

Analysis of Climate Change Effects on Agriculture in Bhutan

Abstract

The effects of climate change on agriculture are particularly noticeable due to the worldwide phenomenon of global warming. Similarly, Bhutan is also experiencing the repercussions of climate change on its agricultural sector and the livelihoods of its people. Although some researchers conducted research on climate change vulnerability on agriculture in Bhutan based on their research area and problem definition, climate change effects on paddy, maize, chilli, and cardamom in five districts (Dagana, Monger, Pemagatshel, Zhemgang, and Trongsa) have been least explored and limited. Therefore, this paper, conducted in five districts of Bhutan, analyses the trends of paddy, maize, chilli, and cardamom and the vulnerability of this variable under extreme weather. Apart from this, the effects of climate change were analyzed by comparing trends of temperature and precipitation (1901–2021). The study employed a non-probability sampling technique to conduct research and used ARIMA model to find the trends of temperature and precipitation. The results showed that there is a negative relationship as well as a positive relationship between climate change and agriculture production in the study area. Further, the study area is under threat of extreme weather, especially drought, flash flooding, windstorms, and hailstones. Additionally, results revealed that, in next decade, there is a threat of climate change, which results in a more rapid decline in paddy and maize production in all five districts. Climate adaptation policies such as climate smart agriculture (CSA) and climate smart villages (CSV) must be promoted in villages to reduce the long-term vulnerability of agriculture to climate change.

Keywords: agriculture, climate change, climate smart agriculture, extreme weather, ARIMA model

1. Introduction

Climate change, described as an unprecedented alteration in weather patterns and temperatures resulting from both natural processes and human activities (UN, 2022), poses a formidable challenge to sustainable development and food security at local, national, and global scales. The impact of climate change on food security and development is evident globally, with Africa facing severe droughts and floods in countries like Nigeria and Sudan (UNF, 2022), underscoring the urgent need for climate resilience measures. Particularly vulnerable to these changes are rural populations in developing nations, with Himalayan countries like Bhutan facing heightened risks due to their reliance on agriculture and hydropower (Royal Government of Bhutan, 2020). In Bhutanese districts such as Dagana, Monger, Pemagatshel, Trongsa, and Zhemgang, where agriculture, including maize, rice, chilli, and cardamom cultivation, forms the

backbone of the economy, the variability in temperature and precipitation poses significant challenges to farmers' livelihoods (Reddy et al., 2022).

Studies conducted in various regions, such as Goa in India (Reddy et al., 2022), Pakistan (Ali et al., 2021), and the upper region of Ghana (Derbile et al., 2022), emphasize the vulnerability of smallholder farmers to climatic extremes and stress the need for prompt adaptation measures. Scientific advancements, including agriculture biotechnology, remote sensing, and geographic information systems, offer promising avenues for mitigating the adverse effects of climate change on agriculture in Asia (Mokhtar et al., 2022). While some regions may benefit from climate change, as seen in the potential for introducing new fruit tree species in Argentina's North Patagonia (Barrio et al., 2020), others face challenges such as increased water demand for crops like maize in northern China (Lin & Li, 2022).

In Bhutan, irrigation water scarcity is a significant concern, with climate change exhibiting both positive and negative effects on crop production, such as increased mandarin orange yields but reduced citrus and apple production (Chhogyel et al., 2020; Tenzin et al., 2019; CIAT & World Bank, 2017). Thus, addressing climate change impacts on agriculture remains imperative for sustainable development and livelihood security in Bhutan and other vulnerable regions. Bhutan has witnessed numerous temperature variations, rainfall patterns, flash floods, windstorms, hailstorms, and droughts, resulting in massive losses and damage to agriculture farmers (Shrestha et al., 2012; UNDP, 2013). Bhutan's farming resistance to climate change must be strengthened by government aid, greater investment, Research and Development (R&D), and technology creation (Chhogyel & Kumar, 2018).

Therefore, the purpose of this paper is to analyze the trends and forecast the cereal (paddy and maize), vegetable (chilli), and species (cardamom) in five districts of Bhutan from 2004 to 2021. It also aims to analyze the impact of extreme weather events on paddy, maize, chilli, and cardamom production in five districts of Bhutan, as well as the other control factors like flashflood and windstorm that influence agricultural productivity in the research region. It also gives a possible option for dealing with the detrimental impact of climate change on Bhutan's agricultural productivity.

2. Methods and Materials

2.1 Study area

The research was carried out in five districts of Bhutan as shown in figure 1. The five districts of Bhutan are located at different altitudes and experience variations in temperature and precipitation. Thus, study for climate change effects on agriculture in this area will be significant for farmer.

Dagana: Dagana is 1722.83 square kilometres in size and has a population of 24,965 (PHCB, 2017). Agriculture is the primary source of income for the majority of farmers. Dagana has more orchard land than wet land and dry land combined, with dry land measuring 5432.334 hectors, wet land measuring 18167.165 hectors, and orchard land measuring 1922.564 hectors (RGoB, 2018). The city is located at an elevation of 1580.23 metres (5184.48 feet) above sea level and has a temperate highland tropical climate with dry winters. The average annual temperature is 9.61 °C, with 142.46 wet days and 71.39 millimetres (2.81 inches) of precipitation. The hottest

month is August, while the coldest month is January with $-2.68\text{ }^{\circ}\text{C}$ (Weather & Climate, 2022). Aside from rice and maize, farmers in Dagana mostly grow cardamom and mandarin. Their subsistence is dependent on grain and cash crops.

