The Impacts of Climate Change on Rice Production and Small Farmers' Adaptation: A Case of Guyana

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Abstract

Prior research has concluded that climate change is having an overall negative impact on rice production worldwide. The vast majority of climate change impacts on rice production result from fluctuations in precipitation and temperature, which lead to flooding, water scarcity, and increases in insects and pests, diseases, and weeds. As a small developing country, Guyana is highly vulnerable to climate change despite its insignificant contribution to global warming. Guyana heavily relies on rice cultivation for food, employment, and export earnings. While generally increasing, rice yields have fluctuated over the last two decades. For example, in 2016, rice yields declined by 12.7 percent due to a drought. This dissertation explores the relationship between fluctuating yields and climate change, and how farmers are adapting.

Of particular importance are the impacts of climate change on small farmers (those cultivating less than 4.45 hectares or 11 acres) and their ability to successfully adapt. Small farmers are especially vulnerable to a changing climate because they often lack the necessary knowledge, support, and resources to effectively respond and adapt. Given the large percentage of rice farmers engaging in small-scale production in Guyana, this study investigates the impacts of climate variability on rice production and the extent to which the production and productivity of small farmers are affected. It also identifies the coping strategies small farmers employ to combat the effects of climate change and the extent to which these strategies are successful.

Given that climate change is expected to vary across different regions of the world, the first aim of this study is to show how the climate in Guyana has changed. At the country level, evidence from descriptive statistics, a linear trend model, and a two-sample t-test shows that minimum and maximum temperatures have increased over the last 111 years. The aggregate data is less clear on changes in precipitation over the last 111 years.

However, analysis of farm-level data provides strong evidence of shifts in rainfall patterns. Among 189 small farmers interviewed, 182 (96.3%) perceived changes in rainfall patterns, 170 (89.9%) perceived changes in temperature, 169 (89.4%) perceived changes in extreme weather events, 185 (97.9%) perceived changes in insects and pests, 73 (38.6%) perceived changes in diseases, and 168 (88.9%) perceived changes in weeds.

Changes in precipitation have included an increase in intensity and out of season rainfall, which has impacted harvesting due to poor dams, wet fields, and the lodging of plants. The primary responses farmers have adopted include adjusting planting dates based on water availability and the cultivation of different rice varieties. Changes in temperature have resulted in hotter days, accelerating the evaporation of water from fields. In response, farmers replenish water in their fields, when available. Excess rainfall and resulting flooding, drought, and heavy winds have been the primary extreme weather events observed. Excess rainfall and associated flooding submerges, uproots, and/or kills young plants. The lodging of plants due to heavy winds and flooding has been the main impact. In response to flooding, farmers have pumped water out of their fields. There is very little that farmers can do in response to heavy winds.

The primary change in insects and pests reported by farmers has been an increase in paddy bug infestations, which cause damage to the grains resulting in lower quality and quantity at harvest. As a result, farmers are engaging in more preventative spraying. An increase in brown spot disease was also reported. Brown spots are primarily found on the leaves, damaging and/or stunting the growth of the plants by reducing the amount of food they manufacture through photosynthesis. Farmers have responded by engaging in preventative spraying and the rotation of fungicides. Increases in red rice and duckweed have been the major changes in weeds observed. Both weeds compete with rice for space, sunlight, nutrients, and water. Additionally, red rice reduces the quality and by extension the price farmers receive. Farmers are responding by spraying more herbicide and using a contact chemical to burn red rice.

Multivariate analysis of farm-level data found that land tenure, tractor ownership, membership in an agricultural organization(s), secondary non-agricultural income, and farms located in regions two and four have positive correlations with annual yields. Perceived changes in rainfall, farm size, livestock ownership, participation in rice extension training, and household members help with rice farming were found to have negative correlations with annual yields.

Policy recommendations to improve rice production and farmers' resilience include improving research and development capacity; tax exemption for agricultural inputs and equipment; improving extension services; improving the management of irrigation systems and water resources; enhanced access to credit, insurance, and subsidies; improving weather forecasting and climate monitoring; and improving the management of drainage infrastructure.

The analytical framework used in this research produced a rich dataset and interesting results that are important to our understanding of farm-level impacts and responses to climate change. As such, it may prove useful for studying climate change impacts in other developing countries that have similar characteristics and face similar risks from climate change as Guyana.

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General Audience Abstract

The vast majority of climate change impacts on rice production result from variations in rainfall and temperature that lead to flooding, water shortage, and increases in insects and pests, diseases, and weeds. Guyana is highly exposed to climate change. More importantly, the country relies heavily on rice farming for food, employment, and foreign income. Of particular importance are the impacts of climate change on small farmers (growing less than 4.45 hectares) and their ability to successfully adapt. Small farmers are especially helpless because they often lack the necessary knowledge, support, and resources to effectively respond and adapt. Given the large percentage of rice farmers engaged in small-scale production in Guyana, this study explores the impacts of climate variability on rice production and the extent to which the production and output of small farmers are affected.

Analysis of farm-level data shows that changes in rainfall have included an increase in intensity and out of season rainfall which has affected harvesting due to poor farm-to-market roads, wet fields, and lodging of plants. The main responses involved adjusting planting dates based on water availability and the cultivation of different rice varieties. Changes in temperature resulted in hotter days which increased the loss of water from the field. In response, farmers replenish water in their fields, when available. Excess rainfall and resulting flooding, drought, and heavy winds have been the main extreme weather events observed. Excess rainfall and associated flooding submerges, uproots, and/or kills young plants. The lodging of plants due to heavy winds and flooding has been the main

impact. In response to flooding, farmers have pumped water out of their fields. There is very little that farmers can do in response to heavy winds. An increase in paddy bug infestations damaged the grains resulting in lower grain quality while an increase in red rice and duckweed increased the competition for space, sunlight, nutrients, and water. Farmers engaged in more defensive spraying and used a contact chemical to burn red rice.

Dedication

I dedicate this dissertation to my wife for her unconditional love and support throughout this entire journey. You have been a great source of strength, motivation, and inspiration and I am grateful for your patience, understanding, and constant words of encouragement. You have never wasted an opportunity to remind me to stay positive when progress was slow, and I am thankful for having you in my corner. To my daughter Sofia for reminding me each day that there are more important things to life than writing a dissertation. I hope you will understand one day the sacrifice I have had to make between spending more time with you and working on this research. To my mother who taught me never to leave for tomorrow what can be done today. Your support over the last several years is immeasurable and I am very grateful for all you have done to help get me through this arduous process. To my father for helping to ensure my early academic endeavors were realized and to my brother and sister for their loyalty, friendship, and responsiveness over my academic career and in my times of need. You have all contribute to my growth and development as a person and my achievements could not have been possible without your commitment, guidance, and involvement. In one way or the other, you have enabled me to achieve so much in such a short period of time.

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List of Abbreviations

AEZ	Agroecological Zone Analysis
AGE	Applied General Equilibrium Model
AOGCM	Atmosphere-Ocean General Circulation Model
APSIM	Agricultural Production Systems Simulator
AQUACROP	Crop-water Productivity Model
BoG	Bank of Guyana
CAEPNET	Caribbean Agricultural Extension Providers Network
CERES	Crop Estimation through Resource and Environment Synthesis
CGE	Computable General Equilibrium Model
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon Dioxide
CRU	Climate Research Unit
CV	Coefficient of Variation
DEI	Disaster Exposure Index
DSSAT	Decision Support System for Agrotechnology Transfer
ECLAC	Economic Commission for Latin America and the Caribbean
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
FLAR	Latin American Fund for Irrigated Rice
GCM	General Circulation Model
GDP	Gross Domestic Product
GMSL	Global Mean Sea Level
GNBS	Guyana National Bureau of Standards
GRA	Guyana Revenue Authority
GRDB	Guyana Rice Development Board
GREB	Guyana Rice Export Board
GRIF	Guyana REDD+ Investment Fund
GRMMA	Guyana Rice Milling and Marketing Authority
GTAP-W	Global Trade Analysis Project-Water
H_2O	Water Vapor
HadCM	Hadley Center Coupled Model
HDI	Human Development Index
HYDROMET	Hydrometeorological Service
IDB	Inter-America Development Bank
IFC	International Finance Corporation
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
ITCZ	Inter-tropical Convergence Zone

KN	Kaieteur News
KNMI	Royal Netherlands Meteorological Institute
LAC	Latin America and the Caribbean
LCDS	Low Carbon Development Strategy
MA	Moving Average
MMAADA	Mahaica, Mahaicony, Abary Agricultural Development Authority
MoA	Ministry of Agriculture
MoF	Ministry of Finance
MONICA	Model for Nitrogen and Carbon in Agroecosystems
MoP	Ministry of the Presidency
N_2O	Nitrous Oxide
NCEP	National Center for Environmental Prediction
NCDC	National Climatic Data Center
ND-GAIN	Notre Dame Global Adaptation Initiative
NDIA	National Drainage and Irrigation Authority
NIS	National Insurance Scheme
NOAA	National Oceanic and Atmospheric Administration
NPRGC	National Padi and Rice Grading Centre
O_3	Ozone
OLS	Ordinary Least Square
PTCCB	Pesticides and Toxic Chemicals Control Board
RCP	Representative Concentration Pathway
RH	Relative Humidity
RPA	Rice Producer Association
SB	Stabroek News
SRES	Special Report on Emissions Scenarios
UAH	University of Alabama Huntsville
UDEL	University of Delaware
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USGCRP	United States Global Change Research Program
VAT	Value-added Tax
VIF	Variance Inflation Factor
WB	World Bank
WMO	World Meteorological Organization
WWR	World Weather Records

Chapter 1 Introduction

1.1 Background and Motivation

In the first two decades of the 21st century, the impacts of anthropogenic climate change have attracted considerable attention across the world. Of particular concern are the impacts of climate change on agricultural production and food security in terms of access, consumption, and stable prices (Dinar and Mendelsohn 2011; IPCC 2014b; FAO 2016; FAO 2018). The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report notes with high confidence the negative effects of climate change on agricultural production (IPCC 2014a). Crop agriculture is especially sensitive to a changing climate. Variations and changes in rainfall and temperature, and the frequency and intensity of extreme weather events such as floods, droughts, and windstorms are expected to negatively affect future yields in some regions (WB 2010b; IPCC 2014b; FAO 2018).

Although climate change respects no borders, vulnerability remains disproportionate across different countries, groups, and crops. For developing countries like Guyana that depend heavily on agriculture for food, employment, and export earnings (ECLAC 2011; MoA 2013; MoP 2015), climate change represents a clear and present danger with far-reaching socio-economic implications. The effects of climate change usually translate into lower incomes at the household and national levels (FAO 2016).

More importantly, small farmers are especially vulnerable to a changing climate (Frank and Buckley 2012; Harvey et al. 2014; Holland et al. 2017; Harvey et al. 2018). Although they may boast significant experience in responding to climate variability, the sheer magnitude of the variability associated with long-term climate change is beyond traditional coping strategies (Pettengell 2010). In addition, their marginalized status often prevents them from accessing the resources needed to successfully cope with climate shocks (Harvey et al. 2014). According to

Vorley and Chan (2012), small farmers usually lack access to technology, credit, and the institutional support that are crucial for helping them respond to climate change.

1.1.1 Research Location

The geographic focus of this research is the five rice-producing regions of the Cooperative Republic of Guyana. Guyana is located on the northeastern corner of South America between 2°N and 8°N Latitude and 57°W and 61.5°W Longitude and shares borders with Suriname to the east, Brazil to the south and southwest, Venezuela to the west, and the Atlantic Ocean to the north. Figure 1.1 shows the administrative regions of Guyana. Guyana has a land area of 83,000 square miles and a population of approximately 757,000 people, the majority of whom live along the agricultural belt on the Atlantic coast. Rice is primarily cultivated in administrative regions 2, 3, 4, 5, and 6[1] spanning the three counties of Essequibo, Demerara, and Berbice.

[1] Rice is also grown at Moco Moco in Upper Takutu-Upper Essequibo (Region 9).

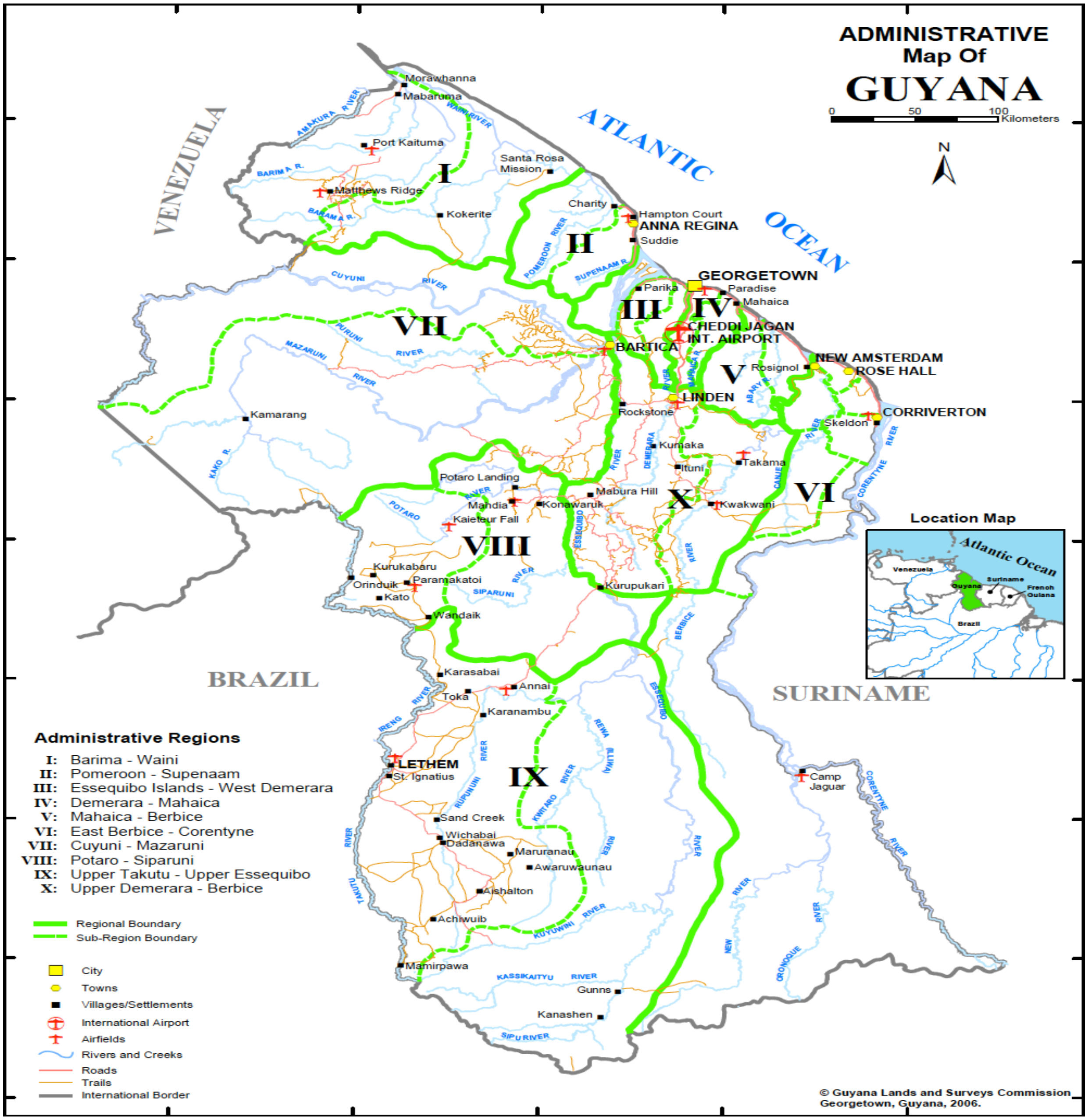

Figure 1.1 Administrative map of Guyana
Source: GLSC (2006)

1.1.2 Guyana's Vulnerability to Climate Change

Guyana is extremely vulnerable to climate change. Approximately 90 percent of the population is concentrated on the low coastal plain natural region (MoP 2015) which forms the heart of the country's economic activities (ECLAC 2011; NAPG 2016), key among them is the agricultural sector (Hickey and Weis 2012; Velasco 2014). The coastal zone ranges from 8 to 65 kilometers in width (Velasco 2014) and runs 425 kilometers along the Atlantic coast (Hickey and Weis 2012). The majority of this relatively flat region is located below sea level and highly susceptible to flooding due to rising seas and excess rainfall. Figure 1.2 shows the coastal zone of Guyana.

Figure 1.2 Map showing the low coastal zone of Guyana
Source: Velasco (2014)

According to the Inter-American Development Bank (IDB) Disaster Exposure Index (DEI), Guyana is the fourth most exposed country to natural disasters in Latin America and the Caribbean (LAC) (Garlati 2013). Barr, Fankhauser, and Hamilton (2010) grouped Guyana among countries that face the highest risks related to climate change. These rankings are especially troubling considering that Guyana is spared from major tropical storms and lies outside of the Caribbean hurricane corridor (MoP 2015). In the LAC region, Guyana is ranked number one in terms of flood risk and faces a very high risk of droughts (Garlati 2013). In the last two decades, Guyana has experienced both floods (2005, 2006, 2008, 2010, 2011, 2013, 2014, and 2015) and droughts (1997-1998, 2009-2010, and 2015-2016) (NAPG 2016). Extreme rainfall events coupled with inadequate infrastructure were chiefly responsible for these flood events.

Equally important is the country's resilience and adaptive capacity. As a developing country, Guyana is one of the poorest countries in the LAC region. It is ranked 125th on the United Nations Development Program (UNDP) Human Development Index (HDI) (UNDP 2018). The Notre Dame Global Adaptation Initiative (ND-GAIN)[2], ranks Guyana 111th in the world (ND-GAIN 2016). Thus, considering Guyana's limited capacity to adapt, a changing climate poses significant threats to the country's economic base.

1.1.3 Climate Variability, Insect Infestation, and Rice Cultivation in Guyana

Although there is a lack of empirical evidence of climatic impacts on rice production in Guyana, articles in the local media and letters to the editor highlight the effects of climate variability on rice farming in recent years. As recent as January 2019, rice farmers in Region 2 were advised to conserve water since low rainfall during the short rainy season [December 2018–

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[2] Summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience (ND-GAIN 2016).

January 2019] resulted in lower water levels in the main water conservancy (SN 2019). Similarly, the start of the 2019 spring season [December 2018- January 2019] has been severely affected by drought like conditions in Region 6. Reports suggest that over 3,237 hectares [8,000 acres] of rice are at risk while another 3,237 hectares [8,000 acres] remain uncultivated due to the lack of water (KN 2019).

In June 2018, heavy rainfall coupled with the lack of maintenance prompted emergency work by the Mahaica, Mahaicony, Abary-Agricultural Development Authority (MMA-ADA) on the Onverwagt access dam [farm-to-market road] in Region 5. This dam is a major access point to rice farms in the region. Yusuf (2018) reported in July 2018 that impassable dams made worse by rainy conditions resulted in over 80 hectares [200 acres] of rice left unharvested in Region 6. Inclement weather and inaccessible dams negatively affect harvesting and increased the costs of transporting the grains from the field to the mills (SN 2018). In September 2018, heavy rainfall and poor access dams delayed harvesting by a week in Region 2 (KN 2018a). Delays in harvesting usually result in lower than expected yields. According to Khan (2018a), waterlogged land affected the harvest of approximately 8,093 hectares [20,000 acres] of rice on the northern side of Region 2.

In January 2017, heavy rainfall inundated over 1,214 hectares [3,000 acres] of rice in Region 2 forcing farmers to incur additional costs to pump out excess water from their fields (iNews 2017a). In May 2017, poor dams attributed to heavy rainfall restricted farmers' access to their fields in Region 2 (iNews 2017b) while heavy rainfall threatened young rice plants in Regions 5 and 6 in June 2017 (iNews 2017c). The U.S. Department of Agriculture (USDA) Foreign Agricultural Service reported that heavy rainfall slowed sowing and field activities in Regions 2, 3, and 5 in January 2017 and dry condition in October 2017 accelerated plan maturation leading to lower yields (USDA-FAS 2018).

El Niño conditions in 2015-2016 resulted in rice production declining by approximately 13 percent (Fanfai 2016). Young rice plants on the Essequibo coast [Region 2] were affected by flooding as a result of persistent rains, poor drainage, and non-functioning sluices and pumps in at the start of the spring crop in December 2016 (SN 2016). In May 2015, 404 hectares [1,000 acres] of rice between Queenstown and Devonshire Castle in Region 2 were threatened by flooding attributed to heavy rainfall which was exacerbated by a non-functioning pump (SN 2015).

Reported incidences of insects and pests have also appeared in the local media. In March 2018, rice farmers on the Corentyne [Region 6] reported that their fields were being attacked by worms and flies (iNews 2018). In November 2018, farmers in Region 2 that planted late in the autumn season were severely affected by paddy bug infestations (Khan 2018). The late planting is usually due to heavy rains that delayed harvesting in the previous season and/or the lack of water at the beginning of the current season. As a result, farmers were forced to burn 404 hectares [1,000 acres] of rice in the region because of the paddy bug infestation (KN 2018b). Confirmed reports of paddy bug infestation in Region 2 were also reported in 2015 (Khan 2015). Despite such evidence, empirical research in this area is significantly lacking. As a result, information on how farmers perceive, are impacted by, and respond to climate change remains largely unknown.

1.1.4 Importance of Rice Production to Guyana

Rice (Oryza sativa L.) is important to Guyana because it is a major source of nutrition and rural livelihood. Rice is the main staple in the diet of most Guyanese, with consumption of approximately 50 kg per capita annually (ECLAC 2011). The industry supports about 6,300 farmers and their families directly (GRDB 2018) and 150,000 people indirectly (Ragnauth et al. 2014). The rice sector is the largest user of agricultural land with approximately 87,400 hectares [215,970 acres] under cultivation (GRDB 2018) making it a major source of income and employment for Guyanese. Rice production is also the primary agricultural sub-sector. In 2017, rice contributed 3.4 percent to the gross domestic product (GDP), 20.7 percent to agriculture GDP, and 33.7 percent to crop agricultural GDP (BoG 2017). In 2017, approximately 86 percent of the rice produced in Guyana was exported thus contributing about 14 percent to total export earnings (BoG 2017).

1.1.5 Small Farmers

Morton (2007) suggests that there is no commonly accepted definition of small farmers. One definition is that they are subsistence farmers, consuming the majority of their output within the household (Barnett, Blas, and Whiteside 1996). The scale of production is another often used criteria to identify small farmers. For example, Lowder, Skoet, and Raney (2016) used a threshold of less than 2 hectares to estimate that there are 475 million small farmers in the world. It should be noted that the use of production scale in terms of farm size or farm income is subjective to the national circumstance; small farmers in developed countries are very different from small farmers in developing countries (Morton 2007). Additionally, the size of farms and circumstances of small farmers are likely different among developing countries.

In Guyana, small rice farmers are not considered subsistence farmers since they sell their entire harvest on the local market (to rice millers). As such, a production scale approach is used to define small farmers in the Guyana context. For the purpose of this research, a small farmer is defined as someone who cultivates 4.45 hectares (11 acres) or less in rice each season. There are approximately 2,714 (42.4% of all rice farmers) small farmers cultivating 6,205 hectares [15,335 acres] in Guyana (GRDB 2017). The average farm size is 2.29 hectares [5.65 acres]. Although small farmers are fully integrated with the local markets, several characteristics distinguish them from large farmers. A great majority of small farmers have a secondary source of income from either off-farm employment or receive a government pension. Off-farm employment sources of income may include agricultural labor with large farmers or non-agricultural employment (e.g., taxi driver).

Farmers engaged in small-scale production in Guyana are also historically disadvantaged in terms of access to credit. Many small farmers do not possess the collateral or production scale needed to secure credit from lending institutions. In instances where they are able to obtain credit from millers, it is often at exorbitant interest rates and/or unfavorable terms. For example, farmers that secure fertilizer credit from a rice miller are contractually required to sell their grains to that miller in addition to paying a fee (usually a percentage) for the fertilizer credit received. While some small farmers may own a tractor and implements, none of them own a combine harvester. As such, small farmers are perpetually at the mercy of large farmers when it comes to timely land preparation and harvesting of their grains. As a result, they are exposed to climate variability due to out of season sowing and harvesting.

1.2 Brief History of the Rice Industry in Guyana

In 2008, Guyana celebrated 100 years as a rice exporter. However, the history of rice cultivation dates back to the days of slavery under Dutch, French, and British rule. While it is unknown when rice was first grown in Guyana, historical records suggest it was introduced in the mid-18th century by the Dutch as a source of food for enslaved Africans (Madramootoo 1973).

According to McGowan (2008), enslaved Africans working on the sugar plantations first planted rice to supplement inadequate food rations while runaway slaves planted rice at their hinterland settlements. The abolition of slavery in 1834 saw a decline in rice cultivation by Africans but the arrival of indentured servants from India beginning in 1838 precipitated increased demand which was met by imports from India (McGowan 2008).

Increased imports from India gave the impetus to produce rice locally. However, the lack of capital, knowledge, and irrigation resulted in several unsuccessful attempts to cultivate rice to satisfy local consumption (Homenauth 1997; McGowan 2008;). Starting in the early 1860s, East Indians began to successfully engage in subsistence rice farming and cultivation expanded throughout the colony in subsequent years, albeit in a haphazard manner (McGowan 2008).

The discontinuation of re-indentureship (renewal of contracts) in 1873 paved the way for East Indians to leave the sugar plantations and engage in small-scale rice cultivation (McGowan 2008). Beginning in the early 1880s, economic depression in the once dominant sugar industry led to agricultural diversification with land, labor, and capital diverted to rice cultivation (Homenauth 1997; McGowan 2008c). It is at this point that the rice industry in what was then British Guiana began to grow reaching unprecedented heights in the decades to come.

