed to rice. It is very important for Pakistan from export point of view and Pakistan has been very good in exporting aromatic Basmati rice [7].

Climate impact on rice production can be estimated more precisely in large areas by new concepts that have been evolved with different processes of GIS, GPS (Global Positioning System) and Remote Sensing (RS) and in this way spatial databases can be produced which can help the policy formers to calculate the important crop yields more precisely [8]. Different studies have been done by using the above concept and estimating the impact of climate change on agriculture by integrating GIS with other models.

Zhai and Zhuang [9] conducted a study on the region of South East Asia to examine the economic losses due to climate change impact by using GCE (Goddard Cumulus Ensemble) model. Jansen [10] used significant data of weather from seven areas of Eastern Asia to investigate the effect of climate change on the rice production. Leemans and Solomon [11] used a plain model on the basis of temperature, sunlight and precipitation data in a GIS background to predict the effect of these climatic variables on various crop’s production at a global scale. Jintrawet and Sringam [12] did a study in Thailand using Decision Support Systems (DSS) approach for the evaluation of large scale crop yields and provincial level production using ArcGIS software. Park and Ko [13] used ArcView software to recognize a spatial variation among different counties of Korea to determine a major reason between high yield area and low yield area in rice production. Olabode et al. [14] stressed on the application of Crop Information System (CIS) using different GIS techniques for sustainable rice yield in Kwara State, Nigeria.

The present study involved the study of rice production patterns in Pakistan and relationship between environmental data of the region, pertaining to climate change and its consequent effect on rice production during the last two decades i.e. 1989 to 2009. The objectives of the study were i) to monitor the production patterns of rice in Pakistan from 1989-2009 ii) detection of change in rice production in Pakistan through map construction and visualization iii) to develop a correlation between change in production and climate changing parameters for the purpose of informing policy makers.

MATERIALS AND METHODS

The data product required for the study included general Pakistan map that was obtained from Survey of Pakistan (1: 50,000). There were two types of data base. Thematic map or base map was prepared using general Pakistan map on 1:50,000 scale employing the tools of ArcGIS. The map was scanned up to the resolution that made all the important features clear and vivid. It was then geo referenced by using the WGS 1984 coordinate system. Attributed data was of secondary source data which was collected through published literatures, reports, online resource, libraries and through other concerned organizations and departments mainly from Ministry of Environment, Pakistan Meteorological Department and Federal Bureau of Statistics. ArcGIS 9.2 software was used to represent the change in production in various regions of Pakistan. The spatial and attribute data base were then integrated through ArcGIS. The Chloropleth maps were developed to visually display the change in rice production in Pakistan during the analysis period of 1989 to 2009. Then correlation and regression analyses were both employed to analyze the data to establish a relationship between climatic data and crop yield; and also, to show the percentage contribution of the variables in crop yield.

RESULTS

The main objective of this study was to monitor the change in rice production in various provinces of Pakistan. GIS tools mainly Arc Map has been adopted. The maps were generated based upon the data derived from different sources, depicting annual change during the last two decades (1989 to 2009).

Rice Production: Rice production in Pakistan holds an extremely important position in agriculture and the national economy. Pakistan is the world's fourth largest producer of rice, after China, India and Indonesia.
Table 1: The Province wise Rice Production in Pakistan

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab</td>
<td>1482.2</td>
<td>1684</td>
<td>2481</td>
<td>2980.3</td>
<td>3643</td>
</tr>
<tr>
<td>KPK</td>
<td>114.6</td>
<td>118.2</td>
<td>129.2</td>
<td>123.2</td>
<td>128.2</td>
</tr>
<tr>
<td>Sindh</td>
<td>1340</td>
<td>1406.7</td>
<td>2123</td>
<td>1499.6</td>
<td>2537.1</td>
</tr>
<tr>
<td>Baluchistan</td>
<td>283.3</td>
<td>237.6</td>
<td>422.4</td>
<td>421.6</td>
<td>643.7</td>
</tr>
<tr>
<td>Pakistan</td>
<td>3220.1</td>
<td>3446.5</td>
<td>5155.6</td>
<td>5024.7</td>
<td>6952</td>
</tr>
</tbody>
</table>

Table 2: Total Rice Production in Pakistan in 1989 and 2009 and Annual change (%)