Trongsa: Trongsa has a population of 19,960 (PHCB, 2017) and a temperate highland tropical climate with dry winters. It is located at a height of 2169.73 metres above sea level. The city has a yearly temperature of $9.61\text{ }^{\circ}\text{C}$, 71.39 millimetres of precipitation, and 142.46 wet days (Weather & Climate, 2022). Trongsa practises mixed agriculture like paddy, maize, chilli, and cardamom cultivation.

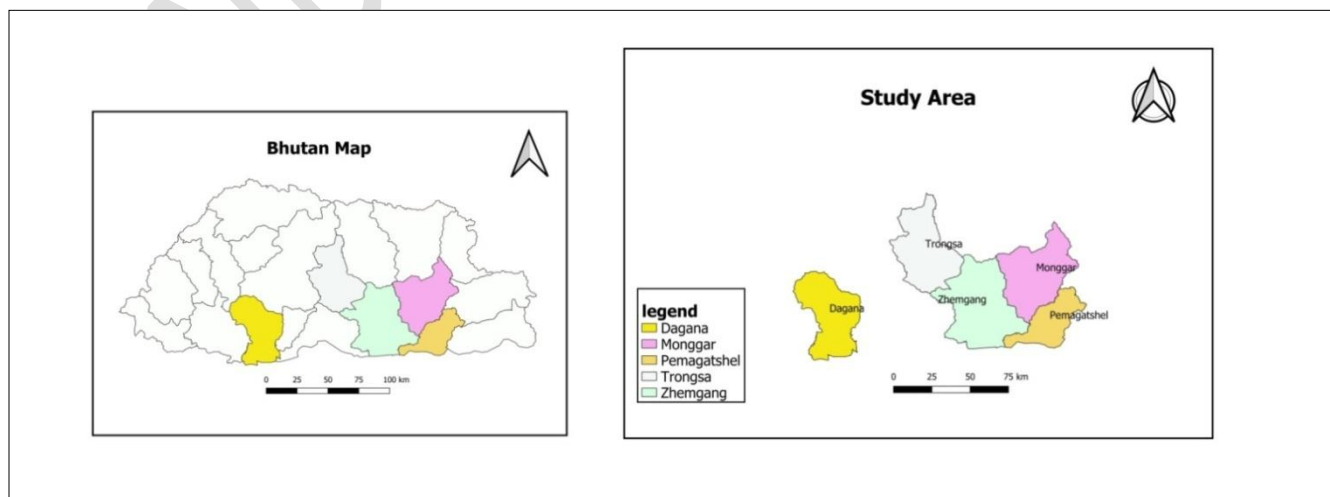
Monger: Mongar Dzongkhag has a population of 37,150 (PHCB, 2017), and it is located between latitude 27.25 and longitude 91.2. Its size is around 1,940.26 square kilometers, and its height ranges from 400 to 4000 metres above sea level. While the northern and upper regions have temperate climates, the lower and southern regions are subtropical. Winters can be frigid, while summers can be hot and muggy. The people of Monger harvested more maize than paddy, and their economy depends on these two types of production as well as chilli production.

Pemagatshel: Pemagatshel mostly cultivates maize and rice, as well as cardamom and chilli, to supplement their income. Pemagatshel has a population of 23,726 (PHCB, 2017), a humid subtropical, dry winter climate, and is located at a height of 1467.34 metres (4814.11 feet) above sea level. The city's annual temperature is $26.75\text{ }^{\circ}\text{C}$, which is 11.15% higher than the national average. Pemagatshel gets roughly 180.8 millimetres (7.12 inches) of rain per year and has 147.56 wet days. The coldest month is January, and the warmest month is May (Weather & Climate, 2022).

Zhemgang: Zhemgang has a population of 17,763 (PHCB, 2017). Zhemgang, which is 572.11 metres above sea level, has a moderate highland tropical climate with dry winters. Around 180.8 millimetres of rain fall on Zhemgang annually, and there are 147.56 rainy days. May is the hottest month, while January is the coldest (Weather & Climate, 2022). Farmers in Zhemgang cultivate more maize than paddy, and their economy depends on these two types of production.

Figure 1

Selected Study Area



Note: Adapted from QGIS 3.4.4

2.2 The Sampling Methods and Design

The study employed a non-probability sampling technique to conduct research. According to Fowler (2002), non-probability sampling employs subjective judgement and a convenient selection of units from the population. The study is based on convenience sampling since five districts (Dagana, Trongsa, Monger, Pemagatshel, and Zhemgang) were chosen for examination from a total of twenty districts in Bhutan. The five districts were chosen because they had the lowest poverty rates in Bhutan and a heavy reliance on agricultural production for a living.

Therefore, it is convenient for collecting secondary data and analyzing the effects of climate change on their products. Since the consequences of climate change on agriculture are the most visible problems that people face and temperature variations occur every year, the study adopts an applied research approach to address the topic of the influence of climate change on farmers' livelihoods. Kothari (2008) defines applied research as seeking to solve a current or everyday problem that individuals and society face.