Between the 1880s and 1920s, the land area under rice cultivation increased rapidly while rice imports decreased. In 1893 about 1,011 hectares [2,500 acres] were under cultivation but this number grew to 24,776 hectares [61,222 acres] by 1919 (GRDB 2008). During this period, rice cultivation was stimulated by the availability of cheap land in lieu of costly repatriation of East Indians, local shortages of ground provisions (e.g., cassava, eddo[3], and yams), production shortfalls in India, and high importation costs of wheat flour (McGowan 2008b). Above all, it was

[3] Taro root.

the persistence and diligence of East Indians that defied the constant threat of malaria to engage in rice production (McGowan 2008b). Thus, Homenauth (1997) credits the success of rice cultivation in Guyana to the arrival of East Indians who brought with them indigenous knowledge from India.

For much of the first half of the 20th century, land preparation, harvesting, threshing (separating grains from the stalk), and transportation were done independent of modern technology and cultivation was almost entirely under the control of small farmers (GRDB 2008). In 1946, two important laws were introduced to further develop the industry. First, the British Guiana Rice Marketing Board was created to oversee the purchase and sale of rice paddy. Second, the Rice Producer Association (RPA) was established to protect, promote, and advance the interest of rice farmers (GRDB 2008).

The post-World War II years saw the introduction of new techniques, varieties, and mechanization which led to rice exports almost doubling between 1939 and 1957 (GRDB 2008). Starting in 1957, several land development schemes were established. These include the Black Bush Polder scheme [Region 6] which opened-up 12,545 hectares [31,000 acres] of land and the Tapakuma [Region 2] and Boerasirie Extension Project [Region 3] which helped boost drainage and irrigation and access to additional land (GRDB 2008).

In 1958, there were approximately 27,000 small farmers whose fields ranged from 0.8 hectare [2 acres] to 6.1 hectares [15 acres] and less than 300 farmers held more than 40.5 hectares [100 acres] (GRDB 2008). Additional mechanization in the 1960s and 1970s transformed the industry at the expense of small farmers which began to decline sharply (GRDB 2008). In addition, the establishment of the Mahaica, Mahaicony, Abary Agricultural Development Authority (MMA-ADA) in 1977 made available another 14,163 hectares [35,000 acres] of land (GRDB 2008). However, the prolonged economic troubles that began in the late 1970s would have far-reaching implications for the industry and the country as a whole. Production declined from an average of approximately 150,000 tons in the 1980s to 93,400 tons in 1990 but rebounded to 151,000 tons in 1991 (GRDB 2008).

Until 1995, the rice industry was overseen by three state entities: the Guyana Rice Export Board (GREB), Guyana Rice Milling and Marketing Authority (GRMMA), and the National Padi and Rice Grading Centre (NPRGC). To streamlined operations and improve efficiency, these three entities were replaced with the creation of Guyana Rice Development Board (GRDB) in 1995 (GRDB 2008). The primary objectives of the GRDB are to develop the industry and expand exports, conduct research and disseminate information through extension services, and other promotional and development activities mandated by the Board.

With the establishment of the GRDB, the last decade of the 20th century saw a steady increase in rice production reaching 365,500 tons in 1999 before declining to 291,800 tons in 2000 due to political instability, debt repayment problems, and adverse weather conditions (GRDB 2008). The first decade of the 21st century saw fluctuations in rice production due in part to several floods and droughts, including a devastating flood in 2005. Despite these setbacks, rice production increased steadily starting in 2007. This was due in part to the introduction of several high yielding varieties since 2005. In 2017, aggregate production was 630,104 metric tons of rice, earning approximately US $201M in revenues (BoG 2017). Figure 1.3 illustrates aggregate rice production for the period 1970-2017.

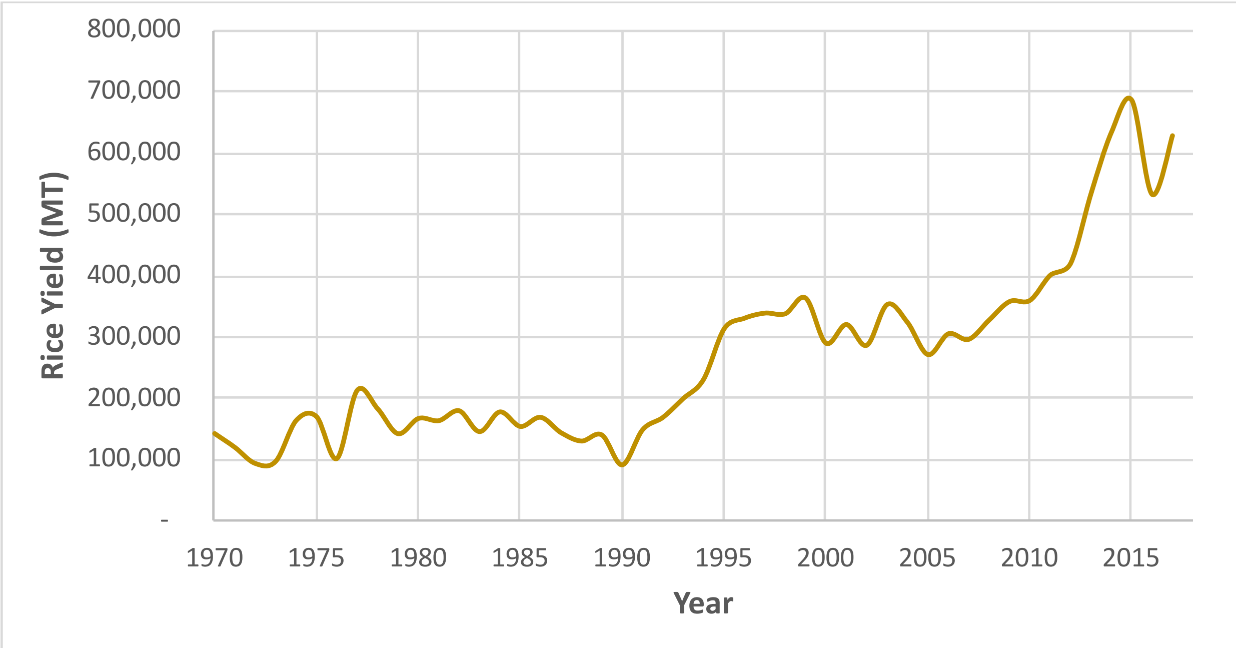

Figure 1.3 Aggregate rice production for Guyana (1970-2017)

1.3 Contemporary Rice Production in Guyana

Today, rice is still cultivated under irrigation; rainwater stored in the many canals and water conservancies that crisscross the agricultural belt is released into irrigation canals[4]. However, water levels are highly susceptible to variation in rainfall patterns and timing. There are two seasons per year: spring and autumn. For the spring season, sowing is done primarily between December and January and harvesting between March and May. For the autumn season, sowing is done primarily between May and June and harvesting between September and November.

Rice is grown under a highly mechanized system where tractors and combines are used for land preparation (plowing, harrowing, and puddling) and harvesting, respectively. The crop is directly seeded using pre-germinated seeds sown onto lightly flooded fields. On small farms, sowing, fertilizer application, and the control of insects and pests, diseases, and weeds are strictly

[4] The islands of Hogg, Leguan, and Wakenaam in Region 3 rely exclusively on rainfall since there is no water conservancy on the islands while in some areas in other regions farmers depend on nearby rivers in the absence of irrigation systems.

done by physical labor[5] while on some large farms, aircraft are used for sowing, applying fertilizer, and controlling insects and pests, diseases, and weeds.

Harvested rice paddies are usually transported in bulk to the mills. The processing of paddy into rice is done at rice mills located throughout Guyana's rice belt. Smaller mills produce rice mainly for domestic consumption while larger mills concentrate mainly on production for export. Export markets include the Caribbean, Central and South America, and the Europe Union (GRDB 2015a). Since 1997, 15 new rice varieties have been released by the GRDB Rice Research Station (GRDB 2015b). In April 2018, GRDB 15 became the latest variety to be released. Among other characteristics, it promises higher yields and the ability to withstand lodging. However, such assurances can be easily offset by poor infrastructure exacerbated by unfavorable weather conditions attributed to climate change.

1.4 Other Challenges Facing the Rice Industry in Guyana

Apart from the vagaries of weather, the rice industry in Guyana is plagued with several other challenges that compound the impacts of increased climate variability on farmers in general and small farmers in particular. The following briefly describes several of these challenges reported in the media and by key informants interviewed as part of this research.

1. ***High cost of production*** – The high cost of inputs such as fertilizer, chemicals, and fuel are further exacerbated by the value-added tax (VAT) farmers are required to pay on inputs. In addition, import duties on equipment and machinery are usually passed on to small farmers that rely on large farmers to prepare their land and harvest their grains. When the costs of climate change adaptation are factored, profit margins are usually thin.

[5] Laborers apply fertilizer by walking through the field and throwing by hand and use a spray can or motor blower to spray for insects and pests, diseases, and weeds.

2. ***Unstable prices*** – The price received by farmers is dictated by the free market system. In the absence of a minimum established price, farmers are price takers who are at the mercy of the market. In addition, the loss of the lucrative Venezuelan market in 2015 has forced millers and by extension, farmers to accept lower prices from markets elsewhere.
3. ***Poor infrastructure*** – In recent years, the drainage system has been in deplorable condition due to poor maintenance by the government. This has worsened the impacts of excess rainfall which often leads to flooding. Untimely release of irrigation water by some Water User Associations also affects planting in the season. In addition, farm-to-market roads are often impassable due to the lack of maintenance and repairs. This causes delays in accessing the fields and/or transporting harvested grains.
4. ***Generic weather forecast*** – Although weather forecast information is readily available, it lacks specificity as it relates to rainfall patterns across the agricultural belt. Hence, the lack of details limits farmers' ability to consider such information when making farm management decisions.
5. ***Late payments*** – Farmers in some areas of the country often face significant delays in receiving their payments which is in contravention of the Rice Factories Act of 1998. The law requires rice millers to pay 50 percent of the amount due to farmers within two weeks of receipt of the grains and the remainder within 42 days. Significant delays of payments deny farmers vital working capital needed to replant in the subsequent season. Furthermore, late payments are not accompanied by interest on the outstanding amounts owed to farmers.
6. ***Rent and service charge*** – In 2017, the government raised the rental and drainage and irrigation charges for lease land to in excess of 600 percent for some charges. This is a

significant burden on rice farmers already struggling to cope with low prices and high cost of production.

7. ***Roaming cattle*** – In some areas, unattended cattle cause significant damage to rice fields. Cattle usually enter the rice fields at night and consume the plants thus leaving a trail of destruction in the process.

1.5 Research Questions

To the researcher's knowledge, there has been no previous study on the impacts of climate change on rice production for Guyana. As such, this research is both novel and timely given the reports in the media regarding changing climatic conditions and insect infestation problems farmers are facing. In addition, the socioeconomic implications for small farmers, the rice industry, and the country as a whole compels a closer examination of this problem. Therefore, the objective of this study is to examine the impacts of climate change on rice production in Guyana and to assess how small farmers are adapting. To achieve this objective, the following research questions are proposed and addressed by this research:

1. How has the climate in Guyana changed?
2. What non-climatic factors influence rice yields of small farmers?
3. How do small rice farmers and key informants perceive changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?
4. What impacts are farmers and key informants seeing due to the observed changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?
5. What adaptive measures are they adopting in response to these impacts?

1.6 Contributions and Anticipated Impact

Given the lack of empirical evidence on the impacts of climate change on rice production in Guyana, this study will enrich our knowledge and understanding of how farmers in general and small farmers specifically perceive, are impacted by, and respond to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. Since most studies are predominantly quantitative in nature, another contribution of this study is the use of qualitative methods to explore cognitive dimensions of and adaptation to climate change.

This study also has broader implications for regions of the world where small farmers that are important to agricultural production may be facing similar challenges. Since little is known about how small rice farmers in Latin America and the Caribbean (LAC) region respond and adapt to climate change, this study will contribute to that literature. This research will also contribute to the broader body of knowledge of how small farmers in the global south perceive, are impacted by, and respond to climate change. The findings will highlight novel strategies and best management practices that can be used to develop appropriate adaptation measures and institutional responses based on local conditions and needs.

1.7 Study Overview

Including this initial chapter, this study comprises of seven chapters. Chapter 2 provides an overview of the relevant literature on climate change and crop agriculture. It includes a discussion on the interaction between climate change and crop agriculture, the common methods used to study the relationship, and a summary of studies on climate change impacts from across the world. Chapter 3 describes the data source and collection, and methods used in the analyses. Chapter 4 examines the changes in rainfall, minimum and maximum temperature over the last 115 years for Guyana. Chapter 5 explores the effects of perceived changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds together with socio-economic, farm-level, and institutional characteristics on rice yields at the farm-level. Chapter 6 documents small farmers' and key informants' perceptions of changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds and the impacts and responses to the observed changes. This chapter also presents the adaptation practices implemented and small farmers' ability to pay for these changes in farming practices. A summary of the service and support provided to farmers by district rice extension officers is also discussed. Chapter 7 summarizes the key findings and explores the overall policy implications of this study. Opportunities for future research are subsequently identified.

Chapter 2 Review of Literature: Climate Change and Crop Agriculture

2.1 Introduction

Agricultural production is vulnerable to a changing climate. As such, the purpose of this chapter is to provide an overview of the relevant literature at the climate change – crop agriculture nexus. Section 2.2 provides multiple pieces of evidence of global climate change. The relationship between crop agriculture and climate change is presented in section 2.3 while specific links between climate change and rice are explored in section 2.4. Section 2.5 describes the different approaches to estimating climate change impacts on crop agriculture, while section 2.6 discusses the sources and types of climate data used in climate impact studies. Section 2.7 summarizes empirical evidence of the impacts of climate change on crop agriculture from three perspectives: globally, developed countries, and developing countries. Empirical evidence of farmers' perceptions and adaptation to climate change is presented in section 2.8. Section 2.9 presents the conceptual framework while the gaps in the existing literature are outlined in section 2.10. Section 2.11 provides a summary of key points covered in this chapter.

2.2 Evidence of Global Climate Change

Observed changes attributed to climate change are prominent across the world. Signs of climate change include soaring temperatures, shifting rainfall patterns, more extreme weather events, warming, rising, and more acidic oceans, declining Arctic Sea ice, shrinking ice sheets, and retreating glaciers. These and many other changes provide ample evidence of a changing climate. Perhaps more importantly, many of these changes are linked to the increasing levels of greenhouse gases[6] in our atmosphere, attributed to human activities.

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[6] Gases in Earth's atmosphere that absorb and emit radiation thus causing a warming effect on Earth's surface (Mann and Kump 2015). Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere (IPCC 2012).

2.2.1 Greenhouse Gases and Climate Change

Earth's climate is driven by the amount of solar energy that is absorbed at the surface. Increased concentrations of greenhouse gases, primarily carbon dioxide, methane, and nitrous oxide in the atmosphere absorb the outgoing energy radiated by the surface, resulting in Earth's atmosphere becoming warmer (Bast 2013). In 2017, the average global carbon dioxide concentration was approximately 405 parts per million (ppm) (Dlugokencky et al. 2018). Figure 2.1 illustrates the concentration of carbon dioxide in the atmosphere over time while Figure 2.2 shows the global emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases from 1990 to 2010.

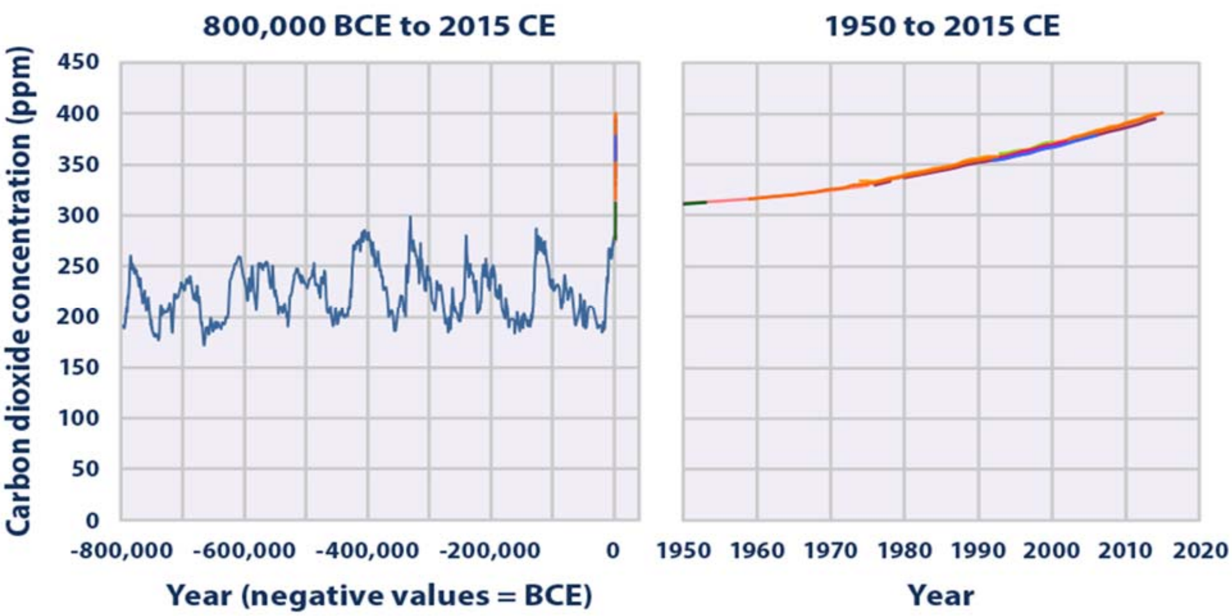

Figure 2.1 Global atmospheric concentrations of carbon dioxide over time
Source: EPA (2016b)

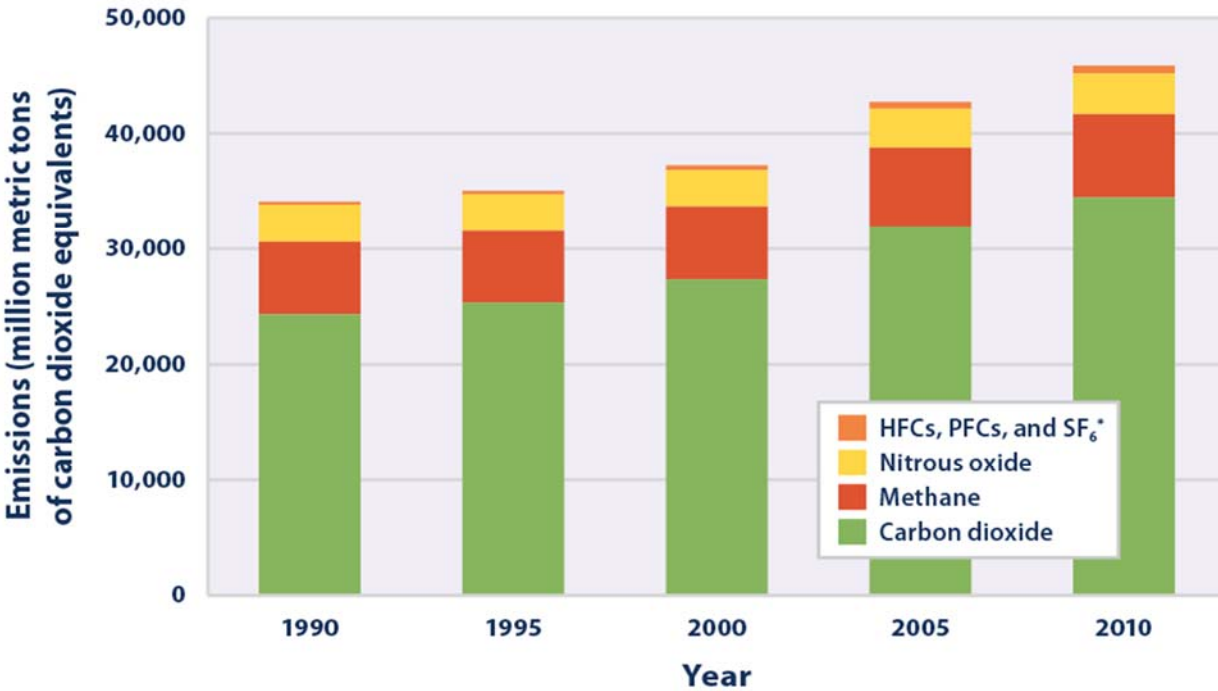

Figure 2.2 Global greenhouse gas emissions by gas (1990-2010)
Source: EPA (2016c)

2.2.2 Global Land Surface Temperature

The global land surface temperature encompasses measures of average near-surface air temperature over land and sea-ice (Mach, Planton, and von Stechow 2014). According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (IPCC 2014b). Ten of the warmest years on record have happened since 1998 with the four warmest years occurring since 2014 (Sánchez-Lugo et al. 2018). There is also high confidence that human-influenced global warming reached approximately 1°C above pre-industrial levels in 2017 (IPCC 2018). Using 1901-2000 average as a baseline, Figure 2.3 shows the change in global annual average temperatures.

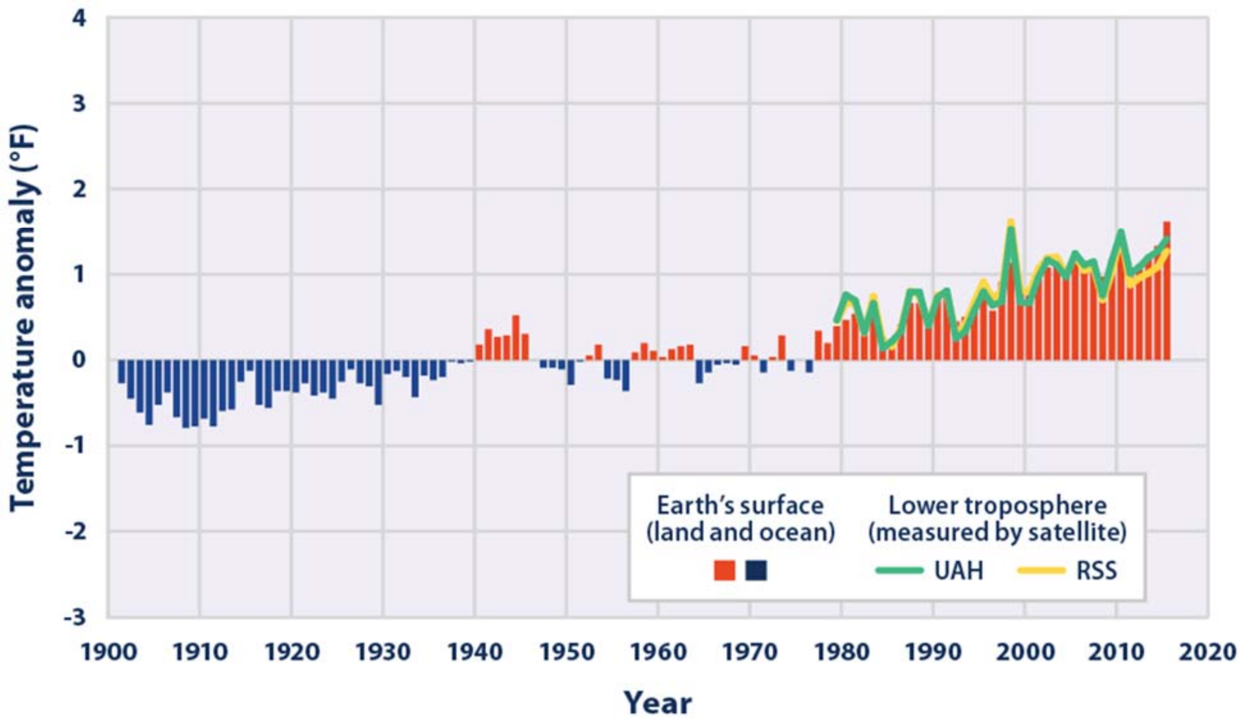

Figure 2.3 Temperature worldwide (1901-2015)
Source: (EPA 2016g)

2.2.3 Global Sea Surface Temperature

Sea surface temperature refers to the temperature of the water just below the surface of the ocean as measured by ships, buoys, and drifters (Mach, Planton, and von Stechow 2014). Although there was a slight decline in the global sea surface temperature in 2017, the long-term warming trend continues to point upwards (Huang et al. 2018). With the average of 1971-2000 as a baseline, Figure 2.4 depicts the changes in the average surface temperature of the world's oceans.