<table>
<thead>
<tr>
<th>Province/Territory</th>
<th>1989</th>
<th>2009</th>
<th>20 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab</td>
<td>1482.2</td>
<td>3643</td>
<td>7.29 (+)</td>
</tr>
<tr>
<td>KPK</td>
<td>114.6</td>
<td>128.2</td>
<td>0.59 (+)</td>
</tr>
<tr>
<td>Sindh</td>
<td>1340</td>
<td>2537.1</td>
<td>4.47 (+)</td>
</tr>
<tr>
<td>Baluchistan</td>
<td>283.3</td>
<td>643.7</td>
<td>6.36 (+)</td>
</tr>
<tr>
<td>Pakistan</td>
<td>3220.1</td>
<td>6952</td>
<td>5.79 (+)</td>
</tr>
</tbody>
</table>

Each year, it produces an average of 6 million tonnes and together with the rest of the Indian subcontinent, the country is responsible for supplying 30% of the world's paddy rice output. The province wise distribution of total rice production in Pakistan during the analysis period is tabulated in Table 1.

Pakistan enjoys a near monopoly status in the export of fine aromatic Basmati rice which fetches a price three to four times that of the normal coarse varieties in the international markets [15]. There was a quantum jump in the rice production in sixties due to large scale adoption of high yielding semi-dwarf varieties. Since then there is marginal increase in the production. After 2000, a severe drought occurred due to which the production was more affected in KPK and Sindh but the momentum was attained in the following years. In order to assess the change in rice production in Pakistan during the last two decades, production maps of 1989 and 2009 were generated for inter comparisons which are shown in Figure 1.

The comparison of rice production in years 1989 and 2009 showed that the total production of rice was increased by 5.79% per year (Table 2). All the provinces observed an increment in total rice production but the maximum increase was observed in Punjab while minimum was observed in KPK.

In this study, the production area and the consumption patterns in this time period were also assessed. Nearly 2.8 million hectares or 11% of Pakistan’s total agricultural area is planted with rice [16]. Area under rice more than doubled from 1948 to 1978 and since then it has remained stable at around 2 million hectares. During 1949-85, rice area has increased at about 2% per annum. On overall basis, rice area increased from 790 thousand hectares in 1947-48 to 2107 thousand hectares in 1989-90 indicating 163.54% increase over the 44 years period. The production area and consumption trends in the study period are shown in Figure 2 and 3.
The Figure 2 shows that in Punjab, Sindh and Baluchistan, the production area was increased from 1281.6, 655.3 and 108.2 thousand hectares in 1989 to 1977.7, 733.5 and 190.1 thousand hectares in 2009 respectively. Only KPK faced reduction in total production area from 61.8 to 61.3 thousand hectares.

According to Qureshi et al. [15] about 92% of Pakistan's rice production is concentrated in the Punjab and Sindh provinces and nearly all the rice is grown on irrigated land. Punjab is the leading rice growing province with about 61% rice area and concentrates on Basmati-rice for export, while Sind produces high yielding varieties and traditional varieties mostly for domestic consumption covering about 31% of total rice area. Of the remaining 8% area under rice, 5% lies in the North-West Frontier and 3% in the Baluchistan provinces, respectively. On the whole, Basmati-rice accounts for about 52% of the total rice area.

The Figure 3 shows that the rice consumption in different provinces of Pakistan which mostly followed an increasing trend due to population increase and this consumption was again dominated by the province of Punjab. About 60% of the crop is destined for local consumption and the remainder exported. The consumption demand for rice at present, forms more than half of the production of rice and it was on average 52% of the rice production [17].

DISCUSSION

Climate is an important factor of agricultural productivity. Climate change is caused by the release of greenhouse gases into the atmosphere. These gases accumulate in the atmosphere, which results in global warming. However, the reliability of the predictions on climate change is uncertain and no firm timescales are known about the result of increase in the concentration of...
greenhouse gases within the atmosphere [18]. The climate change effects on agriculture will differ across the world. Changes in temperature as well as changes in rainfall patterns and the increase in CO₂ levels projected to accompany climate change will have important effects on global agriculture, especially in the tropical regions. The suitable land areas for cultivation of key staple crops could undergo geographic shifts in response to climate change.

Generally, there are many factors influencing crop production and these include soil, relief, climate and diseases among others. In relation to climate, rainfall is the dominant controlling variable in tropical agriculture since it supplies soil moisture for crops and grasses for animals. According to Ayoade [19], agriculture largely depends on climate to function. Hence, precipitation, wind, temperature, relative humidity and other climatic parameters affect and solely determine the global distribution of crops and livestock as well as their productivity. Kurukulasuriya and Rosenthal [20] described the four ways in which climate affect agricultural production; changes in temperature and precipitation directly affect crop production and can even alter the distribution of agro-ecological zones; increased CO₂ is expected to have a positive effect on agricultural production due to greater water use efficiency and higher rates of plant photosynthesis. On the other hand, agricultural losses can result from climate variability and the increased frequency of changes in temperatures and precipitation including floods and droughts. Similarly, according to El-Marsafawy et al. [21] and Edeh et al. [22] climate variability and change have a direct, often adverse, effect on the quantity and quality of agricultural production like rice.