2.3 Methods of Data Collections and Analysis

The data was collected from secondary sources for all the regions. Secondary data includes data collected by someone other than the primary user (Management Study Guide, 2022). To analyze the trends in agriculture production (paddy, maize, chilli, and cardamom), data was collected from the Ministry of Agriculture websites and the National Statistics Bureau (NSB). Furthermore, data on the effects of extreme weather on agricultural production in these regions was collected from news reports, i.e., Kuensel and Bhutanese news.

To study the effects of climate change on these regions, the daily temperature and precipitation records were collected from the Climate Change Knowledge Portal (CCKP). Based on the main objective of this paper, i.e., to analyze the trends of agricultural production, this objective was fulfilled by analyzing the trend using an econometric model, i.e., time series analysis. Other temperature and precipitation trends are analyzed using the Climate Change Knowledge Portal System, and the forecast of agricultural production is done using the ARIMA model from the time series model in SPSS.

3. Results and Discussion

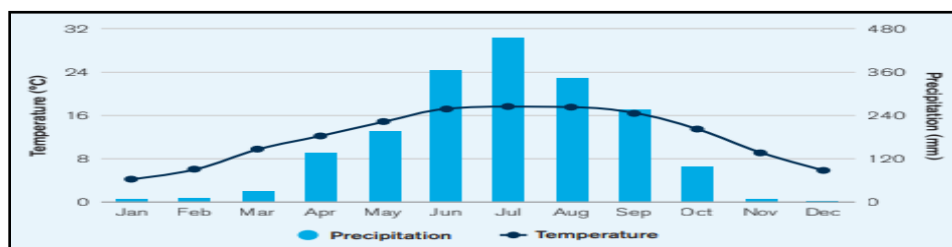
3.1 Overall Trends of annual temperature and rainfall of Bhutan

Since the beginning of the 1960s, the increase in temperature and its impact have been felt by the people of Bhutan. Figure 2 shows that the rate of temperature rise has accelerated in the last decade. Temperature and precipitation increase more in the southern part of Bhutan, while they decrease in the northern part of the country. The graph below shows that in the summer temperatures will be high in Bhutan and that in the winter they will be low. Similarly, the months of May to September will have the highest rainfall and temperatures (Asian Development Bank, 2021). Results also show that there is a decline in the amount of rainfall in the country's wettest regions. The northern and southern parts of Bhutan will receive the highest

rainfall in summer (Awange et al., 2017). As a result of monsoon rain, primary paddy farming begins in Bhutan from May to August. Most farmers in Bhutan grow vegetables during the dry season, which lasts from October to March, and rice during the monsoon. Thus, farmers encounter difficulties in planting paddy on time every year as the country experiences a rise in temperature and a fall in precipitation.

Figure 2

Average monthly temperature and rainfall in Bhutan, 1991–2020



Note. This graph shows the average monthly temperature and rainfalls trends in Bhutan from the year 1991 to 2022. Copyright by 2021 Asian Development Bank.