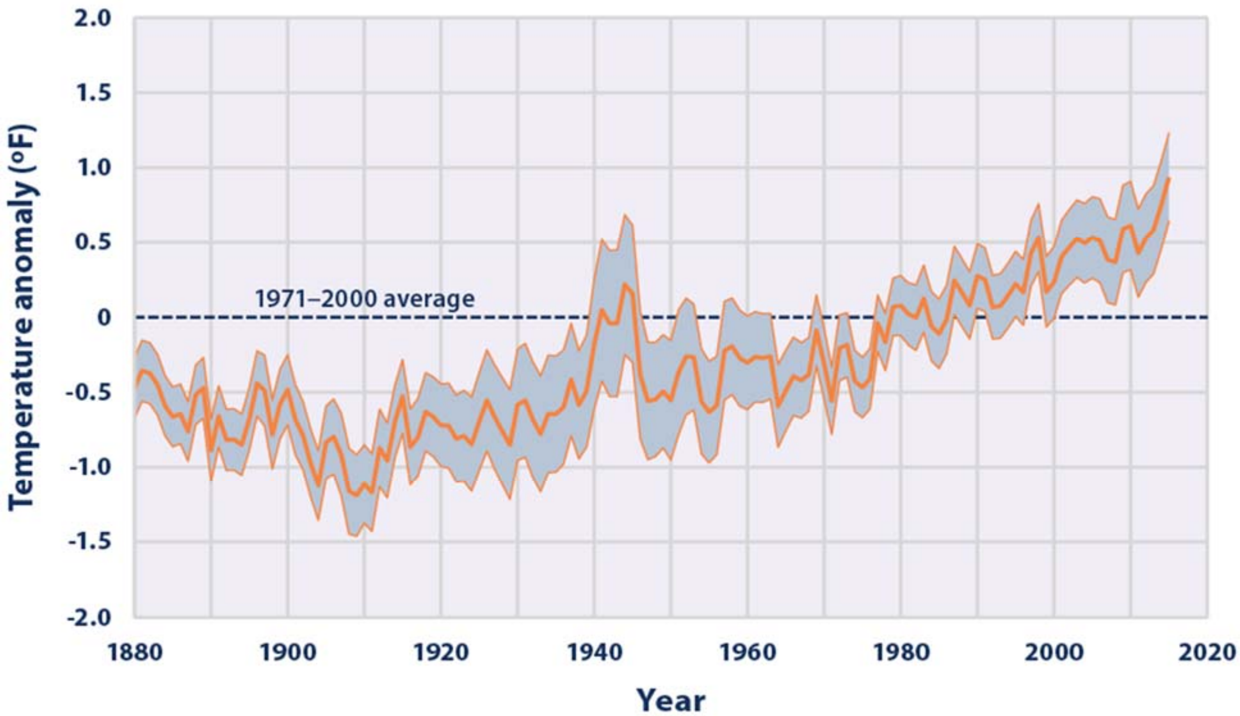

Figure 2.4 Average global sea surface temperature (1880–2015)
Source: EPA (2016c)

2.2.4 Global Precipitation

Changes in precipitation patterns are also evident with more frequent heavy precipitation events (USGCRP 2018). For example, in 2017 precipitation over global land areas exceeded long-term averages, with some areas wetter than others (Vose et al. 2018). Precipitation deficits on the other hand saw a sharp decline in early 2017, then rising above average later in the year (Osborn et al. 2018). Using the 1901-2000 average as a baseline, Figure 2.5 illustrates the global total annual amount of precipitation over land.

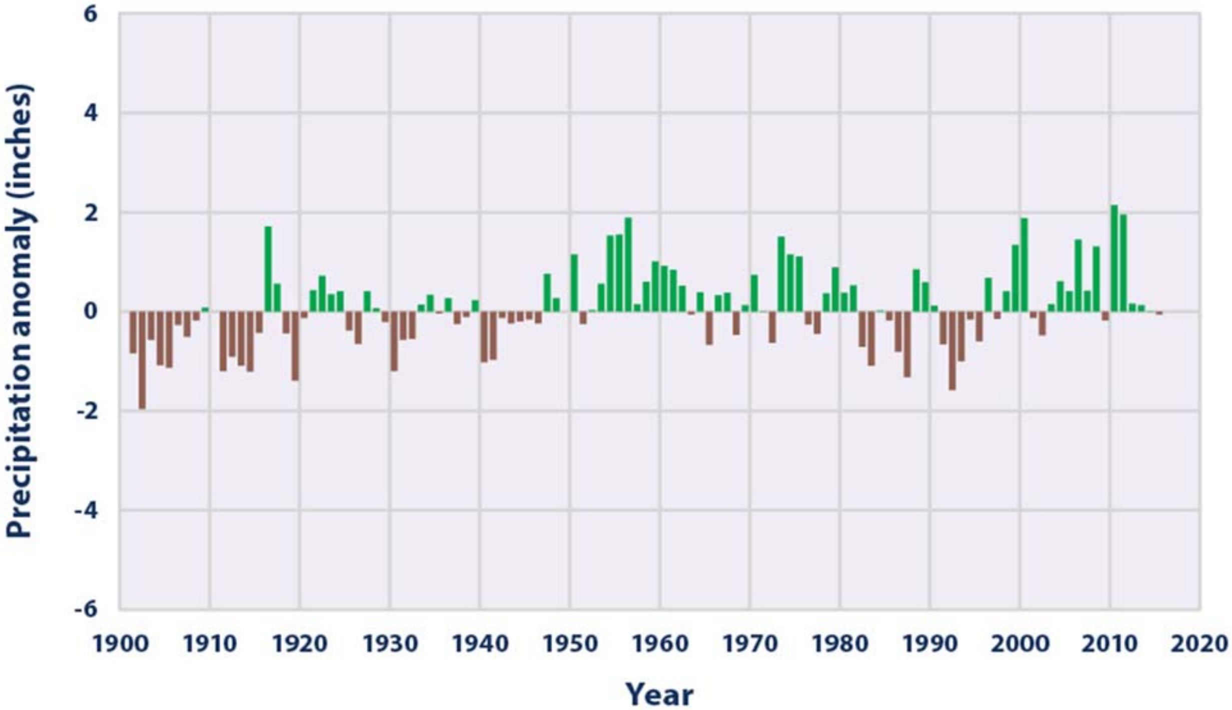

Figure 2.5 Precipitation worldwide (1901-2015)
Source: EPA (2016f)

2.2.5 Global Mean Sea Level (GMSL)

Rising seas are another result of a warming world. In 2017, global mean sea level (GMSL) was approximately three inches higher than it was in 1993[7], rising at an average rate of 1.2 inches per decade (Thompson et al. 2018). Based on long-term tidal gauge measurements and satellite altimetry, Figure 2.6 shows the cumulative changes in sea level for the world's oceans.

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[7] Satellite record began in 1993.

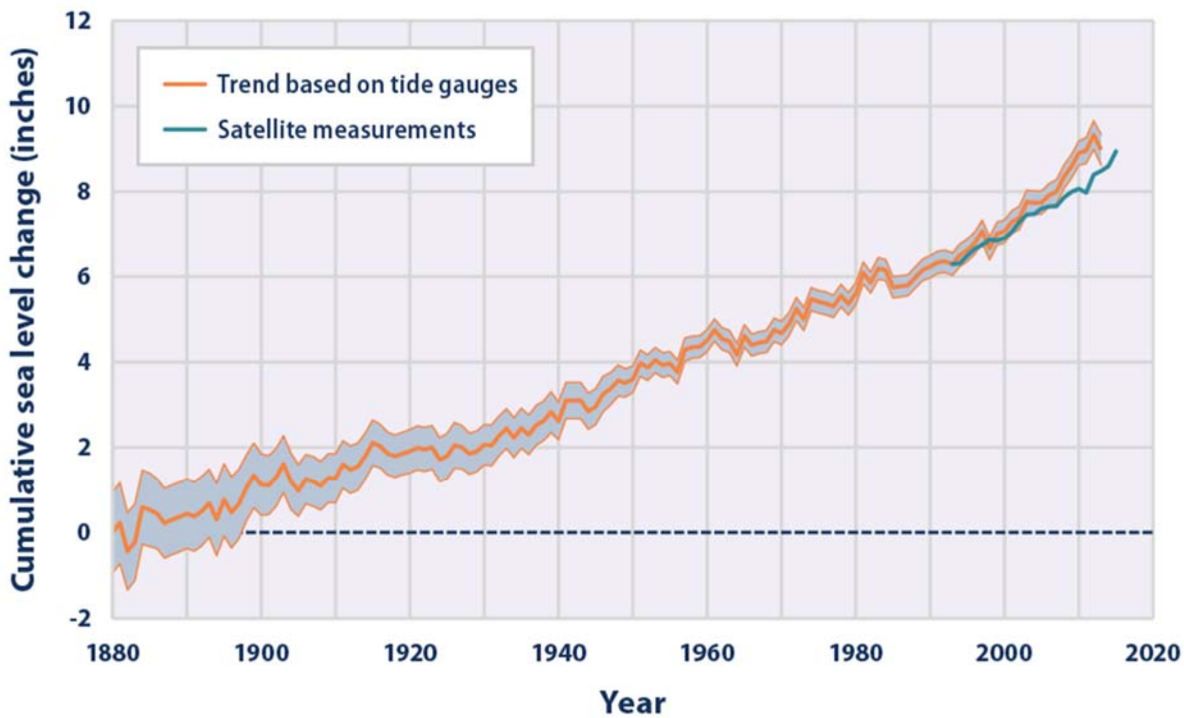

Figure 2.6 Global average absolute sea level change (1880–2015)
Source: EPA (2016d)

2.2.6 Artic Sea Ice

The extent of Arctic Sea ice varies considerably across seasons with minimum and maximum extent typically occurring in September and March, respectively (Meier et al. 2014). In March 2017, the maximum extent of Arctic Sea ice was the lowest ever recorded while in September 2017, the minimum extent of Arctic Seas ice was 25 percent below the long-term average (Perovich et al. 2018). Figure 2.7 shows the extent of Arctic Sea ice for the months of September and March from 1979 to 2016. Figure 2.8 captures the dwindling Arctic Sea ice between September 1979 and September 2015.

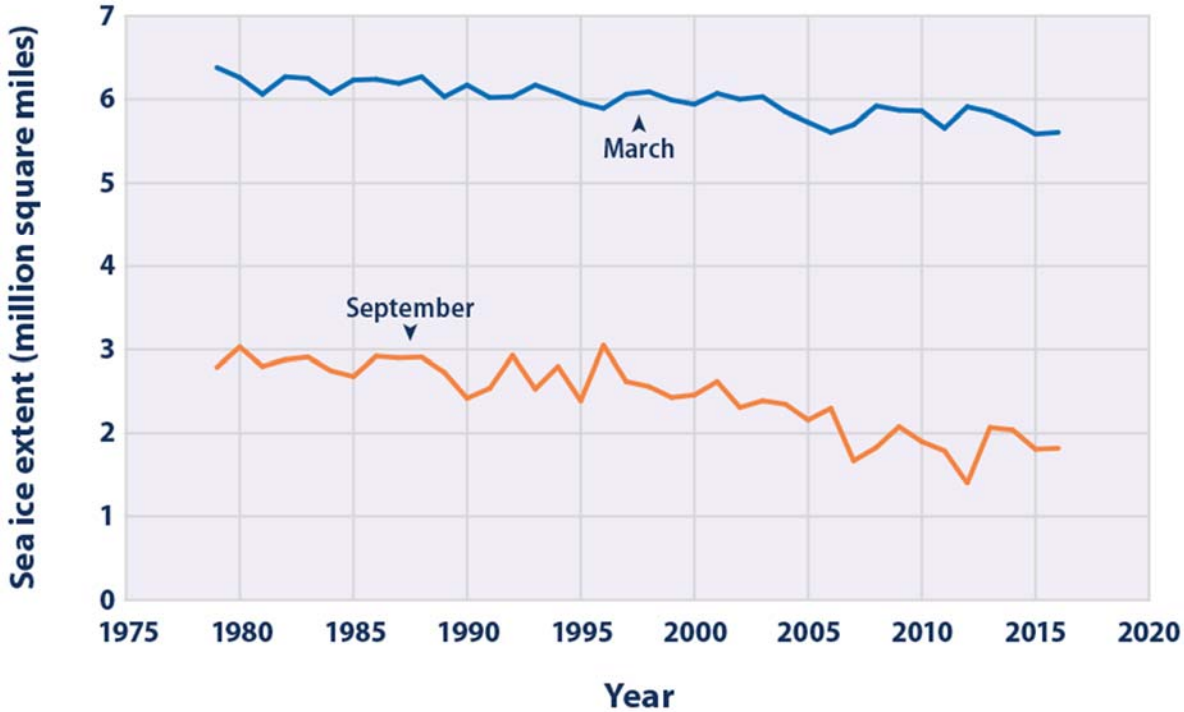

Figure 2.7 March and September monthly average Arctic Sea ice extent (1979–2016)
Source: EPA (2016a)

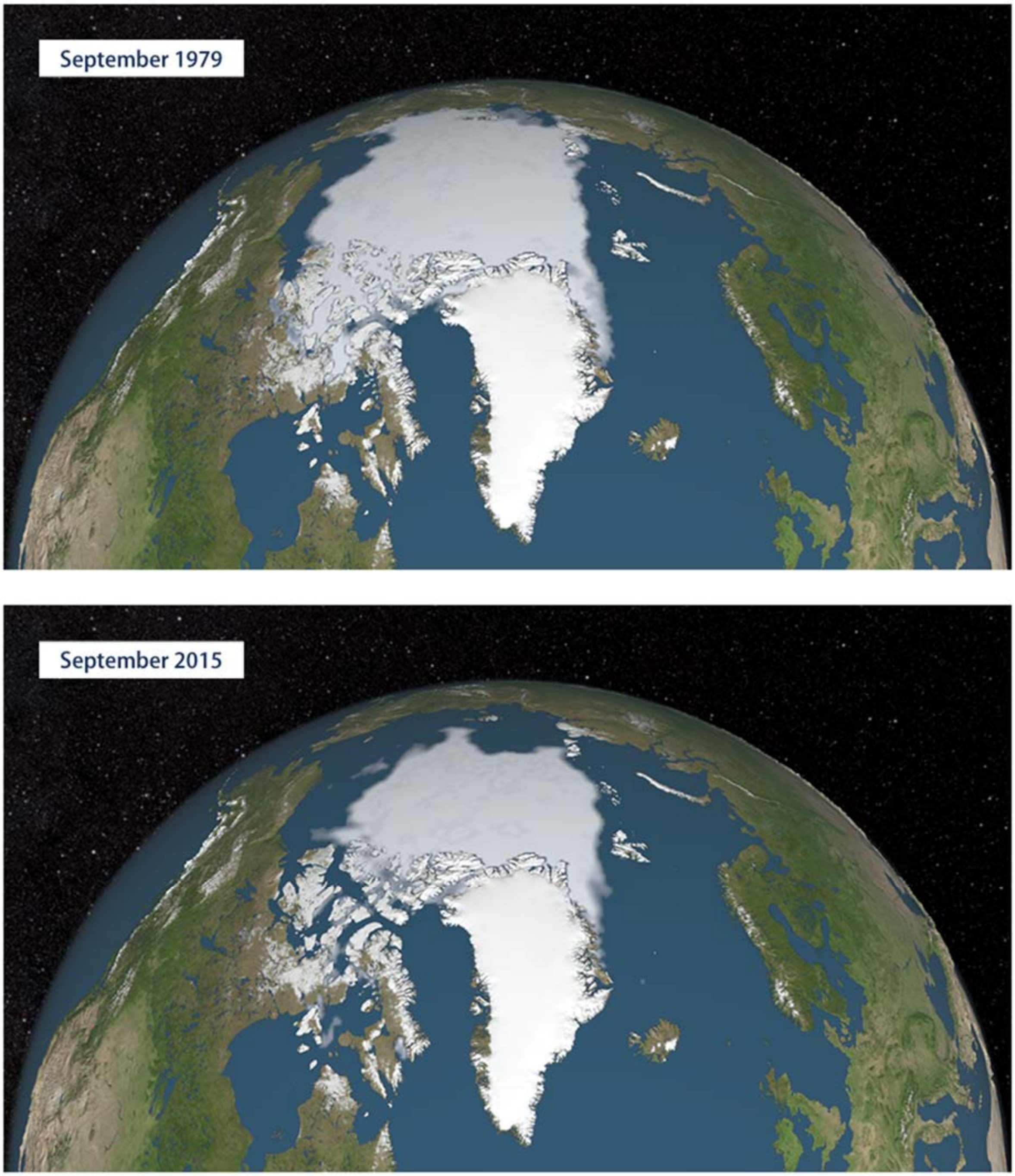

Figure 2.8 Dwindling Arctic Sea ice
Source: EPA (2016a)

2.3 Overview of Climate Change and Crop Agriculture

The agricultural sector is perhaps the most vulnerable to a constantly changing climate. This is because climate is a key determinant of agricultural output (Adams et al. 1998), given that outdoor production practices depend heavily on particular levels of temperature and precipitation (Ackerman and Stanton 2013). A changing climate suggests changing conditions for agriculture, including shifts in growing seasons, seasonal temperatures, rainfall timing, quantity, intensity, and distribution, and extreme weather events (Rose 2015). Hence, climate change impact crop yields in a myriad of ways including temperature extremes, water availability and usage, and soil health. Waggoner (1983) noted that plant systems and hence, crop yields, are influenced by many environmental factors such as moisture and temperature that may act either synergistically or antagonistically with other factors in determining yields.

A quarter of a century ago, Mendelsohn, Nordhaus, and Shaw (1994) concluded that warmer weather was expected to bring net benefits to global agriculture. Today, rising temperatures, variable rainfall, and extreme weather events (e.g., flood and drought), are expected to increasingly disrupt agricultural production. Although climate change can have both positive and negative effects on crop yields, in general, negative impacts have been more common (IPCC 2014a).

Temperature increases have been found to reduce yields and the quality of crops (Adams et al. 1998). Warming generally causes some plants that are below their optimum temperature to grow faster. However, for other plants, faster growth means there is less time to mature. Simpson (2016) notes that rising average temperatures cause stress leading to early maturity. This means that plants spend less time in each development stage including reproduction which causes yields to decline. Additionally, increased nighttime temperature leads to respiration that consumes larger amounts of plants' energy created during the day resulting in less energy available for producing grains; heat waves cause pollen to become sterile during flowering, which means no grain is produced (Simpson 2016).

Temperature increase, particularly in regions where agricultural production is currently limited by a colder climate, extends the growing season available for plants and reduces the growing period required by crops to mature. However, changes in the frequency of extreme climatic events can also be damaging and costly for agriculture (Parry 1990). Extreme weather events that include heat waves, droughts, strong winds, and heavy rainfall can lead to crop failures, soil erosion, flooding, and the occurrence of pest and diseases (Motha 2011).

While plants exposed to increased levels of carbon dioxide (CO_2) are expected to benefit from carbon fertilization, the extent and level of fertilization depend on the species of plant. Increased atmospheric CO_2 concentrations are vital to photosynthesis and can have a direct effect on the growth rate of crop plants and weeds (Parry 1990). Higher concentrations of CO_2

would also result in reduced transpiration (i.e. water loss) as plants reduce their stomatal apertures (Adams et al. 1998). Despite these benefits, elevated CO_2 levels also suggest the potential for increased weed pressure. Weeds are likely to become more prolific and are expected to invade new habitats as global warming increases. As a result, overall yields are likely to decline for crops that compete for vital nutrients with an increased weed population. Additionally, carbon fertilization may interact with other environmental influences. For instance, the interaction between atmospheric CO_2 and tropospheric (ground level) ozone may reduce yields of many plants.

Climate change also causes variation in precipitation in terms of the timing, quantity, intensity, and distribution (Simpson 2016). No rainfall causes water deficits, which reduces soil moisture. This may cause farmers to abandon planting the crop altogether, crop failure, or low yields due to water deficiency. Heavy downpours may lead to flooding which can result in crop failure. Additionally, flooding may result in soil loss and/or degradation, which reduce soil fertility. Less fertile soil is likely to result in lower yields. Rainfall that occurs too early may disrupt harvesting and/or lead to unavailability of water at the start of the planting season. Rainfall that arrives late may lead farmers to abandon the crop altogether. Figure 2.9 illustrates the impacts of climate change on the agricultural sector.

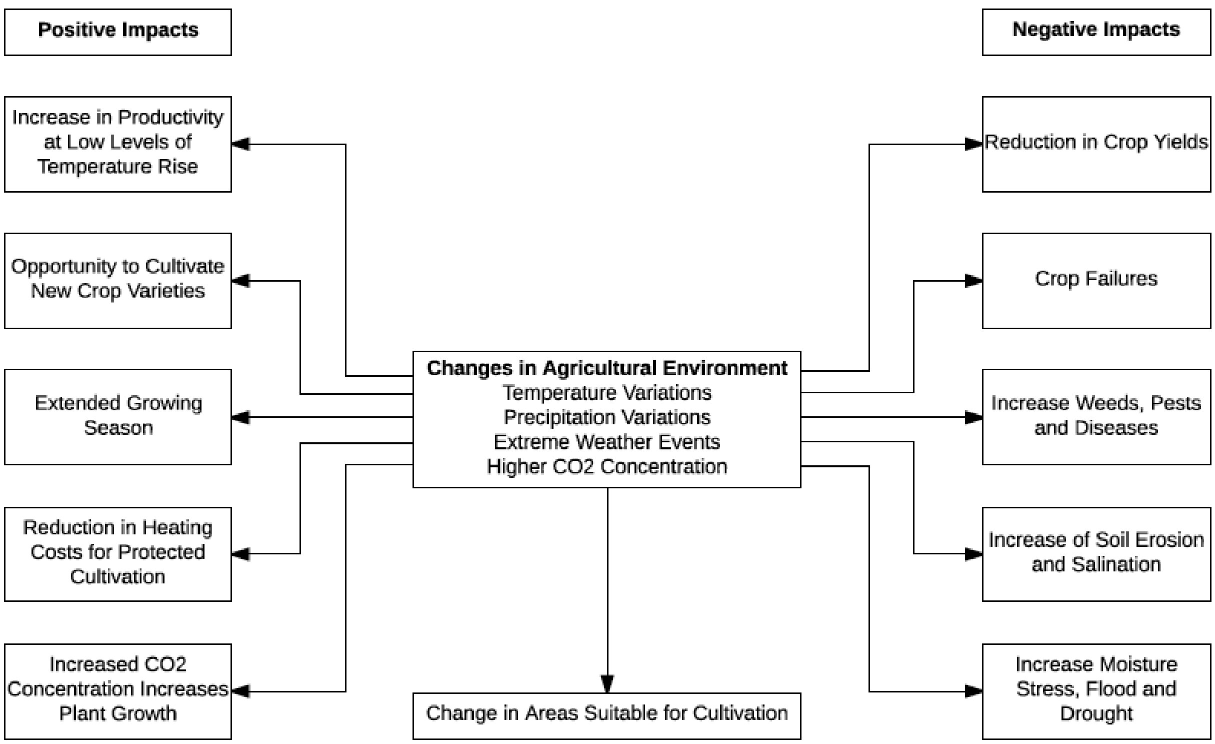

Figure 2.9 Impacts of climate change on the agricultural sector
Source: Author (as adopted from (Kim, n.d.).

2.4 Climate Change and Rice Cultivation

Although the global impact of climate change on crop production is expected to be negative, impacts vary across crops and geographic areas (Zhao, Liu, et al. 2017). Rainfall, temperature, atmospheric carbon dioxide (CO_2), and solar radiation play key roles in rice production; the physiological stages of plant growth, development, and grain formation are directly influenced by these variables (Haque, Ali, and Masum 2016).

2.4.1 Temperature

Rice is vulnerable to extremely low and high temperatures. For each growth stage, critical low and high temperatures (typically below 20°C and above 30°C) differs and also depends on the variety, duration, and daily cycle (Yoshida 1981). Table 2.1 presents the rice plant response to varying daily mean temperature at different growth stages.

Table 2.1 *Rice Plant Response to Varying Daily Mean Temperature at Different Growth Stages*

Growth Stage	Critical Temperature (ºC)		
	Low	**High**	**Optimum**
Germination	10	45	20-35
Seedling Emergence and Establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf Elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of Panicle Primordia	15	-	22-23
Panicle Differentiation	15-20	38	-
Anthesis (flowering)	22	35	33-30
Ripening	12-18	30	20-25

Source: Yoshida (1981)

As Table 2.1 suggests, rice can tolerate maximum temperatures of 45 ºC and minimum temperatures of 7 ºC. However, depending on the growth stage and geographical location, temperatures outside the optimum range can have negative effects on yields. Flowering and ripening stages are highly sensitive to changes in temperature (Sánchez, Rasmussen, and Porter

2013). During the flowering stage, temperatures greater than 35 °C generally cause sterility (Haque, Ali, and Masum 2016) which results in no grains being produced. However, Yoshida (1981) notes that temperatures have to exceed 40 °C for this to become noticeable. Elevated nighttime temperatures reduce grain filling and yield considerably (Peng et al. 2004), increased chalkiness reduce milling quality (Lanning et al. 2011) and can cause increase sterility in rice spikelet (flower) (Reiner Wassmann and Dobermann 2007). Other studies reported a decline in grain quality due to higher temperatures (Counce et al., 2005, Zhong et al., 2005, Tanaka et al., 2009). Higher transpiration losses linked to higher temperatures make rice less productive and increase the water requirements of rice.

2.4.2 Rainfall

The water requirements of low land rice are significant and vary across each growth stage. As such, variability in rainfall in terms of timing, quantity, intensity, and distribution affects plant growth and development which impacts the quality and quantity of yields. Inadequate rainfall causes moisture stress which hampers root and shoot development, delays flowering, and affect pollination, fertilization, and grain filling; excessive rainfall disrupts farming operations such as land preparation, sowing, harvesting, threshing and processing, and seed drying; incessant rainfall during flowering impedes fertilization and grain formation (Basnayake et al. 2006). Rainfall variability that occurs during sowing affects seed establishment and the duration of the crop (Haque, Ali, and Masum 2016). Untimely rainfall may also bring a premature end to the reproductive or ripening stage which significantly reduces yield (Moomaw and Vergara 1965).

2.4.3 Solar Radiation

Solar radiation refers to energy provided by the sun to facilitate plant growth and development. The sun provides the energy needed for seed germination and the physiological development of plant leaves, stems, and shoots (Khadka 2016). Like rainfall and temperature, the intensity level of solar radiation required by each growth stage is different. Low-intensity solar radiation has a profound impact during the reproductive and ripening stages (Basnayake et al. 2006). Under a changing climate, shifting rainfall patterns will disrupt the trade-off between sunshine and rainfall through increase cloud cover. This will likely affect the intensity level of solar radiation needed for photosynthesis.