The present study was concerned with the determination of effect of climate on the production of rice in Pakistan so following climatic variables were selected i.e., Temperature (°C), Humidity (%), Precipitation (mm) and wind Speed (knots per hour). The change in these variables in different provinces of Pakistan during the study period is shown in Figure 4.

These climatic variables were linked with rice variables through the correlation and regression analysis of the four provinces separately which are given in Table 3 and Table 4 respectively.
Table 3: Pearson Correlation Analysis of Rice Production in relation to climatic variables

<table>
<thead>
<tr>
<th>Province</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Wind Speed</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab</td>
<td>.839</td>
<td>-.948**</td>
<td>.889**</td>
<td>-.866*</td>
</tr>
<tr>
<td></td>
<td>.038</td>
<td>.007</td>
<td>.022</td>
<td>.029</td>
</tr>
<tr>
<td>KPK</td>
<td>.810</td>
<td>-.844*</td>
<td>.919**</td>
<td>-.962**</td>
</tr>
<tr>
<td></td>
<td>.048</td>
<td>.036</td>
<td>.014</td>
<td>.004</td>
</tr>
<tr>
<td>Sindh</td>
<td>.998**</td>
<td>-.914**</td>
<td>.284</td>
<td>-.910**</td>
</tr>
<tr>
<td></td>
<td>.000</td>
<td>.015</td>
<td>.321</td>
<td>.016</td>
</tr>
<tr>
<td>Baluchistan</td>
<td>.928**</td>
<td>.266</td>
<td>-.580</td>
<td>-.864*</td>
</tr>
<tr>
<td></td>
<td>.012</td>
<td>.333</td>
<td>.153</td>
<td>.029</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (1-tailed)
*Correlation is significant at the 0.05 level (1-tailed)

Table 4: Regression Analysis for Rice Production and Climatic Variables

<table>
<thead>
<tr>
<th>Province</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab</td>
<td>0.952*</td>
<td>0.906</td>
<td>0.624</td>
<td>5.51</td>
</tr>
<tr>
<td>KPK</td>
<td>0.983*</td>
<td>0.967</td>
<td>0.867</td>
<td>2.30</td>
</tr>
<tr>
<td>Sindh</td>
<td>0.847*</td>
<td>0.717</td>
<td>0.313</td>
<td>5.58</td>
</tr>
<tr>
<td>Baluchistan</td>
<td>0.985*</td>
<td>0.970</td>
<td>0.881</td>
<td>5.46</td>
</tr>
</tbody>
</table>

*Predictors: (Constant), Wind Speed, Temperature, Humidity, Precipitation

Temperature regime greatly influences not only the growth duration but also the growth pattern of the rice plant. During the growing season, the mean temperature and the temperature sum, range, distribution pattern, or diurnal changes or a combination of these may be highly correlated with the grain yields [23]. As the temperature remained in optimum range for all the different stages of growth of rice production during the study period, there was an increase in production of rice and it was positively and significantly correlated.

The effects of relative humidity are generally confused with the effects of solar energy and temperature. The average relative humidity before harvest follows a trend opposite that of the solar radiation values of the same period. Therefore, no importance is attributed to the high negative correlation between relative humidity and grain yield. However, a long dew period often causes increased incidence of blast disease in rice. In such cases, the effects of high relative humidity are often confounded by the night temperature regime, which causes a long dew period [24]. The present study demonstrated that the rice production or yield was negatively and significantly correlated with relative humidity. The reason could be attributed to the fact which has been mentioned above that if the dew period prevails for a longer period of time, then it can cause blast disease in rice due to which the production could be reduced.

A gentle wind during the growing period of the rice plant is known to improve grain yields, because it increases turbulence in the canopy. The air blown around the plants replenishes the CO₂ supply of the plant [25]. On the other hand strong winds often desiccate the panicles of the rice crop, increasing floret sterility and sometimes increasing the number of abortive endosperms. Strong winds also enhance the spread of bacterial leaf diseases of rice [25]. Dry winds have also been known to cause desiccation of dry leaves. Wind can also cause mechanical damage to leaves [26]. In the present study it was observed that wind was positively and significantly correlated with rice production in Punjab and KPK while in Sindh it showed no significant relationship. However, in Baluchistan this relationship was negative, which might be attributed to the intensity of wind but this relationship was not found to be significant.