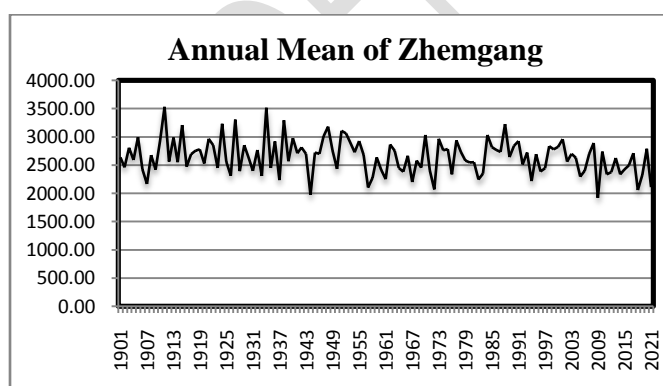
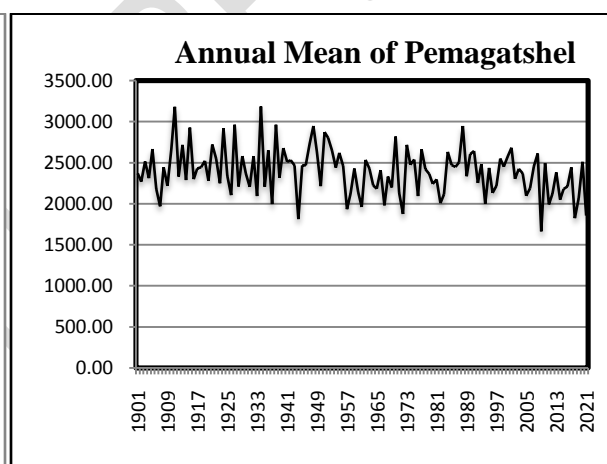
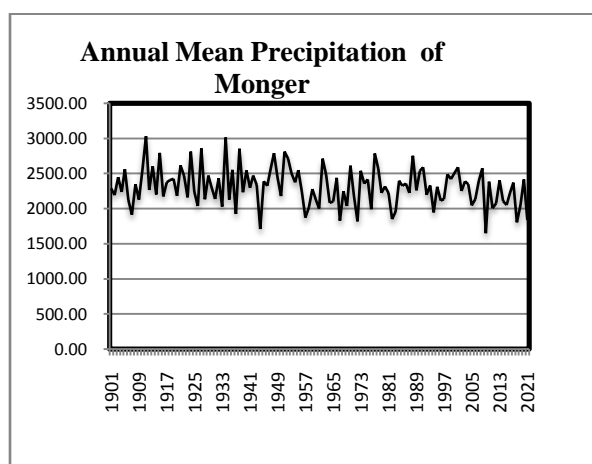
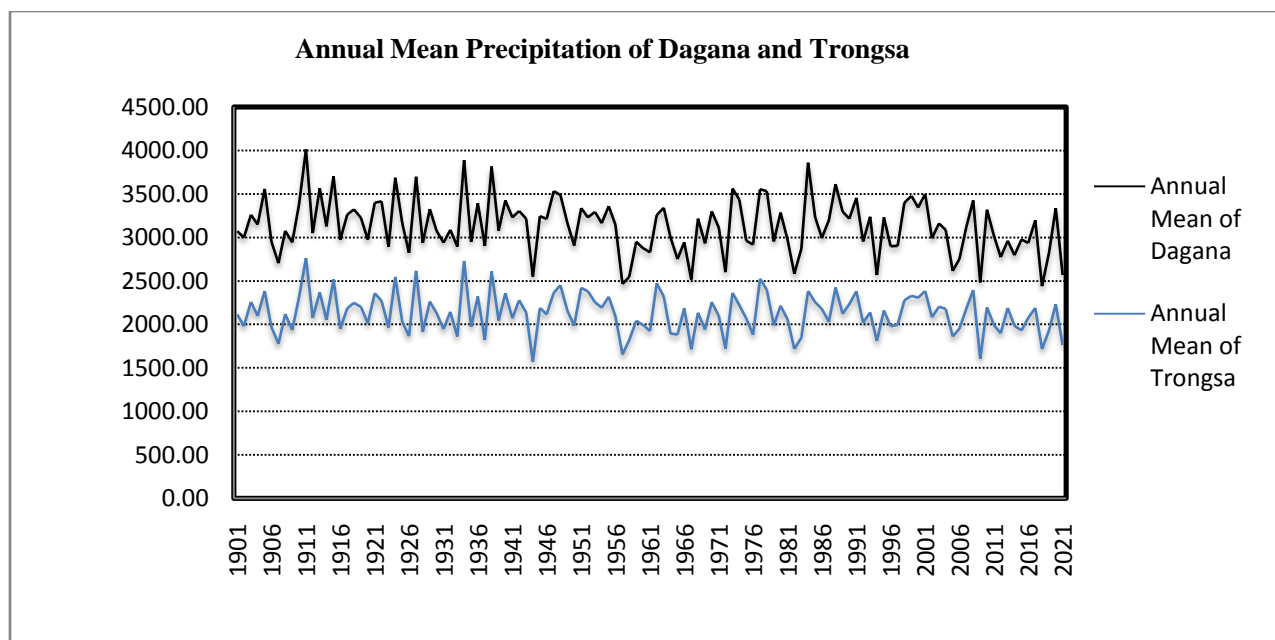
3.2 Trends of precipitation of study area, 1901-2021

This section will examine the average annual precipitation trends in five research areas from 1901 to 2021, as shown in Figure 3. The purpose of assessing average precipitation trends for this research region is to determine the vulnerability of precipitation in study areas and examine the relation between precipitation and agriculture products in the study area. Observations show a year-to-year decrease in precipitation in all five study areas. Observations show that Pemagatshel experiences a more drastic decline in precipitation than other study areas. Compared to the other three districts, Dagana and Trongsa experience a constant decline in precipitation.

Thus, results show that all five study areas face climate change impacts every year. This means that those agriculture products that depend on rainwater for cultivation, like paddy, face challenges in cultivating on time due to the late monsoon and shortage of irrigation. According to the observations, there is a decrease in precipitation in all areas, indicating that drought is a problem in all five districts. Therefore, climate change is impacting the livelihood of these five districts.

Figure 3

Annual mean precipitation of study area (1901-2021)