2.4.4 Carbon Dioxide

Increases in atmospheric carbon dioxide also affect the quality and quantity of rice production. Higher carbon dioxide levels typically increase biomass production in terms of leaf number, shoot dry weight, and shoot length but not grain yield. (IRRI n.d.). Zhu et al. (2018) stated that elevated atmospheric carbon dioxide will decrease proteins, micronutrients, and vitamins found in rice.

2.4.5 Extreme Weather

Erratic rainfall patterns produce extreme events that lead to flood and water scarcity. Excess rainfall usually causes rice fields to become inundated. Although rice thrives in wet conditions where other crops fail, it cannot survive if submerged under water for an extended period of time. Additionally, floods cause indirect damage to rice production by harming the properties and production means of farmers and infrastructures such as farm-to-market roads, and drainage and irrigation systems that support rice production. Wet conditions arising from heavy downpours increase the moisture content of rice paddy which impacts grain quality at harvest. Auffhammer, Ramanathan, and Vincent (2012) found that drought and extreme rainfall negatively affected rice yield (harvest per hectare) in predominantly rain-fed areas of India.

Prolonged dry spells result in water scarcity. Since rice requires abundant water to grow, drought-like conditions significantly reduce rice yields. Average yield reduction in rain-fed, drought-prone areas has ranged from 17 to 40% in severe drought years, leading to production losses and food scarcity (IRRI n.d.). The intensity and frequency of droughts result in water deficits that are estimated to affect more than 23 million hectares of rain-fed rice production areas in South and Southeast Asia; in Africa, recurring drought affects nearly 80% of the potential 20 million hectares of rain-fed lowland rice (IRRI n.d.). Koc and Ceylan (2013) found that drought had a negative effect on rice production in Turkey.

2.4.6 Pests, Diseases, and Weeds

Climate change also indirectly affects rice yields by altering the types, frequency, and magnitude of pests, diseases, and weeds. Basnayake et al. (2006) note that excess rainfall supports an increased incidence of pests and diseases which reduces yields. Surveys conducted by the International Rice Research Institute (IRRI) found that extreme weather events have led to significant increases in the rodent population as a result of unseasonal and asynchronous cropping; weed infestation and rice-weed completion represents a major challenge for sustainable rice production (IRRI n.d.). Water shortages, irregular rainfall patterns, and related water stresses increased the intensity of some diseases, including brown spot and blast (IRRI n.d.).

2.4.7 Climate Change and Future Rice Production

Projections show that the proportion of global rice producing areas exposed to critically high temperatures is expected to grow from 8.0% in the 2000s to 27.0% by mid-century (Gourdji, Sibley, and Lobell 2013). According to the International Food Policy Research Institute (IFPRI) Food Policy Report, global losses in rice yield attributed to climate change could be between 10 and 15 percent by 2050 (Nelson et al. 2009). Most studies have focused on temperature increases. Excluding CO_2 fertilization, successful adaptation, and genetic improvement, four independent estimates found that rice yields will decrease by 3.2% for every one degree Celsius increase in global temperature (Zhao et al. 2017). Field experiments by Zhao, Shilong, et al. (2017) noted appreciable losses under warming conditions with yields decreasing by 5.2% on average.

2.4.8 Rice Cultivation Impact on Climate Change

While the literature review in the preceding sub-sections focused on the impacts of climate change on rice production, it would be remiss if the impacts of rice production on climate change are overlooked. Since rice is grown under lightly flooded conditions, rice cultivation increases methane (CH_4) and nitrous oxide (N_2O), two very powerful greenhouse gases that contribute to climate change. According to Kritee et al. (2018), global rice cultivation accounts for 50.0% of all crop related methane (CH_4) emissions. Although the atmospheric life of methane is about 12 years, it is 86 times more potent than carbon dioxide (CO_2) (Mann and Kump 2015). Increases in nitrous oxide occur in periods between aeration and flooding of rice fields. Kritee et al. (2018) found high fluctuations of nitrous oxide at average and intense-intermittently flooded rice farms. In comparison to carbon dioxide, the atmospheric life expectancy of nitrous oxide is approximately 121 years and 268 times more powerful (Mann and Kump 2015).

2.5 Approaches to Assessing Climate Change Impacts on Crop Agriculture

The literature cites two broad approaches for estimating the impacts of climate change on agriculture: general equilibrium and partial equilibrium models (Zhai, Lin, and Byambadory 2009; Sarker 2012). The discussion that follows describes each approach including their strengths and weaknesses. While it is important to highlight these approaches, this study ultimately assumes a more descriptive approach to help understand the impacts of climate change on rice production in Guyana, and how small farmers are and may adapt in the future.

2.5.1 General Equilibrium Models

General equilibrium models view the economy as a complete set of interconnected markets where economic shock in one market triggers changes in other markets (Nicholson and Snyder 2012). The computable general equilibrium model (CGE)[8] is the most common economy-wide model (Sarker 2012) since it uses real economic data to evaluate how changes in a stimulus (e.g. policy) reverberate across the economy.

2.5.1.1 Computable General Equilibrium Models

The CGE model uses a system of equations to describe the entire economy and capture the interactions among all sectors (Burfisher 2016). Since the impacts of climate change are likely to be felt across various segments of the economy, CGE is a useful tool for assessing climate shocks (Zhai, Lin, and Byambadory 2009). The major advantages of CGE models include: conceptually sound and computationally consistent, accounts for inter-industry linkages and economy-wide effects; and sound welfare analysis (Hertel 1990, 1999). However, CGE models are not without

[8] Also referred to as applied general equilibrium (AGE).

limitations. Common critiques include issues relating to parameter selection, model structure, and functional form (Mckitrick 1998). In addition, there are concerns about data consistency due to calibration problems; lack of statistical tests for model specification; and the complexity and advanced skills required to set up and use CGE models (Gillig and McCarl 2002).

2.5.2 Partial Equilibrium Models

Partial equilibrium models examine a single market or part of an economy in isolation while ignoring interrelationships with other markets or sectors within the economy (Nicholson and Snyder 2012). Partial equilibrium models encompass four primary approaches: agronomic crop models, panel weather studies, and Ricardian cross-sectional climate studies (Blanc and Reilly 2017) and Agroecological Zone Analysis (AEZ) (FAO 1978).

2.5.2.1 Agroeconomic Analysis

This hybrid approach combines crop simulation models[9] with economic models to estimate crop yields. Simulation models express crop yields as a function of different weather conditions, soil conditions, and crop management practices (e.g., planting dates, fertilization rates, and irrigation use). As such, crops are grown in a laboratory setting that simulates how crop yields respond to different levels of temperature, light, water, nutrients, and carbon dioxide (CO_2) (Zhai, Lin, and Byambadory 2009; Blanc and Reilly 2017; Van Passel, Massetti, and Mendelsohn 2017). By exposing crops to different environmental conditions, crop growth and yield can be isolated based on the treatment received. The results of the crop simulation model are subsequently

[9] Also called biophysical models.

integrated into an economic model that incorporates information on agricultural production, consumption, and trade (Blanc and Reilly 2017).

The parameters of crop models are adjusted through iterative experiments and comparison with the results from field trials (Li et al. 2012). There are many global and regional crop models currently in existence. Prominent examples include the Agricultural Production Systems Simulator (APSIM), Decision Support System for Agrotechnology Transfer / Crop Estimation through Resource and Environment Synthesis (DSSAT-CERES), Model for Nitrogen and Carbon in Agroecosystems (MONICA), crop-water productivity model (AQUACROP), and CROPSYST. Several recent studies have used an ensamble of crop models to explore crop yeild responses to changes in climate. These include for wheat (Pirttioja et al. 2015), maize (Bassu et al. 2014; Araya et al. 2015; Durand et al. 2018), rice (Li et al. 2015), potato (Fleisher et al. 2017), sugarcane (Dias and Sentelhas 2017), and soybean (Battisti, Sentelhas, and Boote 2018).

Simulation models can explore the impacts of future climatic conditions and, assuming the underlying economic models are accurate, can predict efficient adaptation (Mendelsohn and Massetti 2017). However, such models may not accurately reflect changes in demand and supply due to climate change (Mendelsohn and Massetti 2017). Considering the complexity of natural and social systems, simulation models may not accurately account for all interactions (Rauff and Bello 2015; Kant et al. 2017).

2.5.2.2 Ricardian Cross-sectional Analysis

The Ricardian cross-sectional approach draws on David Ricardo's rent theory. Ricardo (1817)[10] defined rent as the "portion of the produce of the earth, which is paid to a landlord on

[10] Reprinted in 2004 by Dover Books.

account of the original and indestructible powers of the soil" and that the ownership of more productive land will have a higher rental value. As such, the Ricardian approach assumes a direct cause and effect relationship between climate change and farmland value. The value of the farmland is based on its productivity which depends on inherent characteristics such as climate. Therefore, changes in farmland values would be reflective of the economic impact of various climate induce conditions.

The Ricardian approach uses regression techniques to examine the relationship between various explanatory variables (climate, economic, demographic, and physical factors) and the independent variable (net revenues or land values) (Mendelsohn, Nordhaus, and Shaw 1994). A major advantage of the Ricardian cross-sectional studies is that adaptation is considered implicit and endogenous (Seo et al. 2012). In other words, farmers' long-term response to climate change is captured in the analysis. By treating net revenue (or land value) as the dependent variable, cross-sectional analyses also provide a direct measure of welfare (Mendelsohn and Massetti 2017).

The major critique of Ricardian cross-sectional studies is omitted variable bias (Deschênes and Greenstone 2007; Blanc and Schlenker 2017). Cross-sectional studies do not control for other independent variables that vary across space and are correlated with climate (e.g., topography, soil fertility) (Massetti and Mendelsohn 2018). These independent variables may not be available or difficult to collect. The Ricardian cross-sectional studies also assume prices and carbon dioxide concentrations do not vary across space (Mendelsohn and Massetti 2017). As a result, net revenues (or land value) may be under or over-estimated depending on the output price and level of carbon fertilization. Hence, prices and carbon dioxide concentrations are often introduced exogenously (Massetti and Mendelsohn 2018). Finally, cross-sectional studies assume that current adaptation will continue into the future but ignores the costs of transition (Kelly, Kolstad, and Mitchell 2005).

Ricardian studies have been employed far and wide and on different geographic scales. For example, continental studies include Africa (Seo and Mendelsohn 2008c), South America (Seo and Mendelsohn 2008b), and Western Europe (Van Passel, Massetti, and Mendelsohn 2017). Examples of large country studies include Brazil (Mendelsohn, Basist, et al. 2007; Sanghi and Mendelsohn 2008), Canada (Reinsborough 2003; Mendelsohn and Reinsborough 2007), China (Wang et al. 2009; Chen et al. 2013), India (Mendelsohn, Kurukulasuriya, et al. 2007; Sanghi and Mendelsohn 2008), and the United States (Mendelsohn, Nordhaus, and Shaw 1994; Schlenker, Hanemann, and Fisher 2005; Massetti and Mendelsohn. 2011). Yet, other studies have been done for small countries or regions within (Gbetibouo and Hassan 2005; Kurukulasuriya and Ajwad 2007; Kabubo-Mariara and Karanja 2007; Deressa et al. 2009; De Salvo, Raffaelli, and Moser 2013; Wood and Mendelsohn 2014).

2.5.2.3 Panel Data Analysis

According to Houser et al. (2015), some impact assessments prefer to rely exclusively on panel data studies to measure the impacts of climate change on agricultural outcomes. This is driven by concerns over misspecification in terms of omitted variable bias inherent in the Ricardian cross-sectional approach (Deschênes and Greenstone 2007; Blanc and Schlenker 2017). Panel data analysis employs regression techniques to estimate the effect of climate change on crop agricultural using a production or profit function (Blanc and Reilly 2017). By using panel data, one can assess the vulnerability of farmers across different climates, space, and time.

Panel data models can be estimated using a fixed effects or random effects model (Baltagi 2008; Blanc and Schlenker 2017). A fixed effects model contains an unobserved variable in the error term that is constant over time (Wooldridge 2013). A fixed effect model is attractive because it allows the use of panel data to measure causal relationships (Cameron and Trivedi 2005) by controlling for unobserved heterogeneity that is time invariant. In other words, determinants of the dependent variable that is constant over time but difficult or impossible to measure are absorbed into the model thus, easing concerns over omitted variable bias. For example, fixed effect models may control for unobserved effects that are location specific such as soil quality, fertilizer application, irrigation, and farm household characteristics and that do not change over time. It is assumed that the unobserved effect is correlated with one or more independent variables.

A random effects panel data model assumes no correlation between the unobserved effect and observed independent variables in each time period (Wooldridge 2013). If there is a correlation, random effects model produces inconsistent estimates of the parameters due to serial correlation (Baltagi 2008). Assuming that the unobserved effect is time-constant, fixed effects model are considered more consistent and thus preferred.

The main strengths of panel data analysis is that it overcomes omitted variable bias, uses uncorrelated exogenous weather shocks, accounts for short-term adaptation, has greater degrees of freedom, and can be used for forecasting and validation (Blanc and Schlenker 2017). However, the source of variation, time-varying omitted variables, measurement errors, homogenous seasonal weather, and long-term adaptation are major limitations (Blanc and Schlenker 2017).

2.5.2.4 Agroecological Zone Analysis (AEZ)

Climate, soil, topography, and land cover vary across different landscapes. As a result, some landscapes are more suitable for some crops than others and vice versa. Developed by the Food and Agricultural Organization (FAO) in the late 1970s (FAO 1978), the AEZ method combines crop simulation models with land management decisions to measure crop productivity across different climatic zones (Darwin et al. 1995; Fischer et al. 2005). Under this approach, land units are mapped according to soil, landform, and climatic characteristics (FAO 1996). By classifying an otherwise complex landscape into smaller discrete homogeneous zones (Kurukulasuriya and Mendelsohn 2008b), AEZ encourages maximizing agricultural yields based on land use suitability and potential.

Similar to the agronomic approach, AEZ underscores the importance of the natural science interaction; unlike the agronomic approach, AEZ models the entire eco-physiological[11] process and when combined with soil, climate, and technology state, determines the most productive crop to produce in a given area or zone (Mendelsohn and Tiwari 2000). Since climate is a key input of the model, the impacts of changes in rainfall and temperature can be captured. A major drawback of this method is that all relevant components must be available before final outcomes can be predicted (Mendelsohn and Tiwari 2000).

2.6 Climate Data

The use of climate variables in agricultural economics analyses is not a new phenomenon (e.g., Fisher 1925; Wright 1928). While studies rely on rainfall and temperature data to identify weather shocks, the source and type of weather data used in assessing the economic impacts of climate change are important considerations. Weather data fall into four primary categories: ground station, gridded, satellite, and reanalysis data (Dell, Jones, and Olken 2014).

Ground or land-based station data are the most common type of weather data. It is based on observations of rainfall, temperature, dew point, relative humidity, wind speed and direction, atmospheric pressure, and other weather variables collected through instruments located across the

[11] Includes factors that influence plant growth (e.g., length of growing cycle, yield formation period, leaf area index, and harvest index).

world (Mendelsohn, Kurukulasuriya, et al. 2007). Assuming it exists, ground station data can be highly accurate for a specific location (Dell, Jones, and Olken 2014). However, in developing countries like Guyana, sparse station coverage and poor record keeping due to lack of capacity (Colston et al. 2018) can be of concern. Regardless, ground station data are still considered advantageous for locations near the station (Dell, Jones, and Olken 2014).

Concerns over incomplete coverage inherent in ground station data can be mitigated by gridded data. Through interpolation of station data, gridded data provides more comprehensive coverage of weather data (Dell, Jones, and Olken 2014). While gridded data adjust for issues related to missing station data, elevation, and urban heat island effect (Dell, Jones, and Olken 2014), it is not without limitations. Issues raised by Auffhammer et al. (2013) include course resolution, the spatial correlation of climate variables, correlation of weather variables, differences in cross-sectional versus time series variation, and endogeneity of weather coverage. Those from the Climate Research Unit (CRU) at East Anglia University and Matsuura and Willmott (2018) at the University of Delaware (UDEL) are two frequently used gridded datasets.

Satellite measurements, which began in the late 1970s are another source of weather data. While satellite offers a solution in areas with limited ground coverage, such data have lower resolution than gridded data and are usually less accurate since temperature and rainfall are not directly measured (Dell, Jones, and Olken 2014). Toté et al. (2015) found that satellite data overestimated low and underestimated high decadal rainfall. Examples of satellite products include those produced by the University of Alabama Huntsville (UAH) and Remote Sensing Systems (Dell, Jones, and Olken 2014).

Finally, reanalysis data entail combining information from multiple sources (e.g., ground station, satellites, weather balloons), to estimate weather variables across a grid (Dell, Jones, and

Olken 2014). It is different from gridded data in that it uses a climate model instead of interpolation. The chief limitation of this dataset is the oversimplification of reality embedded in climate models (Dell, Jones, and Olken 2014). Auffhammer et al. (2013) found that the correlation of reanalysis data for temperature and average rainfall was slightly below the CRU and UDEL gridded datasets. Examples of reanalysis products include those produced by the National Center for Environmental Prediction (NCEP) in the United States and the European Center for Medium-Range Weather Forecasting (Auffhammer et al. 2013).

2.7 Empirical Evidence of Climate Change Impacts on Crop Agriculture

Empirical studies on the impacts of climate change on agriculture are numerous. Some studies have examined climate change impacts on a global scale while others have looked at impacts across a specific continent or sub-continent. Other studies have focused on large industrialized countries while others have focused on small developing countries. The review of literature that follows highlights the findings of a sample of these studies.

2.7.1 Evidence from Global Agriculture

Early studies on the impacts of climate change on agriculture worldwide are overwhelmed with uncertainties. Parry (1990) evaluated the implications of climate change on global agriculture under existing production management and technology and concluded that a doubling of carbon dioxide (CO_2) could reduce yields by 10-30 percent in northern mid-latitude regions while warming and CO_2 fertilization could enhance yield potential towards the pole-ward edge of current agricultural regions. It was also noted that disagreement on how the amount and distribution of precipitation will be affected by global warming makes it difficult to estimate impacts at lower latitudes.

In assessing the likely impacts of climate change on world food supply, Rosenzweig and Parry (1994) found that global agricultural production will decrease slightly under a twofold increase in CO_2 concentration. The results also indicate that vulnerability to climate change is uneven between developed and developing countries with countries in the global south experiencing greater losses. Interestingly, simulation results suggest that adaptation efforts are ineffective is closing the gap between developed and developing countries.

Darwin et al. (1995) reported that while increases in temperature and changes in precipitation patterns over the next century will impact agriculture across the world, adaptation efforts will mitigate the risk to world food production. They also reported unequal impacts with arctic and alpine regions experiencing an increase in agricultural production while tropical regions and the U.S. Corn Belt and southeast seeing a decline.

Using the Hadley Center Coupled Model (HadCM2) global climate scenarios, Parry et al. (1999) reported that high and mid-latitudes regions will experience an increase in yields while the opposite is true for lower latitudes. They also noted that regional differences will grow with the passage of time leading to a clear division of impacts between developed and developing countries. However, gains in some regions are expected to offset losses in other regions thus resulting in production, prices, and risk of hunger being relatively stable under a changing climate.

Parry et al. (2004) used the HadCM3 global climate model under the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) to estimate the impacts of climate change on global food production. Under a fossil fuel intensive economic growth model, the results indicate that an increase in global temperatures will severely impair crop yields at the regional and global levels. Nelson et al. (2009) reported that global food security will be threatened as the overall impacts of climate change on agriculture are expected to be negative. They also noted that developing countries will be hardest hit with yield declines in the most important crops and corresponding price increases.

Calzadilla et al. (2013) employed the Global Trade Analysis Project – Water (GTAP-W) model which accounts for water (rainfed and irrigated agriculture) to assess the potential impacts of climate change and CO_2 fertilization on global agriculture based on the IPCC SRES A1B and A2 scenarios. They found that future climate scenarios will likely alter regional water supply and soil moisture which would disrupt the distribution of cultivated land. As a result, global food production, welfare, and Gross Domestic Product (GDP) will decline and higher food prices can be expected.

The Food and Agricultural Organization (FAO) reported that global food production patterns will be modified as a result of climate change (Elbehri, Elliott, and Wheeler 2015). Agricultural production is expected to be negative across low latitude and tropical regions while high latitude regions may experience a slight increase. The authors also noted that while water lessens the impacts of climate change, water deficits in many regions of the world impede adaptation.

The underlying theme of these and other studies is that climate change impacts will vary across regions of the world with low latitude developing countries experiencing the brunt of this negative environmental externality. Consequently, global food production and security remain at risk under a changing climate.

2.7.2 Evidence from Africa, Western Europe, and South America

Several studies have examined the impacts of climate change on agriculture in Africa, South America, and Western Europe. These studies employed a Ricardian cross-sectional approach to estimate the impacts of climate change.

Kurukulasuriya et al. (2006) utilized survey data from over 9,000 farmers across 11 African countries to study the impacts of seasonal climate on net farm revenues. They found that revenues declined for dryland crops and livestock and increased for irrigated crops due to changes in temperature. Also, changes in precipitation have a positive effect on revenues for all farm types. Applying future climate data to the same dataset, Kurukulasuriya and Mendelsohn (2008a) predicted that net revenues from dryland farms are very sensitive to climate change. If the future climate is mild and wet, net revenues could increase by over 50 percent or decrease by approximately 40 percent under hot and dry conditions.

To determine the adaptive behavior of farmers, Seo and Mendelsohn (2008c) compared the choices farmers face under different environmental conditions. In warmer areas, they found that African farmers changed from cattle to more heat tolerant goats and sheep while in wetter areas farmers changed from cattle and sheep to goats and chicken. In another study, Seo and Mendelsohn (2008a) employed a cross-sectional approach to study approximately 5,000 livestock farmers across ten African countries. The results indicated that large farms were more vulnerable to changes in temperature and in warmer areas large farms have fewer animals per farm.

Seo et al. (2012) studied the impacts of climate change across sixteen Agroecological Zones (AEZs) in Africa. While net revenue from crop agriculture is more sensitive to climate change, they found that combined net revenues from crops and livestock were more climate resilient. The results suggest climate change impacts will be disparate across the African landscape with existing productive areas being more vulnerable while non-productive areas will become more productive in the future.

Based on a sample of 2,300 farms, Seo and Mendelsohn (2008b) examined the impacts of climate change across seven South American countries. The results suggest that an increase in temperature and precipitation will be harmful with climate change impacts varying across farm types (crop-only, mixed, and livestock-only) and geographical regions. Warning in the hot and wet Amazon and Equatorial regions are likely to suffer loses while cooler altitudes and southern regions will benefit.

Moore and Lobell (2014) employed time series and cross-sectional approaches to assess the efficacy of adaptation to climate change in Europe. They found that under future warming conditions, meaningful adaptation will benefit maize but have less of an impact on wheat and barley. The results suggest that overall, the benefits of adaptation are slight while the costs of non-adaptation are significant. Using farm-level data from 41,030 farms across Western Europe, Van Passel, Massetti, and Mendelsohn (2017) reported that under warming conditions, European farms were marginally more vulnerable than American farms while farms in Southern Europe are relatively more sensitive.

2.7.3 Evidence from the Brazil, Canada, China, India and United States

This section introduces evidence from Brazil, Canada, China, India, and the United States. Comparing the U.S. and Brazil, Mendelsohn, Basist, et al. (2007) found that higher climate variance enhances the chance of land being used for agriculture in both countries while high temperatures reduce cropland values. Using panel data from Brazil and India, Sanghi and Mendelsohn (2008) explored how farm values varied with climate and how farmers responded. Results indicated that Brazil could suffer annual losses as low as 1.0 percent and as high as 39.0 percent.

Reinsborough (2003) reported marginal benefits of climate change on Canadian agriculture. However, the large margin of error encouraged further study. In a comparison of climate change impacts on U.S. and Canadian agriculture, Mendelsohn and Reinsborough (2007) found that warmer weather had no effect on Canadian agriculture but increase precipitation was beneficial.

Using survey data from 8,405 farm households across 28 provinces in China, Wang et al. (2009) studied the effects of climate change on both rainfed and irrigated farms. The results indicate harmful and beneficial effects for rainfed and irrigated farms, respectively. There are also regional impacts with slight effects for farms located in the Southeast and larger damages for farms in the Northeast and Northwest. Another study by Chen et al. (2013) examined the impacts of climate change using farm-level data from 13,379 farm households across 316 villages, distributed in 31 provinces. They found that the marginal effects of increased temperature and rainfall on net revenue per hectare were positive and negative, respectively. They also found regional differences due to changes in precipitation.

In comparing the explanatory power of satellite and ground station data in India, Mendelsohn, Kurukulasuriya, et al. (2007) found surface wetness index produced by satellite were superior even though irrigation may be at work. Temperature measured by satellite appears promising for climate and agricultural studies. Sanghi and Mendelsohn (2008) found that farm values in India could suffer losses ranging from 4.0 percent to 26.0 percent due to climate change.

Perhaps access to reliable agricultural and climate data may have encouraged multiple studies on the impacts of climate change on U.S. agriculture. Early studies relied on crop simulation models to estimate the impacts of climate change on U.S. agriculture (Adams 1989; Rosenzweig 1989; Adams et al. 1995; Kaiser et al. 1993). While these studies highlight the negative impacts of climate change on U.S. agriculture, they also contended that U.S. agriculture is resilient with economic adjustment and adaptation. For instance, Kaiser et al. (1993) found that farmers can effectively adapt to a changing climate by planting long maturity cultivars, changing crop mix, and altering field operations to maximize longer growing seasons.

With the introduction of the Ricardian approach, a new wave of studies followed. Mendelsohn, Nordhaus, and Shaw (1994) used economic and geographical data from approximately 3,000 counties to study the impacts of climate change. The results indicated that higher temperatures in winter, spring, and summer reduced farmer values while increased rainfall independent of autumn increased farm values. They also found that future climate change could be beneficial to U.S. agriculture.