Variability in amount and distribution of rainfall is the most important factor limiting yields of rain fed rice [27], which constitutes about 80% of the rice grown in South and Southeast Asia. Annually, 2000 mm of rainfall is adequate for one rice crop provided rainfall distribution is reasonably uniform. Pakistan often gets inadequate or
excessive rainfall during the rainy season. As a result, drought or flood, or sometimes both cause excessive damage to rain fed rice production. So, Pakistan grows rice primarily with irrigation due to which the production is increased. Therefore, the observed relationship with rainfall/precipitation was significantly negative.

A few similar studies have been conducted all over the world which studied the effect of climatic variables on the crop yield. Ajewole and Iyanda [28] studied the effect of climate change on cocoa yield with the use of correlation analysis and concluded that optimal temperature and minimal rainfall would give better yield of cocoa in Nigeria. Olanrewaju [29] studied the effect of relative humidity on different crops in Edu/Lafiaji and he found that crops like groundnut, millet, sorghum and rice were negatively correlated with relative humidity. Similar results were obtained by Tunde et al. [30], when the effect of climatic variables like temperature, relative humidity and rainfall on crop production in Nigeria was studied.

The regression analysis computed for the crop production and climatic variables revealed that the rice production have coefficient of determination of 0.91, 0.97, 0.71 and 0.97 for Punjab, KPK, Sindh and Baluchistan respectively. This indicates that 91, 97, 71 and 97% of the variance in rice production can be explained by the climatic parameters under study (Table 4). The implication is that 7, 3, 29 and 3% of the variance in rice production can be respectively explained by other factors not included in the study. Climatic variables therefore, have impact on selected crop yield over the years under study. The study has actually revealed that other factors, such as solar radiation, type of soil, soil fertility and farm methods may also be responsible for crop yield. Tunde et al. [30] observed the 76% of the variance in rice production.

In the present study the change in productivity of rice was determined by using ArcGIS and climatic effect on the agricultural variables of rice were studied with the help of correlation and regression analysis. The change in rice production was found out to be positive and the production increased considerably in all the provinces. Similarly, Kim et al. [31] studied the relationship among rice yield and weather variables in Korea. The results revealed that average rice yield was positively related to temperature and negatively associated with precipitation. Knox et al. [32] presented a report in which they gave the findings of the projected impacts of climate change on food crop productivity in South Asia and Africa till the year 2020’s. The results were found positive for rice production in Pakistan.

Climate in the recent times has no significant negative impacts on the production of rice in Pakistan. However, it is hoped that Pakistan does not face any extreme climatic fluctuation in the near future otherwise it can aggravate the situation of rice production in the country. In the future, these positive aspects can be linked with good technology and irrigation system so that the production of rice can be further increased to earn more foreign exchange and profits for the country.

**CONCLUSION AND RECOMMENDATIONS**

The present study was carried out to analyze the impact of climate change on rice yield in Pakistan. It has been analyzed that the climatic variables have significant impact on the production of rice. Rice production in Pakistan followed an increasing trend from 1989-2009. In the future, the temperature is expected to rise more and it can even cross the optimum limit. Similarly, drought conditions sometimes prevail and the major cause of decreased production after 2000 in Pakistan was drought. When drought prevails, production reduces and the foreign exchange which is earned by exporting rice will also decrease. So the rice will have to be produced in such a way that it can adapt to the future changes in climate which are expected to aggravate in the future.

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes, while mitigation focuses on reducing the emission of greenhouse gases from rice production and minimizing deforestation resulting from upland rice cultivation. There are a range of technological options that are presently available or which can potentially be developed in the near future for enhancing the rice production systems’ ability to adapt to and mitigate the effects of global climate changes as mentioned below.

- Rice varieties have different abilities to tolerate high temperature, salinity, drought and floods. The selection of appropriate rice varieties is, therefore, a technical option for adaptation to global climate changes.
- Also, the development of rice varieties that have not only high-yielding potential, but also a good degree of tolerance to high temperature, salinity, drought, and flood is strongly recommended.
- As already mentioned that increase in CO₂ concentration could increase rice yield so the high CO₂ concentration present in the atmosphere under global warming could be harnessed to increase the productivity of the rice crop.
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