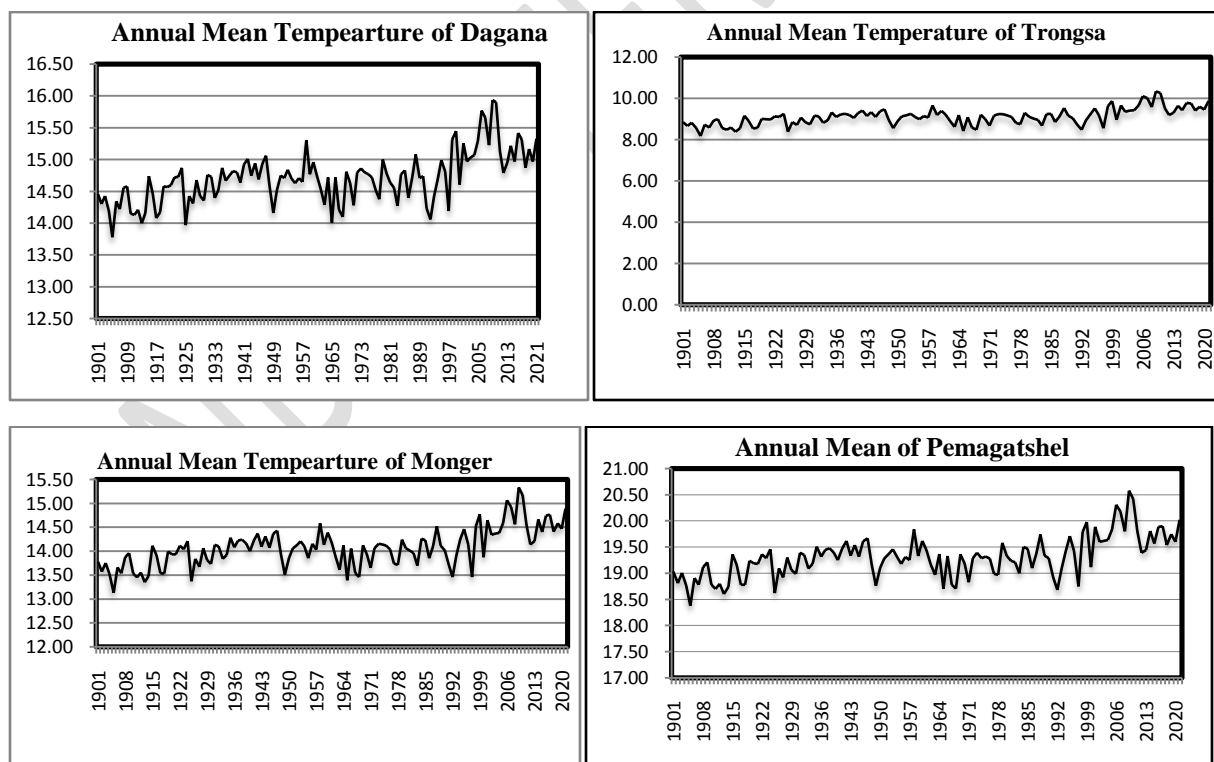
Note. The graph show the overall decline in annual mean precipitation trends from 1901 to 2021 of Dagana, Trongsa, Monger, Pemagatshel and Zhemgang. Copyright by 2021 The World Bank Group.

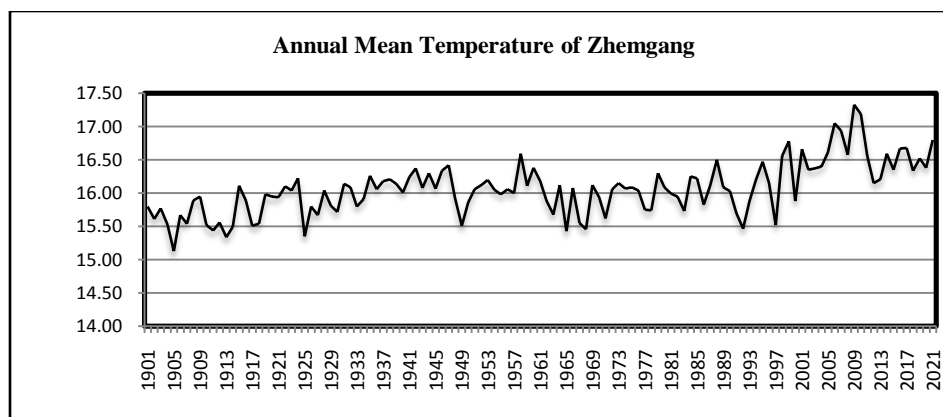
3.3 Trends of Temperature of study area, 1901-2021

This section examines the study area's maximum temperature changes from 1901 to 2021. Due to the recent increase in temperature and the difficulty farmers have had in cultivating in past years, five research locations have been selected to evaluate temperature patterns. The goal of this study was to determine the temperature change and the sensitivity of the studied region to climate change. The following trends show that the annual mean temperature has continued to rise from 1901 to 2021 in all five research areas. According to the data, Pemagatshal is the hottest site among the others, with a temperature of 25°C in 2021, indicating that this region is more sensitive to climate change than other areas. In 2009, almost five area experience maximum temperature, Dagana with 21.4°C, Zhemgang with 22.94°C, Trongsa with 16.11°C, Monger 21.16°C and Pemagatshal with 26.1°C. Based on the analysis, the growing trends in maximum temperature as shown in the trends analysis show their sensitivity to climate change, particularly temperature.

Figure 4

Annual mean temperature of study area (1901-2021)





Note. The graph show the overall increase in annual mean temperature trends from 1901 to 2021 of Dagana, Trongsa, Monger, Pemagatshel and Zhemgang. Copy right by 2021 The World Bank Group.

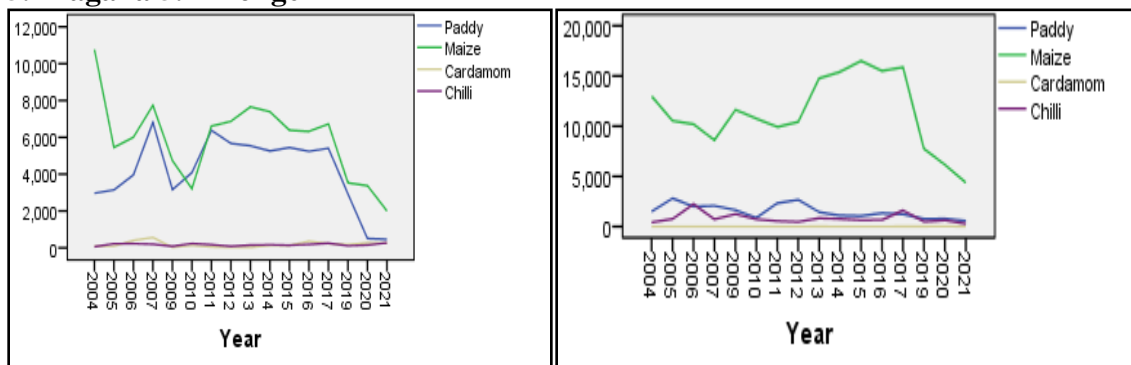
3.4 Trends analysis of different crops under different regions