Schlenker, Hanemann, and Fisher (2005) studied the impacts of climate change on 2,197 dryland non-urban counties, in the U.S. They estimated that annual losses of approximately $5 to $5.3 billion can be attributed to climate change. Using panel data to estimate the Ricardian function, Massetti and Mendelsohn (2011) found that mild warming is advantageous to U.S agriculture while extreme conditions would be harmful.

2.7.4 Evidence from Other Developed and Developing Countries

The literature also offers evidence from smaller nations and regions within countries that have significant local climate variation. These studies primarily used the Ricardian approach.

In studying land prices across England and Wales, Maddison (2000) found that climate, soil quality, elevation, and structural attributes of farms were important determinants of farmland values. Seo, Mendelsohn, and Munasinghe (2005) examined the impacts of climate change on net revenues of rice, coconut, rubber, and tea in Sri Lanka. They found that increases in rainfall are expected to be beneficial while higher temperatures are predicted to be harmful.

Using data from 300 districts across South Africa, Gbetibouo and Hassan (2005) studied the impacts of climate, soil, and socioeconomic variables on net revenues of seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower, and soybean). The results indicate that an increase in temperature and a decrease in rainfall have a positive and negative impact on net revenues, respectively. They also reported that future climate change will demand different responses across agro-ecological zones including shifts in cropping calendars, growing seasons, and crops altogether.

Kurukulasuriya and Ajwad (2007) used farm-level data to estimate the impacts of climate change on small farmers' net revenues in Sri Lanka. They found that lower rainfall during key agricultural periods have a significant impact on net revenues and that non-climatic factors explained approximately half of the variation in net revenues. Not surprisingly, they also noted that impacts vary across regions.

Fleischer, Lichtman, and Mendelsohn (2007) found that irrigation is very important in assessing climate change impacts in Israel. The inclusion of irrigation reduces the marginal impacts of temperature on net revenues. With technology, irrigation, cover, and marketing arrangements playing an important role, the study also found that higher temperatures would actually increase net revenues.

Kabubo-Mariara and Karanja (2007) used survey data from 816 small farm households across Kenya to examine the economic impact of climate change on net crop revenue. The findings revealed that increases in precipitation result in higher net revenues while warmer summer and winter temperatures have a negative and positive effect on net revenues, respectively. The study also stressed the importance of effective adaptation in maintaining optimal conditions for agriculture production.

Studying farms in Germany, Lippert, Krimly, and Aurbacher (2009) found that land rent increases with an increase in temperatures and a decrease in spring rainfall, except in eastern Germany. They also found that under severe changes in temperature and precipitation, income losses will become more apparent in the long-run. In Cameroon, Molua (2009) found that net revenues were more susceptible to a decrease in rainfall than an increase in temperature.

Deressa and Hassan (2009) used data collected from different agroecological zones in Ethiopia to assess the impacts of climate, household, and soil variables on net crop revenues. The results show that a slight increase in temperature during summer and winter seasons reduce net revenues significantly while a marginal increase in spring rainfall has a strong positive relationship with net revenues. The authors also noted climate change impacts vary across agroecological zones and that adaptation can help mitigate the consequences of future climate scenarios on net revenue.

Mendelsohn, Arellano-Gonzalez, and Christensen (2009) used data collected from 621 farm households in Mexico to measure the impacts of climate change. They found that each additional degree of warming reduces farmland values by 4,000 to 6,000 pesos. They also found that rainfed farms are slightly more sensitive than irrigated farmers. Under future climate scenarios, farmland values will decline between 42 and 54 percent on average.

De Salvo, Raffaelli, and Moser (2013) evaluated the impacts of climate change on apple and grapes production in the Italian Alpine region. They controlled for farm characteristics and strategic decisions (e.g., specialization and quality certification) and tested three functional forms. They concluded that climate change reduces annual net revenues in the study area.

Arguing that climate, soils, and socioeconomic factors are challenging to model over wide geographic areas, Wood and Mendelsohn (2014) studied the impacts of climate change on net revenues in Fouta Djallon, West Africa. The authors found that higher temperatures and rainfall were negatively and positively associated with agricultural revenues during the rainy season and cool dry seasons, respectively.

Bozzola et al. (2017) used a dataset of 16,000 farmers to investigate the impacts of climate change on Italian agriculture. While the results indicate that farm net revenues are sensitive to seasonal changes in temperature and rainfall, differences exist between crop and livestock farms and rainfed and irrigated farms. They also noted that more severe changes in climate will have progressively damaging impacts.

2.8 Empirical Evidence of Farmers' Perceptions and Adaptation to Climate Change

Farmers' decision to and choice of adaptation strategy begins with their ability to perceive and understand climate change risk. This section presents a review of the literature on farmers' perceptions and decisions to adapt to climate change from multiple countries.

Based on in-depth interviews with farmers across two counties in New York State, Takahashi et al. (2016) found polarized views about climate change among farmers. Specifically, some farmers are of the opinion that climate change is a serious problem and are taking measures to adapt while others remain skeptical that climate change is real. The researchers also found that past experience plays a crucial role in influencing farmers' beliefs and perceptions. In addition, the study found that farmers with more years of experience are engaging in short-term adaptation practices as part of their normal operations.

Ayanlade, Radeny, and Morton (2017) compared farmers' perceptions of climate change with meteorological data in southwestern Nigeria. Approximately two-thirds of farmers observed changes in climate which is consistent with observed climate trends for the area. In terms of adaptation, years of farming experience and income strongly influence the choice of adaptation practice undertaken.

Tripathi and Mishra (2017) investigated farmers' perceptions of and adaptation to climate change in Uttar Pradesh, India. The results indicate that while farmers are cognizant of long-term changes in temperature and rainfall, they do not associate these changes with climate change. They also found that farmers are conscious of the risk related to climate variability and extreme weather events and are responding by adjusting sowing and harvesting dates, cultivating short duration crop varieties, inter-cropping, changing cropping pattern, and investing in irrigation and agroforestry.

Using data collected from 150 randomly sampled farmers in three selected provinces in South Africa, Elum, Modise, and Marr (2017) found that farmers' perceptions are consistent with changes in climate parameters. The results also indicate that farmers are engaging in different adaptation practices, chief among these being the use of drought-tolerant varieties. However, the lack of awareness and/or the inability to afford insurance is limiting farmers' uptake of crop insurance.

Mase, Gramig, and Prokopy (2017) studied survey responses of approximately 5,000 corn farmers across 22 Midwestern U.S. Watersheds. The study highlights the critical role of perceptions given the strong positive relationship observed between farmers' belief of climate change and variable weather observed on their farm and across the U.S. Corn Belt. As it relates to adaptation practices, farmers are relying on new technologies, crop insurance, and conservation agricultural practices to manage the risk of weather and climate. Importantly, the researchers suggest that crop insurance may be subsidizing lack of adaptation efforts by farmers.

Gandure, Walker, and Botha (2013) examined small farmers' perceptions and responses to long-term climate change in the rural village of Gladstone, Free State Province, South Africa. They found that farmers' perceptions are correlated with observed data on long-term climate change. The results also indicate that rainfall variability and temperature extremes are not perceived to have a strong negative impact on livelihoods and that farmers are more worried about the impacts of weeds, insects, and worms. Rainfall harvesting techniques are the most common risk management and adaptation strategy. The researchers also suggest that greater awareness and education about climate change needs to be prioritized at different levels of society.

Alam, Alam, and Mushtaq (2017) utilized survey data from 380 resource impoverished farm households in Bangladesh to explored farmers' perceptions and adaptation to climate change and climate hazards. They found that farmers' perceptions of changes in climate are analogous to observed climate data. Adaptation strategies undertaken by farmers include planting new crop varieties, adjusting planting dates, gardening, planting trees, and migration. Better access to finance and more information on suitable adaptation strategies remains paramount to supporting adaptation and building resilience among vulnerable farm households.

Mulwa et al. (2017) found that farmers' decision to adapt to adverse changes in weather patterns are influenced by specific plot characteristics, credit constraints, and the availability of climate-related information. They also found that withstanding financial constraints, farmers remain motivated to engage in adaptation if climate-related information is readily available. The researchers conclude that enhance access to information about relevant adaptation practices, easy access to inexpensive credit, and strengthening access to assets are key policy implications.

In assessing farmers' attitudes and determinants of adaptation across Borana, Ethiopia; Nyando, Kenya; Hoima, Uganda; and Lushoto, Tanzania, Shikuku et al. (2017) found that farmers were more amenable towards planting new crops, using different varieties, and adjusting planting dates instead of soil, land, and water management practices. The findings also suggest that providing climate information is crucial to successful short-term adaptation while enhancing financing is an important long-term strategy.

As the preceding studies highlight, analyzing farmers' perceptions is a practical approach to understanding climate change in a variety of countries and settings. More importantly, farmers' perceptions can be used to test the consistency of observed weather variables in addition to providing more descriptive accounts of how climate variables have changed. These studies also draw attention to different adaptation strategies and barriers to adaptation that is based on local characteristics and contexts.

2.9 Gaps in the Existing Literature

The review of the literature highlights several important gaps. Despite the economic implications for both farmers and the rice industry as a whole, to the researcher's knowledge, no previous study has been undertaken to examine the impacts of climate change on rice production in Guyana. Additionally, there is little understanding of how farmers in general and small farmers specifically perceive, are impacted by, and respond to changes in rainfall, temperature, extreme weather events, insects and pests, diseases and weeds. As such, research in this area is needed to identify and assess the economic ramifications of climate change on rice production and to inform policy at the national and rural levels.

In general, studies tend to group the impacts of climate change as being either positive or negative or high, medium or low. However, little emphasis has been placed on understanding specific impacts at the farm household level. By decoupling impacts, this research provides a deeper understanding of how small farmers are affected by and respond to changes in rainfall, temperature, extreme weather events, insects and pests, diseases and weeds.

Other studies have primarily focused on the direct impacts of climate change in terms of changes in rainfall, temperature, and extreme weather events. However, indirect impacts such as changes in insects and pests, diseases, and weeds have not received similar attention. By considering indirect impacts, this study provides a more comprehensive analysis of the impacts of climate change on rice production in Guyana.

This study will also have broader implications for the Latin America and Caribbean (LAC) region. Although the overall impact of climate change on the agricultural sector in LAC is expected to be negative, impacts vary by crops and countries (Fernandes et al. 2012). Additionally, little is known regarding how small rice farmers in the LAC region respond and adapt to climate change. Moreover, the results of studies done in other regions of the world are less likely to be homogenous given specific climatic conditions, geographic characteristics, agricultural systems, and technological state (Sarker 2012). By using Guyana as a case study, the proposed research will close the gap in knowledge by providing empirical evidence on: the impacts of climate change on small rice farmers, small farmers' perceptions of climate change, adaptations at the farm-level, and factors that drive and constrain adaptation decisions. The results will serve as catalysts by highlighting novel strategies and best management practices that can be used to develop appropriate adaptation measures and institutional responses based on local conditions and needs.

2.10 Conceptual Framework

Considering the impacts of climate change on crop agriculture, Figure 2.10 illustrates the conceptual framework adopted for this research. Specifically, climate change has both direct and indirect impacts on rice yields. Direct impacts include changes in precipitation patterns which affect the availability and timing of water while temperature extremes cause heat stress and higher evapotranspiration. Indirect impacts include changes in the incidence and range of insects and pests, diseases, and weeds. In addition, excess rainfall can be accompanied by heavy winds and/or cause flooding and soil erosion while drought leads to salt water infiltration in the irrigation system and/or on the farmland. Socioeconomic, farm-level, and institutional characteristics influence rice yields and adaptation strategies.

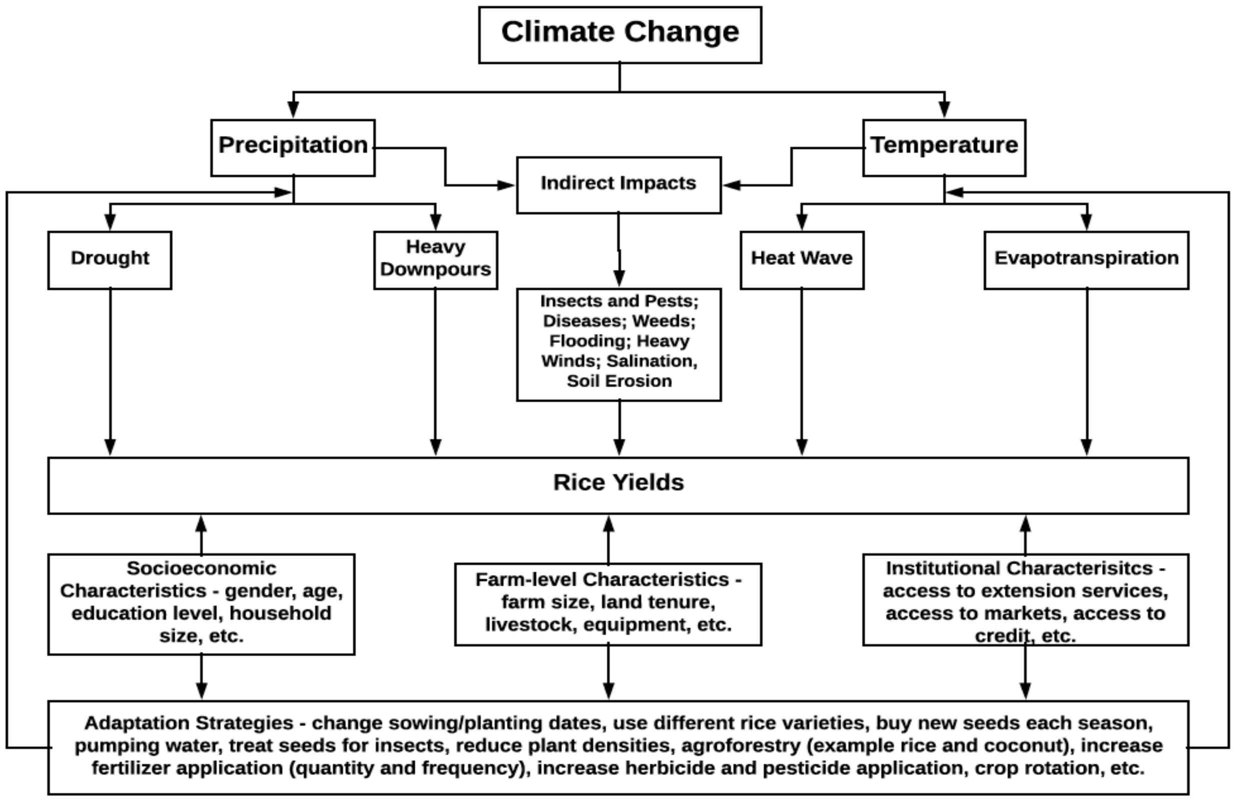

Figure 2.10 Conceptual framework of climate change impacts on rice yields and adaptation strategies
Source: Author

2.11 Conclusion

Our climate is shaped by many complex processes. Observed changes in greenhouse gases, land and sea surface temperatures, precipitation, sea level rise, and Arctic sea ice provide ample evidence of climate change in the Anthropocene. This evidence sets the stage for the rest of this research.

The impacts of climate change on the agricultural sector are well documented. Rising temperatures, shifting rainfall patterns, and extreme weather events have both direct and indirect negative effects on agricultural productivity. However, carbon fertilization and longer growing seasons remain the key positive impacts. In terms of rice production, rainfall, temperature, atmospheric carbon dioxide (CO_2), and solar radiation influence different stages of plant growth and by extension the quality and quantity of grains harvested. In addition, ongoing climate change is also expected to disrupt future rice production. While climate change affects rice cultivation, the opposite is also true. The flooded conditions that rice is grown under produce methane (CH_4) and nitrous oxide (N_2O), two very powerful greenhouse gases.

There are two broad approaches for estimating the impacts of climate change on agriculture: general equilibrium and partial equilibrium models. Most of the studies undertaken have employed a partial equilibrium approach that encompass four primary methods: agronomic crop models, panel weather studies, Ricardian cross-sectional climate studies, and agroecological zone Analysis. While earlier studies have employed agronomic crop models, the majority of recent studies have employed the Ricardian approach. However, panel data studies are becoming increasingly popular.

A key component of studies on climate change and agriculture is the type of climate data used. There are four primary sources of weather data: ground station, gridded, satellite, and reanalysis data. While ground station data are considered the gold standard, lack of spatial coverage and poor record keeping are concerns. Gridded data overcome issues relating to spatial coverage but is hampered by coarse resolution and spatial correlation of climate variables. Satellite data helps with missing ground coverage but are usually less accurate since temperature and rainfall are not directly measured. While reanalysis data combines information from multiple sources it is critiqued because it oversimplifies the reality embedded in climate models.

A great many empirical studies have been undertaken at the global, continental, country and, agricultural ecological zone levels. At the global level, concerns over food security are omnipresent. Africa appears to be the most negatively affected continent. The individual country impact depends on the type of crop, irrigation, technology, and the overall ability of farmers to effectively adapt. Regardless, the underlining finding of many of these studies is that climate change impacts will vary across regions with countries in the global south being disproportionate affected.

Farmers' perceptions of climate change play an important role in their decisions to adapt. The evidence presented suggests that farmers' perceptions of climate change are in line with meteorological data collected. More importantly, their choice of adaptation is driven by specific perceptions. Based on the review of the literature, the conceptual framework was developed to help answer the research questions posed and to close the gaps in knowledge highlighted.

Chapter 3 Data and Methods

3.1 Introduction

The main purpose of this research is to offer insights into how small farmers[12] perceive, are impacted by, and respond to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. Responses from key informants[13] are used to triangulate and better understand small farmers' perceptions, impacts, and adaptation. As such, this chapter provides a detailed description of the data and methods used to answer the following research questions:

1. How has the climate in Guyana changed?
2. What non-climatic factors influence rice yields of small farmers?
3. How do small rice farmers and key informants perceive changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?
4. What impacts are farmers and key informants seeing due to the observed changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?
5. What adaptive measures are they adopting in response to these impacts?

To answer each research question, several data sources and methods are employed. Section 3.2 introduces the data source and methods used to analyze climate variability and climate change in Guyana. Section 3.3 presents the underlying theoretical and empirical framework used to explore the relationship between non-climatic variables and rice yields. Section 3.4 outlines the research design, data source, and methodology used to collect farm-level data. Section 3.5 introduces the method of analyzing rice yield and non-climatic data at the farm-level. Section 3.6

[12] Farmers that cultivate 4.45 hectares (11 acres) or less in rice each season.

[13] Key informants comprise of district rice extension officers, an experience farmer (+25 years of experience), a rice miller, and senior staff (Chief Scientist/Plant Breeder, Plant Pathologist, Agronomist, Entomologist, and the Rice Extension Manager) at the Burma Rice Research Station in Guyana. Please refer to Chapter 3 – Data and Methods for additional information.

describes the method used for analyzing small farmers' and key informants' perceptions, impacts, and adaptation. Section 3.7 provides a summary of the various data and methods introduced.

3.2 Analyzing Climate Variability and Climate Change in Guyana

To answer research question 1, three methods are used to analyze secondary rainfall and temperature data for Guyana. The sections that follow describe the data source and methods used.

3.2.1 Data Source and Description – Climate Data

Average annual rainfall and temperature data for Guyana were obtained from the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) at East Anglia University for the period 1901-2015. The CRU CY dataset is derived directly from the CRU time-series (CRU TS v. 3.21), which is an updated version of the high-resolution monthly datasets initially developed by New, Hulme, and Jones (1999, 2000) and subsequently updated by Mitchell and Jones (2005) and covers all land areas with the exception of Antarctica.

The data used to construct the CRU dataset were obtained from the archives of climate station records that have been subject to extensive quality control measures and augmented with newly acquired data (Harris et al. 2014). The primary data sources include: internationally exchanged monthly data for about 2,400 stations from countries within the World Meteorological Organization (WMO); monthly climate data for the world produced by the National Oceanographic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC); and World Weather Records (WWR) decadal data publications (Harris et al. 2014).

To construct the CRU time-series, station data are gridded on a global grid with a spatial resolution of 0.5° longitude by 0.5° latitude using the Climate Anomaly Method (CAM). Using this method, each station series must contain at least 75% of the data for each month in order to calculate the based period (1961-1990) average or normal (Harris et al. 2014). Unless considered outliers[14], normals produced for each month are included in the gridding process and converted to anomalies. This is done by subtracting the 1961-1990 normal from each station's data on a monthly basis (Harris et al. 2014). The gridding operation itself entails triangulated linear interpolation that produces values on a grid with half-degree resolution. The spatial averages are calculated using area-weighted means (Harris et al. 2014). To make the dataset complete, station data located further away are used for infilling and if not possible the 1961-1990 average for the specific grid box is used (Harris et al. 2014). New station data for earlier periods that become available are subsequently incorporated when the dataset is updated.

The CRU CY dataset contains monthly, seasonal, and annual data for mean temperature (TMP), maximum and minimum temperatures (TMX and TMN), precipitation total (PRE), vapor pressure (VAP), cloud cover (CLD), rainday counts (WET), and potential evapotranspiration (PET). Minimum and maximum temperature are measured in degrees Celsius and monthly, seasonal and annual precipitation data measured in millimeters (mm).

3.2.2 Methods of analyzing climate data

To characterize climate variability in Guyana, three statistical methods are employed: descriptive statistics, a simple trend model, and a two-sample t-test.

[14] "Values that fall more than three (3) standard deviations from the normal (4.0 for precipitation)" (Harris et al. 2014).

3.2.2.1 Descriptive statistics

Descriptive statistics entail simplifying data to more understandable forms without compromising the data integrity (Agresti and Finlay 2014). This is done through the collection, organization, summarization, and graphical display of data (Jaisingh 2006). To analyze climate data, descriptive statistics comprising of the moving average, standard deviation, and coefficient of variation (CV) are used to show changes in rainfall and temperature over time.

3.2.2.1.1 Moving average

A moving average is a time series constructed by moving the arithmetic mean values through the time series (Mason, Lind, and Marchal 1999). In other words, it is a running average of a subset of sequential values in a time series. Given a set of values x_t, *where* $t = 1,2,3\ldots,i,$ the moving average of a subsequence of n terms can be computed as follows:

$$\overline{x_t} = \frac{1}{n}\sum_{t=t-n+1}^{t} x_t\,, \qquad [3.1]$$

where,

$n \leq t$

$\bar{x}_t$ = moving average at time (t)

n = the number of observations in the subsequence

t = time

For example, if we have ten measurements of maximum temperature (T_{MAX}) in a time series (T_{MAX1}, T_{MAX2}, T_{MAX3}…, T_{MAX10}), the moving average (MA) of a sequence of five measurements can be computed as follows:

$$MA_5 = (T_{MAX1} + T_{MAX2} + T_{MAX3} + T_{MAX4} + T_{MAX5})/5$$

$$MA_6 = (T_{MAX2} + T_{MAX3} + T_{MAX4} + T_{MAX5} + T_{MAX6})/5$$

$$\vdots$$

$$MA_{10} = (T_{MAX6} + T_{MAX7} + T_{MAX8} + T_{MAX\,9} + T_{MAX10})/5$$

A moving average is used to smooth out any short-term fluctuations and highlight long-term trends (Kenney and Keeping 1962). While short-term perturbations of rainfall and temperature are important from an individual extreme weather perspective, smoothing out such fluctuations removes noise from long-term trends. As such, a 5-year moving average is used to compute the mean, standard deviation, and CV from Climate Research Unit (CRU) gridded time-series country dataset (CRU CY v.3.24.01).

3.2.2.1.2 Standard Deviation

The standard deviation is one of the most common and useful measures of variability (Jaisingh 2006). It measures the dispersion of the data from a center value such as the mean (Coolidge 2013). The sample standard deviation, *s*, is defined as the positive square root of the sample variance, s^2. Per Agresti and Finlay (2014), the sample standard deviation, *s* of *n* observation can be computed as follows:

$$s_y = \sqrt{\frac{\Sigma(y_i - \bar{y})^2)}{\text{n} - 1}} \qquad [3.2]$$

where,

s_y = standard deviation of the respective climate variable y

y_i = ith observation of the climate variable y.

$\bar{y}$ = sample mean

n = sample size

By taking the positive square root of the sample variance, the standard deviation is presented in the same units of the variable. As such, it is easier to interpret any deviation from the mean. Large deviations from the mean indicate that the dataset is more volatile and thus less reliable. Thus, by computing the standard deviation of rainfall and temperature, we can measure the absolute variability with respect to the mean.

3.2.2.1.3 Coefficient of Variation

The more (less) disperse a dataset, the higher (lower) the standard deviation. As such, the standard deviation does not allow a direct comparison of two or more different variables since it is proportional to the mean. Thus, the magnitude of the standard deviation depends on the variable being analyzed (Sarker, 2012). The coefficient of variation (CV) overcomes this problem by allowing us to standardize the variation across variables. This is done by converting the standard deviation (a measure of absolute variability) to a relative value. The sample CV is defined as the sample standard deviation divided by the sample mean expressed as a percentage (Jaisingh 2006). Hence, the CV is computed as follows:

$$CV_y = \frac{s_y}{\bar{y}} \quad [3.3]$$

Given that the moving average and the standard deviation have the same units, the CV is unitless which allows for direct comparison of different variables with different units.

3.2.2.2 Linear trend model

The second method uses a simple trend model to assess the changes in rainfall, and minimum and maximum temperature over time. Gujarati, Porter, and Gunasekar (2012) note that the coefficient of the trend variable in a growth model gives the instantaneous (at a point in time) rate of growth as shown in equation 3.4 below.

$$Y_t = \beta_0 + \beta_1 t + e_t \qquad [3.4]$$

where,
Y = independent climate variable
t = time
e_t = error term

In equation 3.4, the time variable (*t*) is referred to as the trend variable and its coefficient (β_1) indicates the direction of the trend. A positive (negative) coefficient indicates an (a) upward (downward) trend in the climate variable Y. It must be noted that the linear trend model does not imply causation. Rather it suggests the directional change of the climate variable over time.