These sections will analysis the trends of paddy, maize, fruits and vegetable production of five districts i.e., Dagana, Pemagatshel, Monger, Trongsa and Zhemgang under the climate change. The 18 years data (2004-2021) was use to analysis the trends of agriculture variable paddy, maize, cardamom and chilli of five study area. The purpose of analyzing the trends was to determine the vulnerability of these variables to climate change in particular study area and to see the pattern of agriculture production. From the figure 5, observation shows that over the last two decade, agriculture production in this area has seen to be non-stationary over the time. Dagana has been seen drastically decrease in the maize and paddy production over the time and almost constant in chilli production. As a results Dagana are more vulnerability to climate change in term of maize and paddy. Dagana grows maximum of cardamom from decade but climate change has been significantly impacting the traditional management practices of cardamom farming. The harvested production of cardamom has become uncertain due to persistent pests and diseases. Climate change and all these challenges have impacted the productivity and production of cardamom growers in Dagana. Thus, cardamom production in Dagana is slightly decreasing over the year.

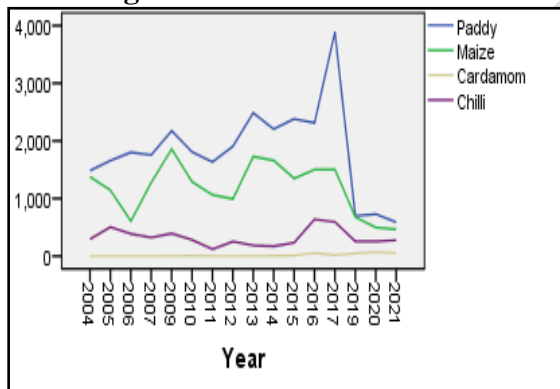
Most of the livelihood of people in Monger depends on maize production and considered maize as the highest production comparing other products. At the same time Monger has been seen decrease in the maize production over the time due to climate change and other factors. Recently, slight increase in cardamom production is also seen in Monger, Pemagatshel, Zhemgang and Trongsa due to change in temperature and precipitation pattern. This shows that there is positive relation between climate change and cardamom production in Monger. The people of Pemagatshel and Zhemgang practice more of paddy cultivation and second as maize. Both the area is seen to be decline in the paddy and maize production over the year. Trongsa seem to be highest grower of maize comparing to paddy, chilli, cardamom respectively. If we look into the trend of temperature and precipitation of Trongsa in figure 4 and 5, we can observe that contributing factors for decline in paddy production in Trongsa is due to increase in temperature and decline in precipitation which leads to drought.

Figure 5
Trends of Agriculture Production in Study Area

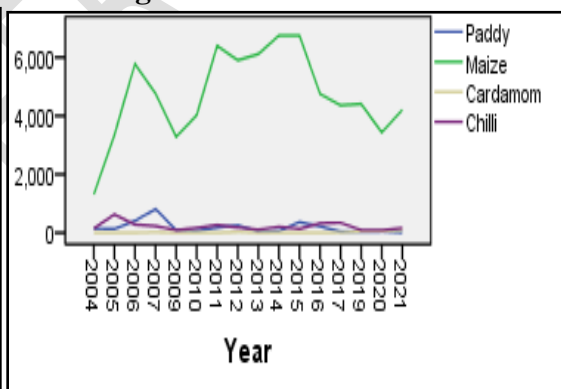
5.1Dagana 5.2 Monger



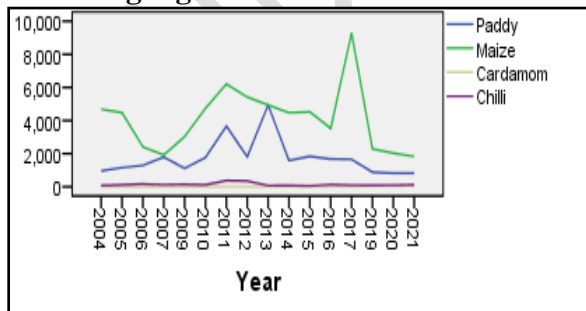
5.3 Trongsa



5.4 Pemagatshel



5.5Zhemgang



Note. The graph show overall decline trends of agriculture production in five districts of Bhutan.