3.2.2.3 Two-sample t-test

The third method uses a two-sample t-test to examine the change in average annual total rainfall (mm), average annual maximum temperature (ºC), and average annual minimum temperature (ºC) between two time periods. Livezey et al. (2007) note that numerous empirical studies and simulations indicate that the latest period of modern global warming began in the mid-

1970s. As such, 1975 is used as the hinge point for a two-sample t-test comparison of climate variables between 1934-1974 and 1975-2015.

In hypothesis testing, a two-sample t-test compares the means of two samples to allow us to make inference about their difference. The null and alternate hypotheses are presented below:

$$\mathbf{H_0}: \mu_1 - \mu_2 = 0$$

$$\mathbf{H_a}: \mu_1 - \mu_2 \neq 0$$

where μ_1 and μ_2 are the means of the respective samples. The null hypothesis (H_0) assumes that statistically significant evidence does not exist to support the difference in the means while the alternate hypothesis (H_a) assumes that there is statistically significant evidence to support the difference in the means. The primary assumptions of the two-sample t-test are that the samples are independent and random, both populations are normally distributed, and the population variances are unknown but assumed equal (Agresti and Finlay 2014).

3.3 Analyzing Small Farmers' and Key Informants' Perceptions, Impacts, and Adaptation

To answer research questions 3 and 4, primary data were collected from small farmers and key informants. The discussion that follows presents the theoretical model and empirical approach, research design, and primary data collection method. Included is a description of the data source, the data collection process, and coding and construction of each variable.

3.3.1 Theoretical Model and Empirical Approach

The discussion that follows presents the underlying theoretical model and the empirical approach used to explore the relationship between socioeconomic, farm-level, and institutional characteristics and rice yields.

3.3.1.1 Theoretical Model

There are many factors that influence crop agricultural productivity. In terms of rice production, the existence of these factors individually or collectively may affect the quantity of rice harvested. In studying climate impacts, different authors have used different classifications or some variant of exogenous variables. Van Passel, Massetti, and Mendelsohn (2017) grouped exogenous variables into climate variables, exogenous control variables, and socioeconomic variables. Climate variables include temperature and rainfall; exogenous controls variables include distance from urban areas, distance from ports, mean elevation, and soil; and socioeconomic variables include market access, agricultural land value, and ownership of land (Van Passel, Massetti, and Mendelsohn 2017).

Similarly, Antle and Stöckle (2017) classified exogenous variables into three subgroups: physical, biological, and socioeconomic. Physical factors include temperature and precipitation, humidity and solar radiation, social conditions and atmospheric CO_2; biological factors include crop genetics and pest and diseases; and socioeconomic factors include technology, prices, policy, and institutions (Antle and Stöckle 2017).

Other classifications of exogenous variables used in assessing the impacts of climate change on agricultural productivity include climate, soil, and socioeconomic variables (Mendelsohn and Nordhaus 1994); purchase inputs, climate variables, labor characteristics, and farm characteristics (Kurukulasuriya and Ajwad 2007); and purchased input prices, climate, soil, hydrological, economic variables (Charles 2009). While the general classification of exogenous variables is different, there are many similarities in the actual variables. Additionally, the variables included under each grouping may be unique to a particular crop, location, and/or agricultural system. Sarker (2012) introduced three categories of non-climatic variables that affect rice yields in Bangladesh: socioeconomic, farm-level, and institutional characteristics.

The model used in this study explores the relationship between socioeconomic, farm-level, and institutional characteristics and rice yields at the farm-level. Although climatic conditions, insects and pests, diseases, and weeds also affect yields, these variables are not considered specifically since such data are not available at the farm-level for Guyana. Instead, perceptions of these variables are included in the model and are treated as farm-level characteristics. In Equation [3.5], rice yield is a function of socioeconomic, farm-level, and institutional characteristics.

Rice Yields = *f* (Socioeconomic Characteristics, Farm-level Characteristics, Institutional Characteristics) [3.5]

3.3.1.1.1 Socioeconomic Characteristics

Socioeconomic characteristics include farmers' age, gender, education level, and sources of income. The age of a farmer serves as a proxy for experience (Kurukulasuriya and Ajwad 2007; Charles 2009; Sarker 2012; Bello and Maman 2015; Closset, Dhehibi, and Aw-Hassan 2015; Huong, Bo, and Fahad 2018. Older farmers may possess greater farming knowledge and experience regarding climate change and agronomic practices and thus are able to obtain higher yields by making changes to their farming practices over time.

In developing countries, traditional gender inequalities often mean that male farmers are more productive. Women often lack the same access to productive resources such as land, technology, financial services, education, and markets (FAO 2011). In Guyana, male farmers usually congregate in the evening and discuss farming practices while female farmers are seldom present during these conversations because of cultural norms. Kurukulasuriya and Ajwad (2007) suggest that the female head of farm households may face discrimination and do not benefit from the household having two adults to contribute to farm labor. Other studies that considered gender in their analysis include Sarker 2012; Ochieng, Kirimi, and Mathenge 2016; Huong, Bo, and Fahad 2018.

Education level is a proxy measure of farmers' intellectual ability to adopt new technologies, and optimize inputs and marketing practices (Kurukulasuriya and Ajwad 2007; Nyuor et al. 2016). Farmers with higher levels of education or more years of schooling are expected to produce higher yields under a changing climate (Kurukulasuriya and Ajwad 2007; Nyuor et al. 2016; Kabubo-Mariara and Karanja 2007; Sarker 2012; Bello and Maman 2015; Ochieng, Kirimi, and Mathenge 2016; and Huong, Bo, and Fahad 2018.

According to Janvry and Sadoulet (2016), small farmers usually derive approximately 50 percent of their income from off-farm employment and self-employment in rural non-farm economy. Such income diversification plays an important role in risk management and income stabilization (Janvry and Sadoulet 2016). Under a changing climate, the availability of non-agricultural income is expected to help small farmers pay for the costs of adaptation that would otherwise be out of their reach. Examples of such practices may include investing in equipment, purchasing additional fertilizer and chemicals, paying for additional land preparation, and purchasing new seeds each season.

3.3.1.1.2 Farm-level Characteristics

Farm-level characteristics include perceived changes in rainfall, temperature, extreme weather events, insects and pests, diseases and weeds. Other farm-level characteristics include primary occupation is rice farming, the size of farm, ownership of farmland, experience of farmer, farmer owned a tractor, farmer owned livestock, type of soil on the land, soil test was done, household member(s) help with rice farming, farmer fully adopted the six-point practice, seasonal labor was employed, and seed variety planted.

In the absence of farm-level climate data, farmers' perceptions of changes in rainfall, temperature, and extreme weather events are used as explanatory variables. Changes in rainfall, temperature, and extreme weather events are also expected to have a positive effect on the presence of insects, diseases, and weeds (Rosenzweig et al. 2001), which are assumed to negatively impact yields. It is assumed that farmers that perceived changes in these variables are also likely to experience changes in their yields and subsequently change their farm management practices leading to better yields.

Farmers whose primary occupation is rice farming is expected to produce higher yields than those that plant rice on the side (Kabubo-Mariara and Karanja 2007; Sarker 2012). This is because these farmers have a vested interest in rice cultivation since it is their main source of income. As such, they are expected to be deeply involved in the day-to-day management of their fields and well-informed about new developments in farm management practices under a changing climate.

The size of a farm is an important factor in determining yields. Large farmers can spread the risk of adverse climatic conditions (J. Benhin 2006) by diversifying crops and livestock (Charles 2009). They can also apply better production technologies (Sarker 2012). Kabubo-

Mariara and Karanja (2007) noted that large farm size may be associated with higher productivity. Large farm sizes have also been found to correlate with higher farm net revenue (Wood and Mendelsohn 2014; Nyuor et al. 2016; Huong, Bo, and Fahad 2018). However, other studies (Sarker 2012; Closset, Dhehibi, and Aw-Hassan 2015) have found a negative relationship between large farms and net revenues. In other words, small farms may be more efficient and hence more productive than large farms.

In developing countries, farm households may have incomplete or no property rights. According to Besley and Ghatak (2010), property rights refer to an owners right to use or transfer a good or asset. As such, property rights encourage farm households to invest in their land and/or allow them to gain access to financial resources such as credit. Kurukulasuriya and Ajwad (2007) argued that land tenure reduces the uncertainty of reaping the benefits of investment in time, inputs, and capital. Hence, farmers with secured property rights can make decisions that optimize their yields.

While age is often used as a proxy for experience, it may not always translate into actual experience. For instance, a farmer may have started planting rice later in life. As a result, the number of years farming would be lower. Therefore, the actual experience of a farmer is a more accurate measure. Sarker (2012) found that although farming experience had a positive impact on net revenues, it was not statistically significant.

Ownership or access to machinery and equipment enables farmers to attend to their fields in a timely manner. For instance, ownership of a tractor allows farmers to become more independent thus avoiding delays in land preparation. They can take advantage of ideal conditions and begin dry land preparation almost immediately. Early land preparation ensures farmers sow and harvest on time which reduces overall losses due to potential flooding and lodging. By preparing the land themselves, farmers are also ensuring that it is done properly. Proper land preparation helps with water management and weed control. Access to tractors was found to have a positive influence on net farm revenues (Charles 2009; Mishra, Sahu, and Sahoo 2016).

The ownership of livestock provides farmers with an additional source of on-farm income. Income from the sale of livestock may help pay for adaptation practices that contribute to better yields. However, livestock ownership could also negatively impact on yields through increase completion for limited on-farm resources such as farmers' time and grazing space. Kabubo-Mariara and Karanja (2007) found that livestock ownership negatively impacted crop agriculture.

Nyuor et al. (2016) noted that there is a direct relationship between household size and agricultural output. This is because household size is often used as a proxy for farm labor (Kabubo-Mariara and Karanja, 2007). Wood and Mendelsohn (2015) found that larger households contribute to higher agricultural net revenues. In Guyana, household member(s) active participation in rice farming may help to ensure timely completion of farming activities and lower overall labor costs. Household members are also likely to take a greater interest in the quality of work performed.

In 2008, the Guyana Rice Development Board (GRDB) Extension Department introduced six improved management practices known locally as the six-point practice. The improved practices include advice on planting in-season (time of sowing), reducing plant densities (seed rate), treating seeds before sowing (seed treatment), controlling weeds, using balance nutrition fertilizer, and managing water in the field. Although the initial focus of the six-point practice was to improve yields, its adoption is viewed as a key response to changes in environmental conditions facing rice farmers. As such, farmers that fully implement the six-point practice would benefit from higher yields.

Since rice is direct seeded in Guyana, other household members' substitution for paid labor are usually not sufficient during peak sowing, fertilizing, and spraying times. As such, seasonal labor is employed to help ensure that specific farming activities are completed in a timely manner. This is especially the case for farmers that maintain off-farm employment and need the extra hands to help with putting the crop in on time. Having worked on multiple farmers, seasonal labor usually boasts good skills, knowledge, and experience broadcasting seedlings, applying fertilizer, and spraying for insects and diseases. As such, the use of seasonal labor may help boost yields. However, the quality of work performed by seasonal labor may lead to lower yields. For example, seasonal labor may do a poor job applying fertilizer or spraying for insects.

Since 1997, there have been 15 rice varieties released through the rice breeding program in Guyana (GRDB 2015b). Each variety differs across many characteristics including days to maturity, yield potential, disease resistance, and grain length, width, and shape. While some older varieties are susceptible to disease, some newer varieties are high yielding. Yet other newer varieties can withstand lodging even though their yields may be lower. Under a changing climate, planting a high yielding variety does not guarantee higher yields at harvest. For instance, heavy rainfall leading up to harvesting can cause a high yielding variety to lodge resulting in greater losses. Regardless, farmers are planting the varieties of their choice. Therefore, the variety planted may influence the yields of farmers.

3.3.1.1.3 Institutional Characteristics

Institutional characteristics include farmer participated in rice extension training(s); access to advance weather information; access to input credit, membership in an agricultural organization(s), access to adequate irrigation, the source of seed, and farmer pumped water.

Agricultural extension plays a crucial role in climate change adaptation. Extension agents transfer knowledge from researchers to farmers, advise farmers in decision-making, educate farmers to make similar decisions in the future, enable farmers to clarify their own goals and possibilities and to realize them, and stimulate desirable agricultural developments (Van den Ban and Hawkins 1996). As such, farmers' access to rice extension training sessions help ensure that they are receiving up-to-date information on adaptation strategies and practices which can help improve farm management practices and by extension yields. The influence of extension services on net farm revenues have been explored by Charles (2009); Sarker (2012); Nyuor et al. (2016); and Huong, Bo, and Fahad (2018).

Successful adaptation to climate change calls for timely and accurate weather information. Sarker (2012) argued that access to advance weather information could augment responses to and lessen the adverse effects of climate change. Farmers that have access to advance weather information can effectively and efficiently adapt to climate change thereby improving yields.

Farm household access to input credit is an important institutional support. Nyuor et al. (2016) noted that credit allows farmers to purchase basic agricultural inputs such as labor, fertilizer, seeds, and herbicides. Under a changing climate, credit also eases the financial burden of engaging in costly adaptation practices. For example, credit may assist a farmer to purchase new seeds each season or purchase a tractor to help with early land preparation. Several studies have explored the relationship between access to credit, adaptation, and farm household net revenues (Sarker 2012; Bello and Maman 2015; Nyuor et al. 2016); Huong, Bo, and Fahad 2018).

Membership in an agricultural organization is advantageous to farmers (Wang et al. 2009). As members, farmers are privy to information on regulations and policies that is likely to influence the rice industry. They may also readily access information on the impacts of climate change, new adaptation strategies, and training opportunities. Access to this information may guide farmers in their response to climate change which can translate into higher yields.

Given that rice cultivation in Guyana is under irrigation, access to adequate water remains paramount to realizing good quality and quantity yields. Moreover, timely release of water under a changing climate is even more crucial to water management practices, especially during dry spells. Given that irrigation is an effective adaptation measure (Gbetibouo and Hassan 2005; Kabubo-Mariara and Karanja 2007), farmers that benefited from adequate irrigation will boast higher yields.

Farmers that pump water to flood their fields may benefit from better yields in that they are able to engage in better water management. Alternatively, pumping water may be a sign of limited water availability in the irrigation system which may negatively affect yields. The definitions, source, and anticipated impact of the socioeconomic, farm-level, and institutional variables are highlighted in Table 3.1.

Table 3.1 Definitions, Expected Signs and Source of Socioeconomic, Farm-level, and Institutional Variables

Non-climatic Variables	Variable	Variable Description	Measure	Expected Sign	Source
Socioeconomic	AGE	Age of the farmer	No. of years	+	Kurukulasuriya and Ajwad (2007); Charles (2009); Sarker (2012); Bello and Maman (2015); Closset, Dhehibi, and Aw-Hassan (2015); Huong, Bo, and Fahad (2018)
Socioeconomic	GENDER	Gender of the farmer	1=male and 0=female	+	Kurukulasuriya and Ajwad (2007); Sarker (2012); Ochieng, Kirimi, and Mathenge (2016); Huong, Bo, and Fahad (2018)
Socioeconomic	EDUC	Education level of the farmer	0=no school 1=primary 2=communit y high 3=high school 4=technical/ vocational 5=university	+	Kurukulasuriya and Ajwad (2007); Kabubo-Mariara and Karanja (2007); Sarker (2012); Bello and Maman (2015); Ochieng, Kirimi, and Mathenge (2016); Nyuor et al. (2016); Huong, Bo, and Fahad (2018)
Socioeconomic	SECNAG	Non-agricultural income	1=yes and 0=no	+	Author
Farm-level	RAINCHNG	Perceived changes in rainfall	1=yes and 0=no	+	Author
Farm-level	TEMPCHNG	Perceived changes in temperature	1=yes and 0=no	+	Author
Farm-level	EXTREWEAT	Perceived changes in extreme weather events	1=yes and 0=no	+	Author
Farm-level	INSECCHNG	Perceived changes in insects and pests	1=yes and 0=no	+	Author
Farm-level	DISEACHNG	Perceived changes in diseases	1=yes and 0=no	+	Author
Farm-level	WEEDSCHNG	Perceived changes in weeds	1=yes and 0=no	+	Author
Farm-level	PRIMOCCU	Rice farming is the primary occupation	1=yes and 0=no	+	Kabubo-Mariara and Karanja (2007); Sarker (2012)

Farm-level	FARMSIZE	Size of farm	No. of hectares	+	Kabubo-Mariara and Karanja (2007); Sarker (2012); Wood and Mendelsohn (2015); Closset, Dhehibi, and Aw-Hassan (2015); Nyuor et al. (2016); Huong, Bo, and Fahad (2018)
Farm-level	TENURE	Ownership of farm land	1=yes and 0=no	+	Kurukulasuriya and Ajwad (2007); Sarker (2012)
Farm-level	FARMEXP	Experience of farmer	No. of years	+	Kurukulasuriya and Ajwad (2007); Sarker (2012)
Farm-level	TRACTOR	Owned a tractor	1=yes and 0=no	+	Charles (2009); Mishra, Sahu, and Sahoo (2016)
Farm-level	OWNLIVE	Owned livestock	1=yes and 0=no	-	Kabubo-Mariara and Karanja (2007)
Farm-level	SOILTEST	Soil test was done	1=yes and 0=no	+	Author
Farm-level	HOUSEPART	Household member(s) help with rice farming	1=yes and 0=no	+	Author
Farm-level	SIXPOINT	Fully adopted the six-point practice	1=yes and 0=no	+	Author
Farm-level	LABOR	Seasonal labor was employed	1=yes and 0=no	+/-	Gbetibouo and Hassan (2005)
Institutional	EXTTRAIN	Participated in rice extension training(s)	1=yes and 0=no	+	Charles (2009); Sarker (2012); Nyuor et al. (2016); Huong, Bo, and Fahad (2018)
Institutional	ADVWEATH	Access to advance weather information	1=yes and 0=no	+	Sarker (2012)
Institutional	CREDIT	Access to input credit	1=yes and 0=no	+	Sarker (2012); Bello and Maman (2015); Nyuor et al. (2016); Huong, Bo, and Fahad (2018)
Institutional	AGMEM	Membership in an agricultural organization(s)	1=yes and 0=no	+	Sarker 2012; Wang et al. 2009
Institutional	ADEQIRRIG	Access to adequate irrigation	1=yes and 0=no	+	Gbetibouo and Hassan (2005); Kabubo-Mariara and Karanja (2007); Charles (2009); Sarker (2012); Huong, Bo, and Fahad (2018)
Institutional	PUMPWAT	Pumped water	1=yes and 0=no	+/-	Author
Regional	REGION2	Farm located in region 2	Region=2	+/-	Author
Regional	REGION3	Farm located in region 3	Region=3	+/-	Author
Regional	REGION4	Farm located in region 4	Region=4	+/-	Author
Regional	REGION5	Farm located in region 5	Region=5	+/-	Author
Regional	REGION6	Farm located in region 6	Region=6	+/-	Author

3.4 Research Design

The survey part of this research was aimed at collecting primary data from small farmers and key informants to answer research questions two, three, four, and five. The sections that follow describe the research design.

3.4.1 Study Area

The study area for this research is the five primary rice-producing regions in Guyana: Pomeroon-Supenaam (Region 2), Essequibo Islands-West Demerara (Region 3), Demerara-Mahaica (Region 4), Mahaica-Berbice (Region 5), and East Berbice Corentyne (region 6)[15]. These administrative regions are located on the low coastal plain natural region which stretches 285 miles along the Atlantic coast and is primarily below sea-level. This low coastal plain flat terrain and fertile soil is the main crop agriculture area in the country. Figure 3.1 and 3.2 illustrate the natural regions and primary rice producing administrative regions, respectively.

[15] Rice is also grown at Moco Moco in Upper Takutu-Upper Essequibo (Region 9).

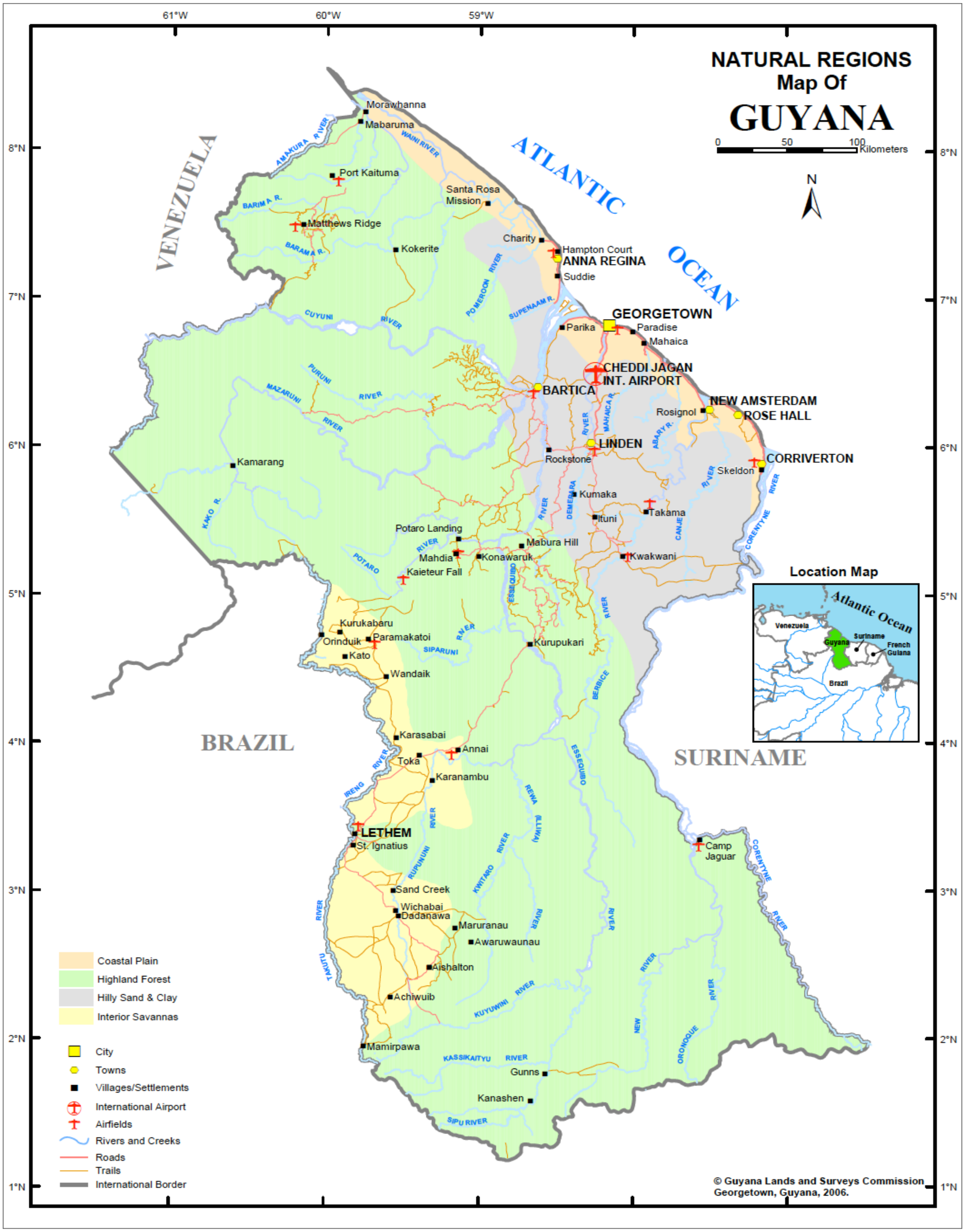

Figure 3.1 Map of natural regions in Guyana
Source: GLSC (2006)

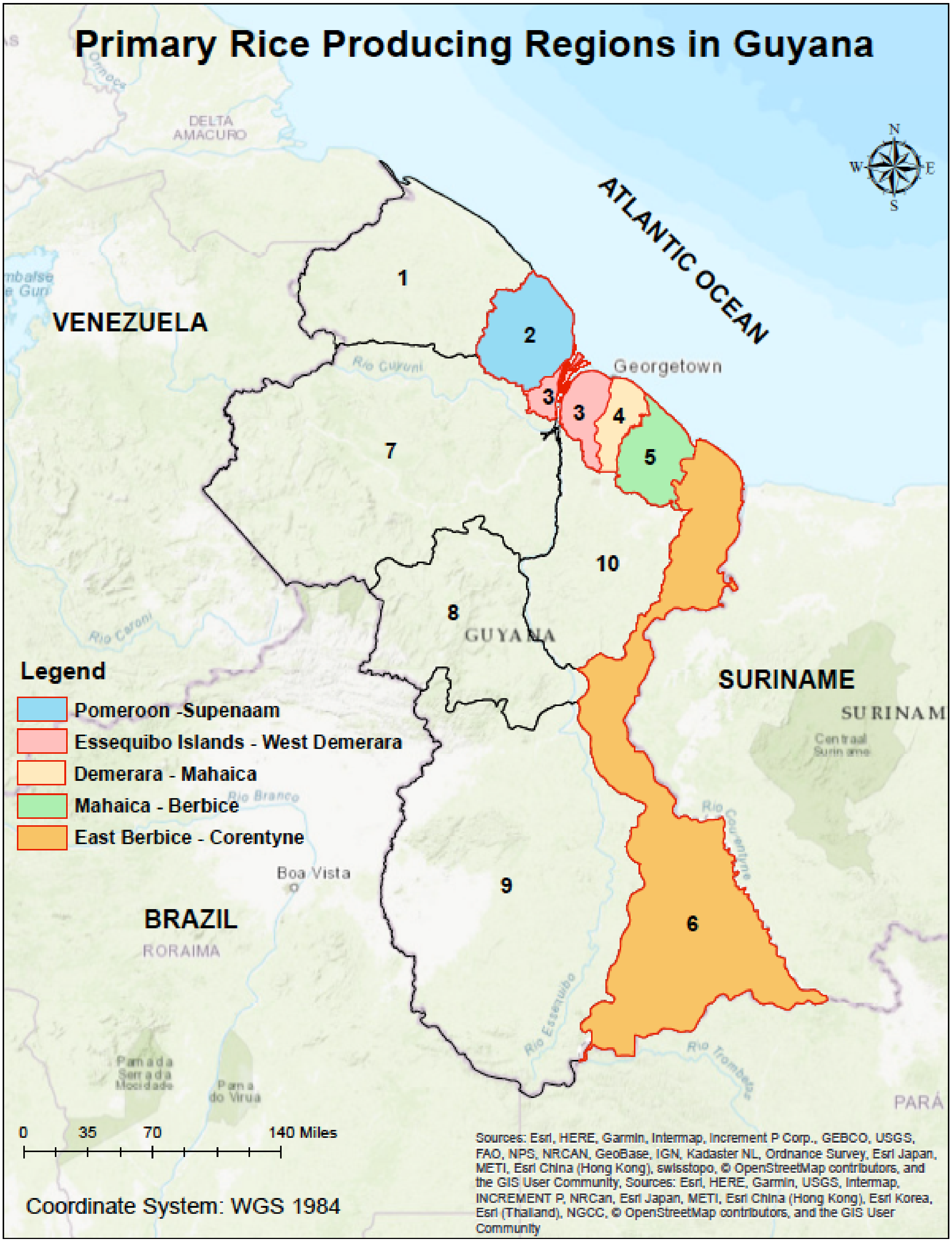

Figure 3.2 Map of primary rice producing regions in Guyana
Credit: Author

In terms of rice production, region two boasts the largest number of small farmers. Regions four and five have the smallest and largest number of acres under cultivation, respectively. Table 3.2 presents a summary of rice farmers by acreage and region as of spring 2018. Figure 3.3 shows the areas rice is grown.

Table 3.2 Summary of Farmers by Acreage and Region

Region/	2		3		4		5		6		Total	
Acreage	# of farmers	Acreage	# of farmers	Acreage	# of farmers	Acreage	# of farmers	Acreage	# of farmers	Acreage	# of farmers	Acreage
1-10	1261	6562	462	2570.75	267	1378.9	554	3650.25	170	1173.25	**2714**	**15335.2**
11-20	299	4540	186	2812.5	77	1149.5	367	5962.23	295	4602.25	**1224**	**19066.5**
21-30	107	2695	86	2189.7	37	930	244	6614.19	251	6939.5	**725**	**19368.4**
31-40	89	3168	43	1527	20	686.2	137	5044.6	87	3239	**376**	**13664.8**
41-50	41	1866	31	1393	13	602.5	115	5408.04	143	6566	**343**	**15835.5**
50 & above	127	14473	94	9473	38	3801.9	459	70792.86	294	34112	**1012**	**132652.8**
Total	**1924**	**33304**	**902**	**19965.95**	**452**	**8549**	**1876**	**97472.17**	**1240**	**56632**	**6394**	**215923.1**

Source: GRDB (2018)

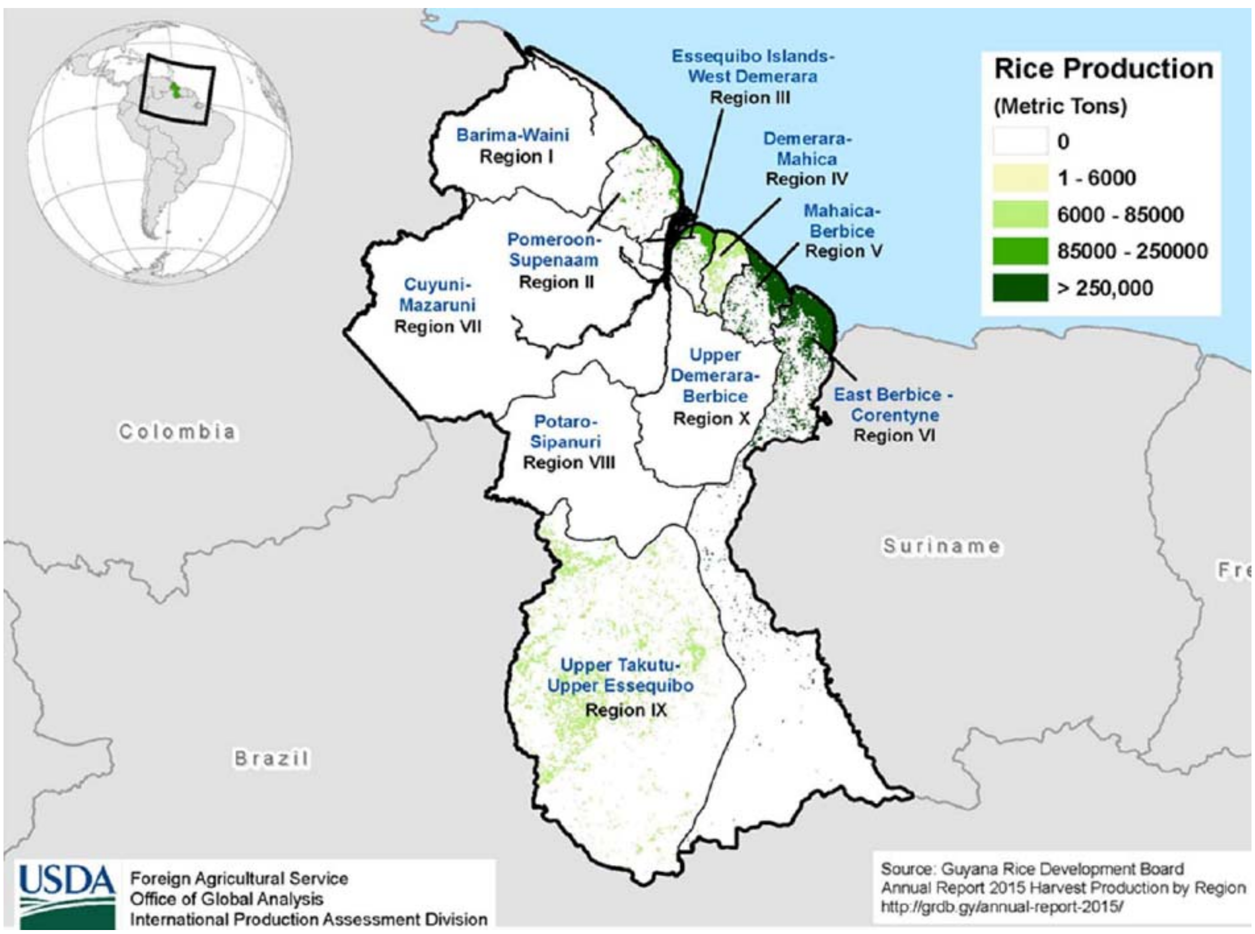

Figure 3.3 Map of Guyana showing rice producing areas
Source: USDA-FAS (2018)

3.4.2 Study Population

The population of this study is all small farmers located in the five main rice-producing administrative regions in Guyana. As of spring 2017, there were 2,896 small farmers across Guyana (GRDB 2017). Table 3.3 presents the number of small farmers in each rice-producing region.

Table 3.3 Small Farmers by Region

Region	# of small farmers	%
Region 2 - Pomeroon-Supenaam	1,366	47.2
Region 3 - Essequibo Islands-West Demerara	495	17.1
Region 4 - Demerara-Mahaica	289	9.9
Region 5 - Mahaica-Berbice	526	18.2
Region 6 - East Berbice Corentyne	220	7.6
Total	**2,896**	**100.0**

Source: GRDB (2017)

3.4.3 Sample Size and Selection

Conventional wisdom suggests larger samples are better. However, access, costs, time, the overall size of the population, and the number of variables also influence sample size. According to Creswell (2012), a sample size of approximately 350 is appropriate for a survey study. In homogenous populations, however, smaller samples can be equally effective (Neuman 2011). Since farmers in each region in Guyana are likely to face similar socioeconomic, environmental, and climatic conditions, a smaller sample can be representative of the population (Blaikie 2000). Following Bartlett, Kotrlik, and Higgins (2001), a five percent sample size was considered sufficiently large.

To select the sample for each region, a copy of the rice farmers' register as of Spring 2017 was obtained from the Guyana Rice Development Board (GRDB). The register is maintained in Microsoft Excel and is organized by regions. Each region contains the following information:

farmer's first and last name, farmer's address (name of the village), farmer's call name[16], and acreage sown. A table summarizing the number of farmers by acreage categories and across regions is also included in the farm register.

Given that the farm register was already stratified by region, a list of small farmers was subsequently created for each region to facilitate the sample selection. This was done by sorting the list of farmers by acreage planted. Farmers that planted more than 4.45 hectares (11 acres) were discarded since they did not meet the definition of small farmer established for this research. Once the list of small farmers was created for each region, the random function (RAND) in Microsoft Excel was used to generate and assign random numbers greater than or equal to 0 and less than 1 for each small farmer in a separate column. Since new random numbers are returned each time the worksheet is calculated, the list of random numbers generated was subsequently hardcoded by copying and pasting the values to prevent the numbers from changing. The list of small farmers for each region was then sorted by the random numbers' column from lowest to highest and the first five percent of small farmers were selected for interviews.

3.4.4 Data Source and Description of Survey Instrument

Two structured questionnaires comprising of both qualitative and quantitative questions were used to conduct face-to-face interviews with small farmers and key informants in Guyana. The main purpose of the questionnaires was to collect data on perceptions, impacts, and adaptation as it relates to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds.

[16] In Guyana, persons usually go by a call name which can be a shortened version of their legal name or a nickname. The call name was very important in locating farmers since this is the name they are usually known by in their respective villages.

At the farm-level, a cross-sectional household survey comprising of 49 questions was designed and used for interviewing small farmers. Question types varied, and several questions contained multiple parts. Open-ended questions solicited a narrative response from small farmers and key informants. This approach was used because it provides a voice for those normally unheard. It also emphasizes the sequence of events from perceptions to adaptation.

Respondent ID, the name of the respondent, village, telephone number, GPS coordinates of interview location and administrative region aside, the questionnaire was divided into four parts as follows: socioeconomic characteristics; farm structure and characteristics; farmers' perceptions, impacts, and adaptation; and institutional accessibility.

The socioeconomic section collected data on the farmers' age, gender, education level, primary and secondary agricultural and non-agricultural occupations/sources of income. The farm structure and characteristics section captured data on household participation in rice farming, the use of part-time labor, acreage planted and yields, land tenure, farming experience, type of farming equipment owned, shared, and/or rented, livestock owned, soil type, and soil testing.

The perceptions, impacts, and adaptation section elicited responses from farmers regarding perceived changes, impacts, and responses to shifts in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. This section also collected data on the cropping season most affected by the observed changes, directional change of yields, crop failure, coping strategies, and changes in farming practice in response to observed changes. The sources of and farmers' ability to pay for adaptation, barriers to adaptation, small farmers' understanding of climate change, and farmers' familiarity with and implementation of six improved management practices introduced by the Guyana Rice Development Board (GRDB) were also collected.

The institutional accessibility section of the questionnaire collected data on farmers' access to and participation in extension training and related activities, access to and source of advance weather information, agricultural credit and insurance, and irrigation facilities. The source of and seed variety planted, the quality of inputs and equipment and farmers' membership in the Rice Producer Association (RPA) or other agricultural related association or institution were also collected. A copy of the questionnaire used at the farm-level is included as Appendix A.

The farm-level questionnaire was modified for interviews with key informants. Key informants comprise of district rice extension officers, an experienced farmer (+25 years of experience), a rice miller, and senior staff (Chief Scientist/Plant Breeder, Plant Pathologist, Agronomist, Entomologist, and the Rice Extension Manager) at the Burma Rice Research Station in Guyana. Apart from the respondent ID, name of the respondent, position, district, telephone number, GPS coordinates of interview location, and administrative region, the questionnaire collected data on the age, gender, education level, and experience of key informants. Key informants were also asked to describe perceived changes and impacts of rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds and how farmers are responding to these changes. In addition, key informants were asked to describe their current efforts to help farmers adapt to observed changes, specific resources needed now and/or in the future to effectively support adaptation, and the barriers or challenges that currently plague the rice sector. A copy of the questionnaire used for key informants is included as Appendix B.

3.4.5 Validity and Reliability of the Survey Instrument

Content validity and measurement reliability are important considerations in research involving primary data collection through the use of a questionnaire. Content validity is the extent to which survey questions measure the full content of a conceptual definition (Neuman 2011). In other words, do the survey questions capture the complete meaning? Given that the questions included in the survey are theoretically defined and based on a review of the literature on the impact of climate change at the farm-level, the questions are considered content valid. Validity was also confirmed by the fact that open-ended elements provided some opportunities for farmers to share information in their own words. Measurement reliability refers to the dependability or consistency of the measure (Neuman 2011). In other words, the results of the survey instrument do not change each time the instrument is used. Measurement reliability was improved through a pre-pilot test of the survey instrument and updating accordingly. This was followed by a pilot test which led to further refinements of the questions.

3.4.6 Pre-Pilot Testing

Although the draft questionnaire had undergone multiple revisions, a pre-pilot testing exercise was conducted in order to enhance the validity and reliability of the instrument. Pre-pilot testing helps to identify problem areas, reduce measurement errors, reduce respondent burden, and determine whether or not respondents are interpreting questions correctly (Ruel, Wagner, and Gillespie 2015). The pre-pilot testing exercise involved rice extension officers and a large farmer who provided valuable feedback which was incorporated into the questionnaire before the commencement of the pilot test.

3.4.7 Pilot Testing

After the pre-pilot testing was completed and the questionnaire updated, the instrument was pilot tested in early July 2017. Five small farmers in Region 3 - Essequibo Islands-West

Demerara were interviewed at their homes. Based on the responses received, further changes were made to refine the questionnaire. These included the re-wording of some questions and the creation of several new questions from existing questions. After the updates were made to the questionnaire, updated approval was sought and received from the Institutional Review Board (IRB) before the first interviews were conducted.

3.4.8 Interviews

Farm-level interviews were conducted in two phases between July and September 2017 and in May 2018. District Rice Extension Officers assisted in locating small farmers randomly selected for interviews. Interviews lasted between 30 and 45 minutes and were conducted primarily at the homes of small farmers. However, other interview locations included by the roadside, on the farm, and off-farm employment sites.

During the initial interviewing phase, four primary difficulties were encountered: farmers refused to participate, farmers could not be located, farmers planted more than 4.45 hectares (11 acres), and farmers no longer planted rice. Two farmers refused to participate. Further discussions with extension officers alluded to a general lack of trust as being the primary reason for non-participation. Difficulties in locating farmers include farmer passed away, farmer migrated overseas, or farmer was not at home. Farmers not at home were traveling, on their farm which was not located nearby or were engaged in off-farm employment. A second attempt was made to interview these farmers but often proved futile.

In several cases, farmers randomly selected for interviews indicated that they were planting more than 4.45 hectares (11 acres). As a result, interviews were discontinued because these farmers did not meet the definition of small farmers established for this research. The GRDB extension manager explained that the difference between the farm register and what farmers reported was due in part to the failure of some extension officers to properly update the data for their respective district each season. It is common for the acreage to change from season to season since farmers may rent additional land thus increasing their acreage. Additionally, there was a compilation error where the acreage of farmers that planted in more than one districts was improperly summed and included in the final register. For example, a farmer that planted eight acres in one district and six acres in another district was incorrectly included in the register as planting eight or six acres instead of 14 acres. Farmers that did not plant rice in 2016 usually rented the land to a large farmer.

Of the 145 small farmers randomly selected for interviews in phase 1, 98 (67.6%) were replaced. Table 3.4 summarizes the reasons for replacing farmers. Replacement of farmers was done in two ways. Replacements were first selected from the next five percent of randomly selected small farmers. However, only 22 (15.2%) small farmers were located and subsequently interviewed. Given the limited success in locating small farmers coupled with time and cost considerations, extension officers were called upon to identify small farmers in the same village or neighboring villages. In some instances, replacement farmers were identified and interviewed from villages that were not previously captured in the random samples taken for each region.

Table 3.4 Reasons for Replacing Farmers

Region	Refused to Participate	Farmer Passed Away	Farmer Overseas	Not at Home	Large Farmer	Did not Plant in 2016	Total
Region 2 - Pomeroon-Supenaam	-	1	-	38	-	-	39
Region 3 - Essequibo Islands-West Demerara	1	3	1	5	3	3	16
Region 4 - Demerara-Mahaica	1	1	2	7	1	1	13
Region 5 - Mahaica-Berbice	-	1	-	15	3	2	21
Region 6 - East Berbice Corentyne	-	-	1	7	-	1	9
Total	**2**	**6**	**4**	**72**	**7**	**7**	**98**

It must be noted that in regions 3, 4, 5, and 6, the population of small farmers are relatively small in comparison to region 2. As a result, a five percent sample amounted to less than 30 small farmers in each of these regions. In order to satisfy the statistical convention of a large sample, the sample size was increased to a minimum of 30 small farmers in each region and the second phase of interviews were conducted in May 2018. During the second phase of interviews, extension officers were relied upon exclusively to identify and arrange interviews with additional small farmers in order to increase the sample size to 30 in regions 3, 4, 5, and 6. This approach helped eliminate the difficulties encountered in phase 1 thus reducing the time and cost involved in trying to locate farmers for an interview. Table 3.5 presents the sample of small farmers selected for each region. Figure 3.4 illustrates the GPS locations where interviews were conducted across the study area.

Table 3.5 Sample Size by Region

Region	**# of small farmers**	**Sample Size**	%
Region 2 - Pomeroon-Supenaam	1,366	68	5.0
Region 3 - Essequibo Islands-West Demerara	495	31	6.3
Region 4 - Demerara-Mahaica	289	30	10.4
Region 5 - Mahaica-Berbice	526	30	5.7
Region 6 - East Berbice Corentyne	220	30	13.6
Total	**2,896**	**189**	**6.5**

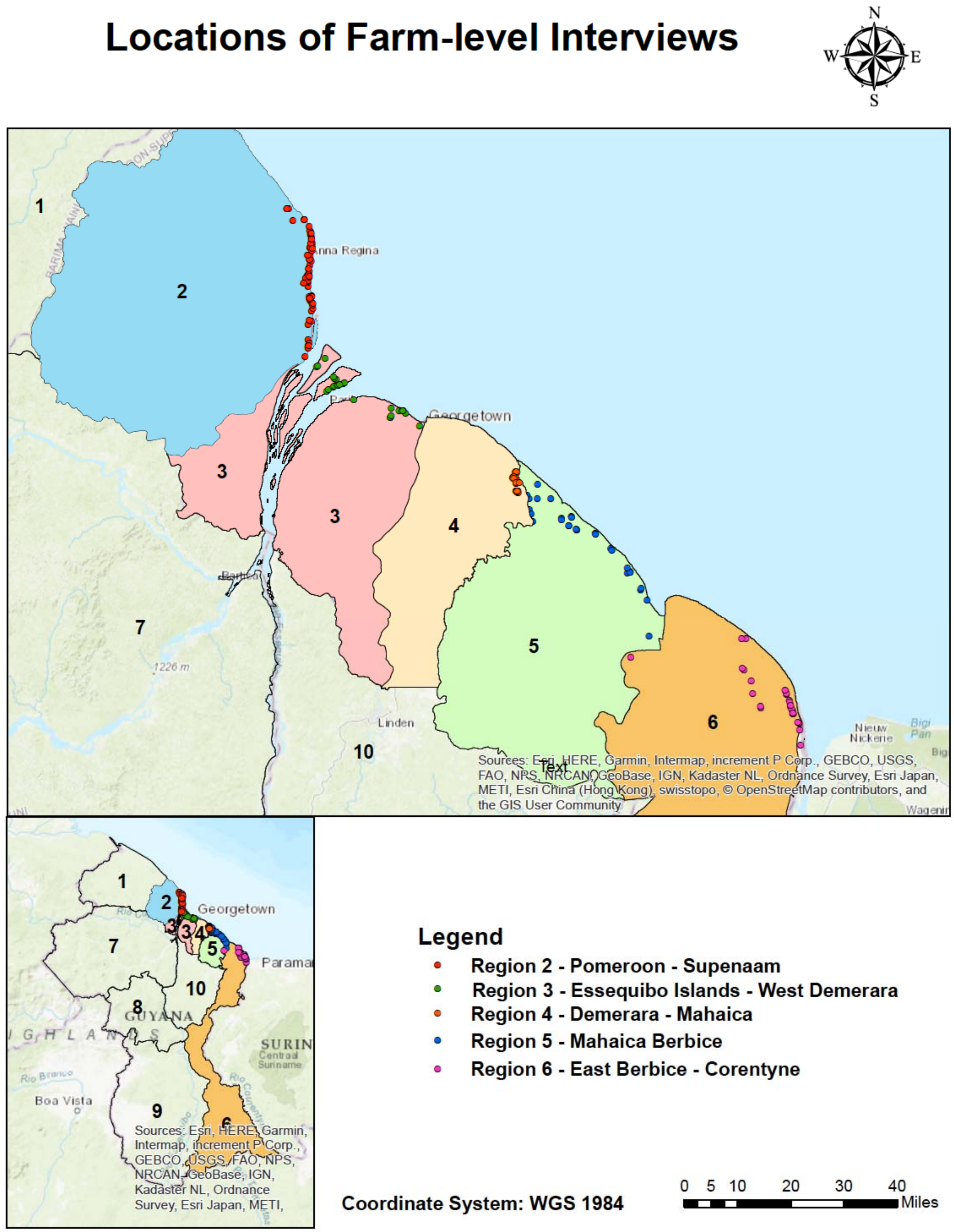

Figure 3.4 Map of locations of farm-level interviews
Credit: Author

To supplement and corroborate data collected from small farmers, interviews were also conducted with key informants. Key informants comprise of district rice extension officers, an experienced farmer (+25 years of experience), a rice miller, and senior staff (Chief Scientist/Plant Breeder, Plant Pathologist, Agronomist, Entomologist, and the Rice Extension Manager) at the Burma Rice Research Station in Guyana. These interviews were conducted at the Guyana Rice Development Board (GRDB) regional offices in each of the five administrative regions and at the homes of the rice miller and seed paddy producer.

3.4.9 Coding and Tabulation Process

The completed questionnaires were reviewed by the researcher before data entry commenced. The purpose of the review was to identify any missing information or inconsistencies in the responses. For the most part, responses were complete. However, in a few instances missing information and/or inconsistencies were resolved by reviewing field notes and/or audio recordings of the specific interview if it was available since not all interviews were recorded.

A codebook was subsequently created to help with data entry. The codebook contained the variable name, variable description, variable type (e.g., text, continuous, categorical, ordinal, binary), and variable codes. The codes were primarily derived from the questionnaire which contained preassigned codes for most questions. In a few cases, however, codes were expanded to capture additional responses. For example, while codes were created and assigned for different rice varieties, no code was preassigned for small farmers that planted multiple varieties on the same field or on separate fields. Using the codebook as a reference, the survey data were entered into a Microsoft Excel and coded accordingly. The list of codes used for analyzing the responses of small farmers and key informants are presented in Appendix C. Microsoft Excel is useful for tabulating survey data and allows for the dataset to be easily imported into Stata statistical software for multivariate analyses.

Upon completion of the data entry, the data was cleaned by reverse tracing the entry from the spreadsheet to individual questionnaires and making corrections where necessary. Once the data was cleaned, summary statistics for each question was created in separate tabs. For example, in the master spreadsheet, the column containing farmers' age was copied to a new worksheet, sorted from low to high, and tabulated using different age ranges. For questions that generated qualitative data (e.g., how did rainfall patterns change?), descriptive statistics were used to analyze each narrative response. A more in-depth discussion on the analysis of the qualitative data collected is presented in section 3.5 - Method for analyzing small farmers' and key informants' perceptions, impacts, and adaptation.

3.5 Method of Analyzing Rice Yield and Non-climatic Data at the Farm-level

The following sections introduce the theoretical model used for statistical estimation and the empirical approach taken. The contents of the multiple regression equations are introduced and described. Stata version 14 was used to generate the results presented in Chapter 5.