3.5 Effect of climate change on agriculture production in study area

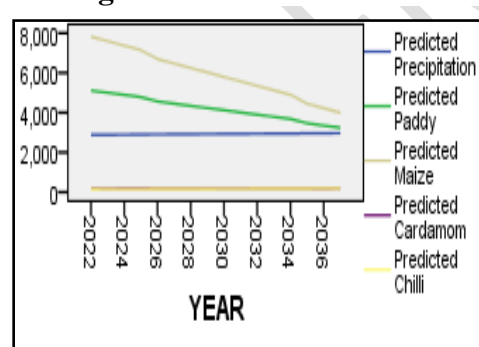
This section will examine the long run effects of climate change on agriculture production in study area by analyzing future trends base on the previous year data. The forecast, of data is done through time series model using ARIMA model. The ARIMA model is econometric model which is used in forecasting the future production. The following figure 6 will forecast the trends of precipitation, paddy, chilli, maize and cardamom. The purpose of this study is to examine long run effects of climate change on agriculture production in study area and to forecast specific crops under precipitation. The forecast was done base on the previous year data from 2004 and 2021 using ARIMA model. Figure 6 shows the forecast of Dagana and observation depicts that, in long run Dagana will experience decline in paddy and maize production due to decline in the precipitation. Other product like cardamom and chilli will experience slight decline or almost stay stationary.

In figure 6 we observed that, due to slight increase in precipitation in future, monger will practice shift in crops from maize to cardamom because cardamom seem favourable in long run in monger. There will be declining trends in maize even after decade in monger. In figure 6, results show Trongsa will experience decline in precipitation over long run and cause decline in paddy and maize production. Cardamom and chilliseems steady increase at constant rate in Trongsa and Zhemgang. Figure 6 depicts that in long run maize production will increase and other product will increase at constant rate. Therefore, base on the previous year data, results show that there is overall decline in precipitation in next decade and paddy and maize too in all study area. Results show study area is vulnerable to climate change in long run which further affects the livelihood of people and food security. From the following results, we conclude that, effects of climate change will be more in next coming decade and damaged on agriculture crops like paddy, maize, cardamom and chilli by extreme weather events will hamper the food security.

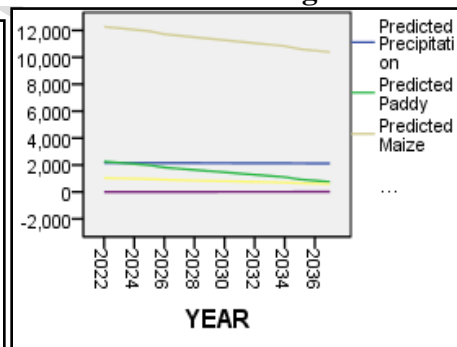
Figure 6

Forecast of precipitation, paddy, maize, chilli and cardamom in study area

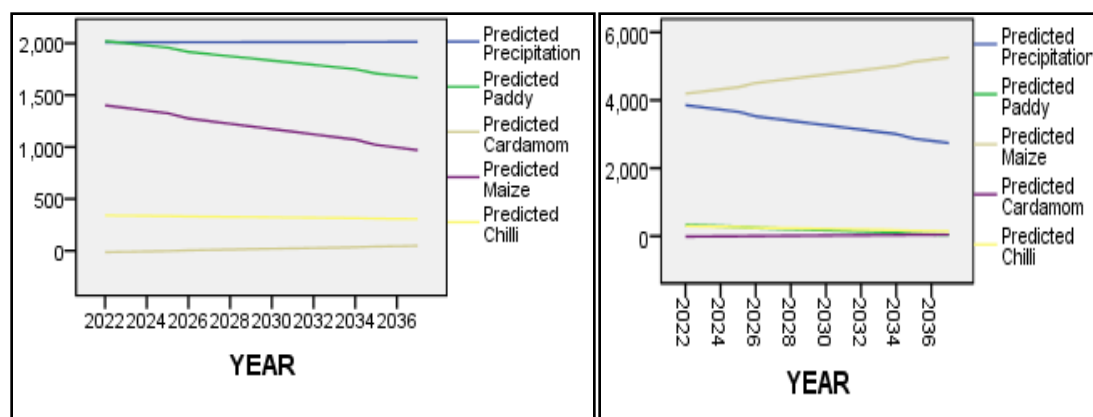
6.1 Dagana



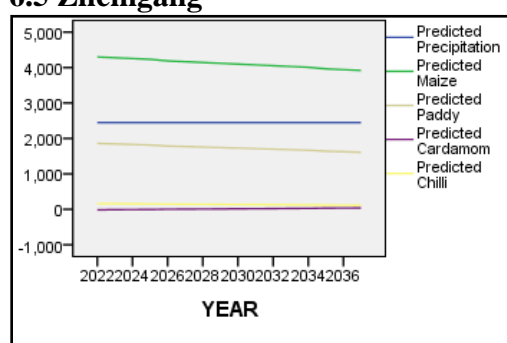
6.2 Monger



6.3 Trongsa 6.4 Pemagatshel



6.5 Zhemgang



Note. The graph shows the overall decline in cardamom, chilli, paddy, maize and precipitation in next decade.

3.6 Effects of Extreme Weather on Agriculture in study area

Based on historical data, this section will investigate the impact of extreme weather on agricultural productivity in the study region. The primary goal is to determine which climatic factors have the greatest impact on agricultural output in the research region and to analyze the sensitivity of these factors to the study area in the present and future. Data was obtained from previous news articles and ministry of agriculture reports to determine the impacts of extreme weather (drought, rainfall, temperature, wind, snowfall, flash floods, landslides, and other variables) on agriculture in each research location. According to the Agriculture Survey Report (2021), acres of paddy crops were damaged in Dagana and Zhemgang owing to frequent rain, resulting in a drop in maize and rice output in this region in 2021. Heavy rains and windstorms recently devastated 167 acres of corn crop in Dagana (Wangmo, 2022). Similarly, Dungmaed village in Pemagatshel would lose 15 acres of grain in 2020 due to a week of constant severe rain. They claim that this is the first time they have experienced a continual downpour in Pemagatshel (Wangchuck & Rai, 2020). This also explains the influence of climate change on agriculture. Furthermore, a flood caused by heavy rain destroyed crops in Mongar, destroying 120,785 kg of corn distributed across 81.23 acres. Similar damage was caused by a hailstorm in Trongsa Dzongkhag, which affected 95.22 acres of cultivated land (Delma, 2016). Thus, a gradual and continuous increase in harsh weather has resulted in significant crop and grain losses in this region.

In Monger, maize is a vital source of revenue; however, owing to climate change, several new pests and diseases have devastated the crop and the livelihoods of farmers. According to Namgyal (2021), armyworm infestation has devastated over 15 acres of corn crop in numerous villages in Monger, and drought has also impacted the growth of maize in another village in Monger (Thangrong gewog) in the same year, causing damage to 54 households. Thus, all of these factors are consequences of extreme weather and climate change on agriculture, implying that climate change is also harming agriculture productivity in Bhutan. As a result, in the research region, wind, rainfall, drought, flash flooding, pests, and diseases are the most prevalent factors affecting agricultural productivity and farmer livelihood. This also suggests that the research region is under threat from climate change, including wind, drought; flash flooding, rainfall, pests, and diseases.

3.7 Other Factors effecting climate change in study area

The other factors that affect agriculture production in the research region were examined in this part based on a news source from the previous year. Bhutan is a Himalayan country with a forest cover that exceeds 60%, making farming difficult for farmers due to land near to forest. In Bhutan, human-wildlife conflict is another factor that affects agricultural production and farmers' means of subsistence. These additional factors make it difficult for farmers to conduct sustainable agriculture. Aside from climate change, the major reasons in farmer crop losses each year are wild animals and human-wildlife conflict. According to statistics, 117.79 acres of paddy fields were damaged by wild animals the most in Trongsa between 2002 and 2011 (Zangpo, 2013). Farmers are thus extremely exposed to wild animals during the peak season of agriculture crops such as potatoes, maize, and rice. As a result of the increased production of maize and paddy, which attracts more wild animals, the research region is also threatened by wild animals.

4. Climate Change adaptation planning

This section will discuss the recommendation for climate change adaptation planning and policy with respect to agriculture in Bhutan. As mentioned in study, major crops and cereal are more vulnerable to extreme weather and this has negative effects on food security and livelihood of farmer in study area. Therefore, to achieve the major sustainable development goal (SDGs) specially ending poverty, zero hunger and climate action, appropriate national planning and policy is needed to mitigate the climate change impact on food security. To support the national planning and policy, paper recommends three policies as follows:

4.1 Climate Smart Agriculture (CSA) and Climate Smart Village Model (CSV)

Climate smart agriculture (CSA) is an integrated method for managing landscapes, including cropland, cattle, forests, and fisheries, that addresses the interconnected challenges of food security and climate change (World Bank, 2021). Climate smart agriculture is a strategy for boosting agricultural productivity and revenue in a sustainable way, adapting to and creating resilience to climate change, and reducing greenhouse gas emissions. People in each village district require proper climatic knowledge, practice, and training in CSA. For example, a location with high temperature vulnerability can substitute crops that are tolerant of high temperatures, and when temperatures are normal, farmers can produce previous crops cultivated in that region.

As a result, farmers may make money and enhance productivity in the long run. To lower costs, a shift in farming systems must use cutting-edge technologies. Climate-smart agriculture will be accomplished by introducing the climate-smart village (CSV) paradigm. Climate Smart Villages (CSV) enable every farmer in the village to employ climate-smart agricultural services, increasing the community's adaptive potential. Climate smart technology and climate information services may be integrated into village development plans with the help of local institutions and local expertise. This can be accomplished by promoting new and shorter maturation times for drought-tolerant crop types, enhanced and novel soil and water conservation technologies such as compost production and application, and the use of appropriate amounts of fertilizer. According to the study, adaptation planning and incorporating climate-smart agriculture will serve as a tool and a path for farmers to make crop farming more productive and resilient in the face of a changing climate system.

5. Conclusion

This study was undertaken in five areas of Bhutan to analyze the impacts of climate change on agricultural products by analyzing trends in certain crops and extreme weather events, as well as the implications of climate change adaptation in the study area of Bhutan. The study relied on secondary data from five districts. We determined that farmers in five areas are more vulnerable to extreme weather occurrences such as drought, flash floods, and windstorms as a result of our findings. Aside from climate change, another regulating element that influences agriculture is human-wildlife conflict. Furthermore, we infer that maize and rice are more sensitive due to the rising temperature and decreasing precipitation trends in our five research locations. Climate change adaptation, such as the promotion of Climate Smart Agriculture (CSA) and the climate smart village concept for smallholder farmers, is critical to reducing all of these severe weather occurrences. Furthermore, employing environmentally friendly agricultural equipment, such as electric power tractors, may aid in the reduction of emissions and the sustainability of livelihoods.

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