3.5.1 Multiple Regression

Climatic conditions aside, socioeconomic, farm-level, and institutional characteristics (non-climatic factors) also influence rice yields. As such, multiple regression is used to determine what non-climatic factors influence small farmers' yields. The regression model is presented in equation [3.6] where β_i are estimated coefficients, μ is the error term, which is assumed to be independent and identically distributed.

$$Y/ha = \alpha + \beta_1 F + \beta_2 G + \beta_3 H + \mu \qquad [3.6]$$

where,

Y/ha = rice yields per hectare
F = set of socioeconomic variables
G = set of farm-level variables
H = set of institutional variables
μ = error

3.5.2 Multiple Regression Equation

Equation [3.7] represents the baseline version of the multiple regression equation. It comprises of those non-climatic independent variables that are expected to affect rice yields based on the literature review and feedback received from key informants. Two additional scenarios are presented in equations [3.8] and [3.9]. The estimates of these equations are presented in Tables 5.15 and 5.16 in Chapter 5.

$$Yields/Ha = \lambda_0 + \lambda_1 RAINCHNG + \lambda_2 TEMPCHNG + \lambda_3 EXTREWEAT + \lambda_4 INSECCHNG + \lambda_5 DISEACHNG + \lambda_6 WEEDSCHNG + \lambda_7 AGE + \lambda_8 GENDER + \lambda_9 EDUC + \lambda_{10} PRIMOCCU + \lambda_{11} FARMSIZE + \lambda_{12} TENURE + \lambda_{13} FARMEXP + \lambda_{14} TRACTOR + \lambda_{15} OWNLIVE + \lambda_{16} EXTTRAIN + \lambda_{17} ADVWEATH + \lambda_{18} CREDIT + \lambda_{19} AGMEM + \lambda_{20} REGION2 + \lambda_{21} REGION3 + \lambda_{22} REGION4 + \lambda_{23} REGION5 + \lambda_{24} REGION6 + v \qquad [3.7]$$

The dependent variable, *Yields/Ha*, is rice yields per hectare. The independent variables include: perceived changes in rainfall (*RAINCHNG*); perceived changes in temperature (*TEMPCHNG*); perceived changes in extreme weather events (*EXTREWEAT*); perceived changes in insects and pests (*INSECCHNG*); perceived changes in diseases (*DISEACHNG*); perceived changes in weeds (*WEEDSCHNG*); age of the farmer (*AGE*); gender of farmer (*GENDER*); education level of the farmer (*EDUC*); rice farming is the primary occupation (*PRIMOCCU*); size of farm (*FARMSIZE*); ownership of farm land (*TENURE*); experience of farmer (*FARMEXP*); owned a tractor (*TRACTOR*); owned livestock (*OWNLIVE*); participated in rice extension training(s) (*EXTTRAIN*); access to advance weather information (*ADVWEATH*); access to input credit (*CREDIT*); membership in an agricultural organization(s) (*AGMEM*); non-agricultural income (*SECNAG*); soil test was done (*SOILTEST*); household member(s) help with rice farming (*HOUSEPART*); access to adequate irrigation (*ADEQIRRIG*); fully adopted the six-point practice (*SIXPOINT*); seasonal labor was employed (*LABOR*); pumped water (*PUMPWAT*); farm located in region 2 (*REGION2*); farm located in region 3 (*REGION3*); farm located in region 4 (*REGION4*); farm located in region 5 (*REGION5*); and farm located in region 6 (*REGION6*).

$$Yields/Ha = \lambda_0 + \lambda_1 RAINCHNG + \lambda_2 TEMPCHNG + \lambda_3 EXTREWEAT + \lambda_4 INSECCHNG + \lambda_5 DISEACHNG + \lambda_6 WEEDSCHNG + \lambda_7 AGE + \lambda_8 GENDER + \lambda_9 EDUC + \lambda_{10} PRIMOCCU + \lambda_{11} FARMSIZE + \lambda_{12} TENURE + \lambda_{13} FARMEXP + \lambda_{14} TRACTOR + \lambda_{15} OWNLIVE + \lambda_{16} EXTTRAIN + \lambda_{17} ADVWEATH + \lambda_{18} CREDIT + \lambda_{19} AGMEM + \lambda_{20} SECNAG + \lambda_{21} SOILTEST + \lambda_{22} HOUSEPART + \lambda_{23} ADEQIRRIG + \lambda_{24} SIXPOINT + \lambda_{25} REGION2 + \lambda_{26} REGION3 + \lambda_{27} REGION4 + \lambda_{28} REGION5 + \lambda_{29} REGION6 + v \qquad [3.8]$$

Scenario 2 is captured by equation [3.8]. In this scenario, equation [3.7] is expanded to include non-agricultural income (*SECNAG*); soil test was done (*SOILTEST*); household member(s) help with rice farming (*HOUSEPART*); access to adequate irrigation (*ADEQIRRIG*); and fully adopted the six-point practice (*SIXPOINT*).

$$Yields/Ha = \lambda_0 + \lambda_1 RAINCHNG + \lambda_2 TEMPCHNG + \lambda_3 EXTREWEAT + \lambda_4 INSECCHNG + \lambda_5 DISEACHNG + \lambda_6 WEEDSCHNG + \lambda_7 AGE + \lambda_8 GENDER + \lambda_9 EDUC + \lambda_{10} PRIMOCCU + \lambda_{11} FARMSIZE + \lambda_{12} TENURE + \lambda_{13} FARMEXP + \lambda_{14} TRACTOR + \lambda_{15} OWNLIVE + \lambda_{16} EXTTRAIN + \lambda_{17} ADVWEATH + \lambda_{18} CREDIT + \lambda_{19} AGMEM + \lambda_{20} SECNAG + \lambda_{21} SOILTEST + \lambda_{22} HOUSEPART + \lambda_{23} ADEQIRRIG + \lambda_{24} SIXPOINT + \lambda_{25} LABOR + \lambda_{26} PUMPWAT + \lambda_{27} REGION2 + \lambda_{28} REGION3 + \lambda_{29} REGION4 + \lambda_{30} REGION5 + \lambda_{31} REGION6 + v \quad [3.9]$$

In scenario 3, equation [3.8] is expanded to include seasonal labor was employed (*LABOR*) and farmer pumped water (*PUMPWAT*).

3.6 Method for Analyzing Small Farmers' and Key Informants' Perceptions, Impacts, and Adaptation

Small farmers and key informants provided a narrative (i.e. qualitative) description of their perceptions, impacts, and adaptation to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. Qualitative data provide a detailed account of a phenomenon thus allowing for a more in-depth analysis. Several recent studies have successfully employed qualitative data in part or as a whole to better understand farmers' perception of climate change and their adaptive capacity (Gandure, Walker, and Botha 2013; Amdu, Ayehu, and Deressa 2013; Bryan et al. 2013; Takahashi et al. 2016; Zamasiya, Nyikahadzoi, and Mukamuri 2017; Hitayezu, Wale, and Ortmann 2017; Tripathi and Mishra 2017; Ayanlade, Radeny, and Morton 2017; Appiah et al. 2018).

A narrative approach using descriptive statistics was subsequently used to analyze the data collected. A narrative analysis involves organizing life experiences into themes or patterns that brings order and understanding in a meaningful way (Denzin and Lincoln 2011; Schutt 2014). Interview responses were first transcribed into Microsoft Excel. Here, each response was carefully read to identify keywords and phrases. Each identified keyword or phrase was subsequently coded to produce descriptive statistics of each response. At the end of the coding exercise, some codes were combined to create categories that added depth and insight. The frequency and percentage of each keyword or phrase were then tabulated. To validate the authenticity of the data collected and coded, quotes from small farmers and key informants were embedded in the analysis. In addition, photos were included to strengthen responses.

3.7 Conclusion

This chapter introduced the various data and methods used to answer the research questions posed. Climate data were obtained from the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) at East Anglia University. The CRU CY v.3.24.01 is a gridded dataset that contains 115 years of minimum and maximum temperature data measured in degrees Celsius and precipitation data measured in millimeters (mm). The dataset has a spatial resolution of 0.5 X 0.5 degrees and is compiled in monthly, seasonal, and annual timeframes.

Farmer-level data were collected through face-to-face interviews with small farmers and key informants. Two structured questionnaires were used to collect the data. The data collected include socioeconomic, farm-level, and institutional characteristics of small farm households. Data on small farmers' and key informants' perceptions, impacts and adaptation as it relates to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds were also collected. Collected data were coded and entered into Microsoft Excel for further analysis.

To analyze climate variability in Guyana, three statistical methods were introduced: descriptive statistics, a simple trend model, and a two-sample t-test. These methods are employed to analyze the 115 years of rainfall and temperature data obtained from the CRU. The results are presented in Chapter 4. Multiple regression is used to assess the impacts of socioeconomic, farm-level, and institutional characteristics on rice yields at the farm-level. The results generated by this method are presented in Chapter 5. Descriptive statistics are used to analyze small farmers' and key informants' perceptions, impacts, and adaptation. Photos and quotes from farmers and key informants are included to strengthen the analysis. The results are presented in Chapter 6.

Chapter 4 An Overview of Climate Variability and Climate Change in Guyana

4.1 Introduction

Climate varies across countries and regions of the world. This is because geographic factors such as latitude, vegetation, altitude, and proximity to the ocean influence regional and local climate regimes (Baede et al. 2001). Although climate change is global in scale, regional variations have also been observed (Hewitson et al. 2014). Additionally, projected rainfall changes show spatial variation where some regions will observe an increase, others a decrease, and yet others little change. Similarly, temperature changes will not be regionally uniform (Collins et al. 2013). Given Guyana's geographic location and diverse land mass, analyzing temperature and rainfall data for the country will provide a better understanding of how the climate has changed locally. It will also provide insights into how rice cultivation may have been affected.

With this in mind, this chapter commences by defining and distinguishing between weather and climate as well as climate variability and climate change. A working definition of climate change is subsequently advanced. A description of the current climatic conditions in Guyana is presented. This is followed by analysis and discussion of rainfall, as well as minimum and maximum temperature over the last 115 years. Future climate change projections for the country are presented followed by some concluding remarks.

4.2 Weather and Climate

Heinlein (1973) wrote, "climate is what you expect, weather is what you get." Weather is what we experience each day. It is the state of the atmosphere at any given point in time (Fry et al. 2010) and consists of short-term variations in atmospheric conditions (NOAA, 2017). For example, air temperature, rainfall, humidity, and wind speed can vary by location and also change within hours or days at a specific location. Thus, weather is highly variable and often unpredictable despite improvements in weather forecasting (Mann and Kump, 2015). On the other hand, climate is more predictable since it encompasses the long-term trends of weather at a specific location. In other words, climate is the statistical expression of weather conditions, including the standard deviation, mean, and extremes over an extended period of time (Fry et al. 2010).

4.3 Climate Variability and Climate Change

The basic difference between climate variability and climate change is the timescale during which each occurs. Climate variability is defined as the deviation in climate statistics (e.g., mean and standard deviation) over all temporal[17] and spatial[18] scales (WMO, 2017). It usually occurs over months, years, or decades (Fry et al. 2010) and is beyond that of individual weather events (Allwood et al. 2014). Rosenzweig and Hillel (2008) note, Earth's climate has always been intrinsically variable with the rates of variation also changing.

In contrast, climate change refers to the overall shift in the average climate conditions over long timescales. Such deviation usually occurs over multiple decades and/or centuries. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as any change in the Earth's climate that continues for a prolonged period, usually decades or longer (Allwood et al. 2014). Changes in climate may occur naturally from internal processes such as the interaction between the oceans, atmosphere, and land masses (Rosenzweig and Hillel 2008) or external forcings such as volcanic eruptions, solar variations, anthropogenic changes in the atmosphere's composition, and land use change (Allwood et al. 2014).

Alternatively, Article 1 of the United Nations Framework Convention on Climate Change

[17] Changes over time ranging from seasonal to geological (up to hundreds of millions of years) (Planton 2013).
[18] Changes over geographic regions ranging from local (less than 100,000 km^2), through regional (100,000 to 10 million km^2) to continental (10 to 100 million km^2) (Planton 2013).

(UNFCCC) defines climate change as a change in climate attributed to human activities which directly or indirectly alters the composition of the global atmosphere (Sands 1992) While the IPCC definition considers both natural and external forcings, the UNFCCC definition places greater emphasis on the anthropogenic changes that have been credited with increasing Earth's average surface temperature over many decades.

While the distinction between weather, climate, climate variability, and climate change are evident in terms of timescale, the difference between climate variability and climate change is not absolute. The very fact that the climate is changing may induce a change in variability around a shifting mean (Rosenzweig and Hillel 2008). In other words, climate change may facilitate climate variability. For the purpose of this research, climate change is defined as a statistically significant shift in average total rainfall, as well as minimum and maximum temperature for a given region over multiple decades or longer. Figure 4.1 illustrates the temporal differences among weather, climate variability, and climate change.

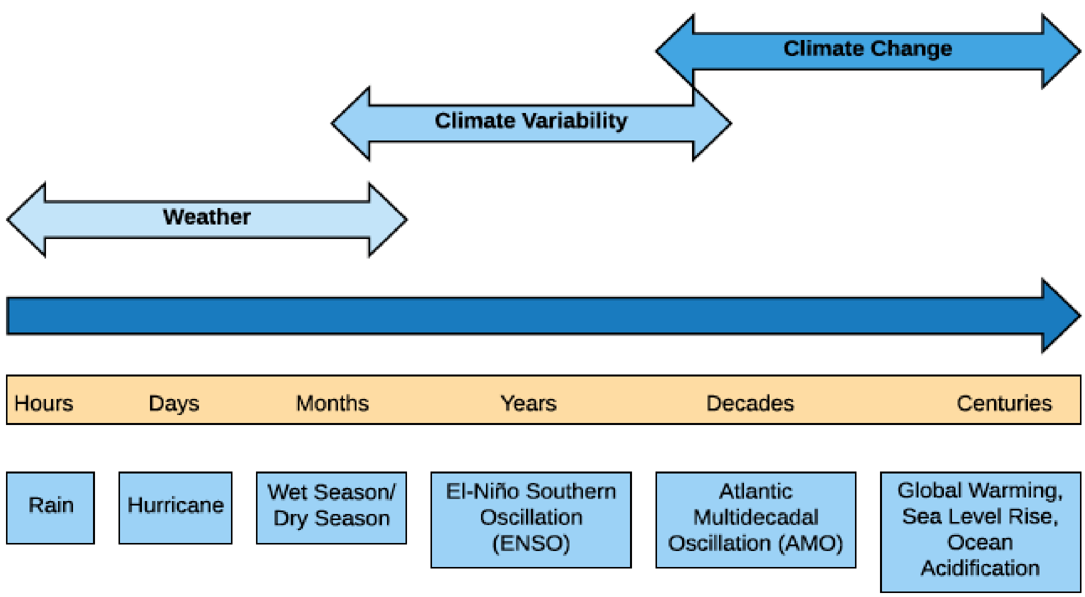

Figure 4.1 Timescale of weather, climate variability, and climate change
Source: Author (as adapted from PCF, 2017).

4.4 Climate of Guyana

The primary controller of weather and climate in Guyana is the Inter-tropical Convergence Zone (ITCZ)[19], which influences rainfall patterns resulting in two wet and two dry seasons (NATCOM1, 2002). As a result, the country experiences a moist tropical climate characterized by high temperatures and ample rainfall (NATCOM2, 2012). The El Niño-Southern Oscillation (ENSO) coupled ocean-atmosphere phenomenon also impacts the country by changing the intensity and duration of the traditional wet and dry seasons (NATCOM1, 2002). Analyzing time series data from 1916 to 2007 for Georgetown, Rama Rao et al. (2012) found that El Niño/ La Niña is directly related to monthly mean rainfall with more profound impacts during the secondary rainy season [December-January].

4.4.1 Rainfall and Climate Types

Guyana receives annual average rainfall of between 1,600 mm and 3,000 mm (NATCOM2, 2012). However, spatial variations in rainfall create three sub-climate zones: the tropical savannah, where annual rainfall is less than 1,778 mm; very wet tropical rainforest, where annual rainfall exceeds 2,728 mm; and wet/dry tropical rainforest, where annual rainfall ranges between 1,778 mm and 2,728 mm (NATCOM2, 2012). The primary rainy season extends from mid-April to the end of July, and the secondary rainy season runs from mid-November to the end of January. However, the Rupununi Savannahs, located in the southwest of the country, only receive rainfall from mid-April to August (NATCOM2, 2012). Figure 4.2 illustrates the three climate types in Guyana based on the Köppen-Geiger classification of climate: Af – tropical rainforest, Am – tropical monsoon and Aw – tropical savannah. Figure 4.3 illustrates the rainfall regimes of Guyana.

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[19] The areas near the equator where the northeast and southeast trade winds converge.

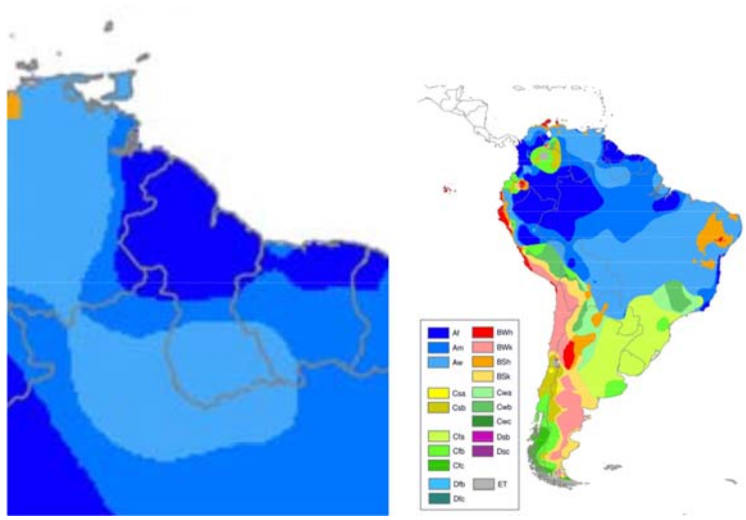


Figure 4.2 Köppen-Geiger climate type map of Guyana
Source: (Peel, Finlayson, and McMahon 2007)

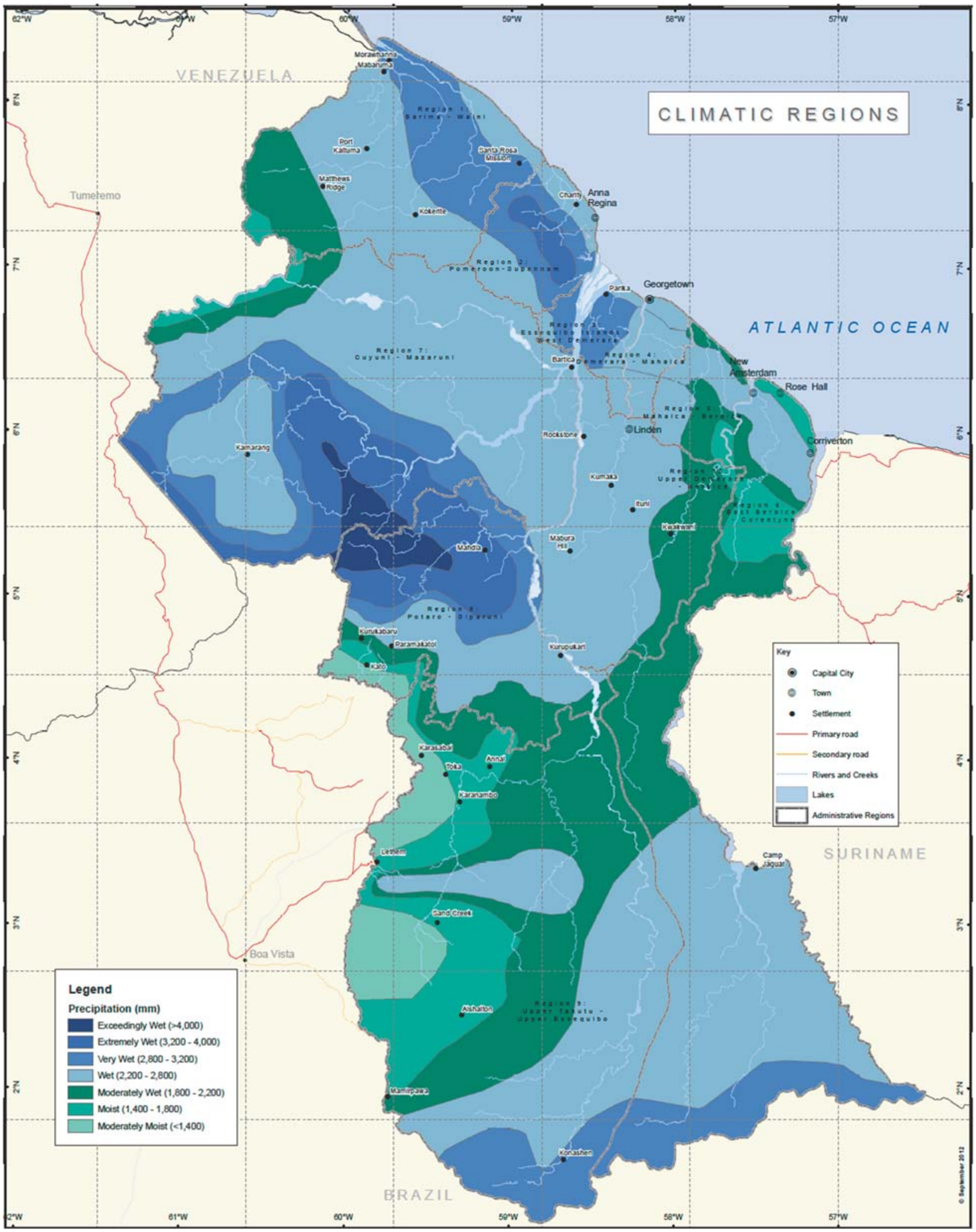


Figure 4.3 Climatic regions of Guyana
Source: Velasco (2014)

4.4.2 Temperature, Wind, Sunshine, and Humidity

Annual average air temperature ranges between 16 and 34° C across the country and between 22 and 31° C along the coastal plain due to the cooling effect of the Atlantic Ocean and a northeastern trade wind of typically about 5 meters per second. (NATCOM2 2012). In the highland regions, the mean annual air temperature ranges between 20 and 23° C (McSweeney, New, and Lizcano, 2010). During the dry and wet seasons, the duration of sunshine averages seven and five hours per day, respectively (NATCOM2, 2012). Relative humidity (RH) averages at least 80% in the coastal regions, 70% in the savannah regions, and 100% in the rainforest regions (NATCOM2 2012). Utilizing the average annual rainfall and temperature data obtained from the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) at East Anglia University, Figure 4.4 shows the mean monthly temperature and total monthly rainfall for Guyana over the last 115 years. The CRU CY dataset is derived directly from the CRU time-series (CRU TS v. 3.21), which is a gridded time-series dataset covering all land areas (excluding Antarctica) at 0.5° resolution. The spatial averages are calculated using area-weighted means (Harris et al. 2014).

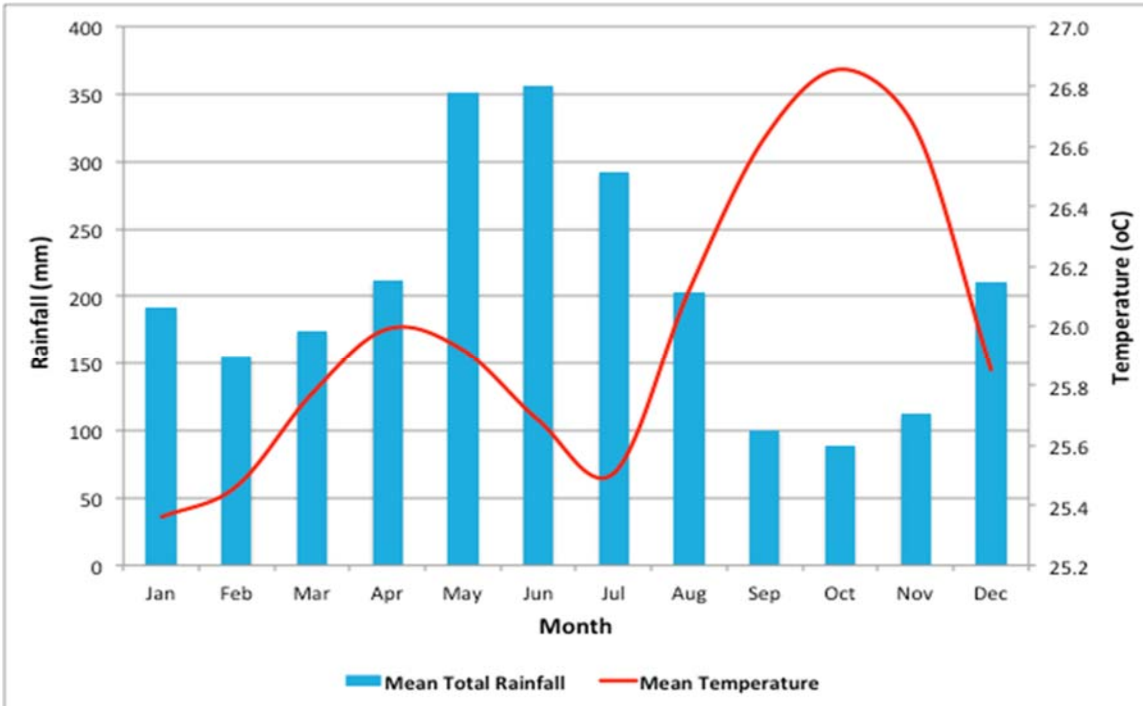


Figure 4.4 Mean temperature and rainfall for Guyana (1901-2015)
Source: Author

4.5 Characterizing Climate Variability in Guyana

To characterize climate variability in Guyana, three statistical methods are employed. The first method utilizes the descriptive statistics mean, standard deviation, and coefficient of variation (CV). The second method uses a linear trend model to assess the changes in rainfall, and minimum and maximum temperature over time. The third method uses a two-sample t-test to examine the change in climate variables. Livezey et al. (2007) note that numerous empirical studies and simulations indicate that the latest period of modern global warming began in the mid-1970s. As such, a two-sample t-test is used to compare average annual total rainfall (mm), average annual maximum temperature (^{0}C), and average annual minimum temperature (^{0}C) between 1934-1974 and 1975-2015. Although Figure 4.4 indicates 115 years of rainfall and temperature data for

Guyana, only 41 years have elapsed since modern global warming began. As such, these two periods allow for the comparison of the 41 years before and after modern global warming began.

In observing century-long data records, one must be cognizant that it is likely that more recent temperature and precipitation data are more reliable, given the increase in station density and the definite improvement in weather instrument technology. Over the last 20 years, the number rainfall stations in Guyana has increased and they have become more widely distributed. Of the 145 rainfall stations currently in existence, 116 have been in existence for less than 20 years. Figure 4.5 illustrates the density of rainfall stations in Guyana.

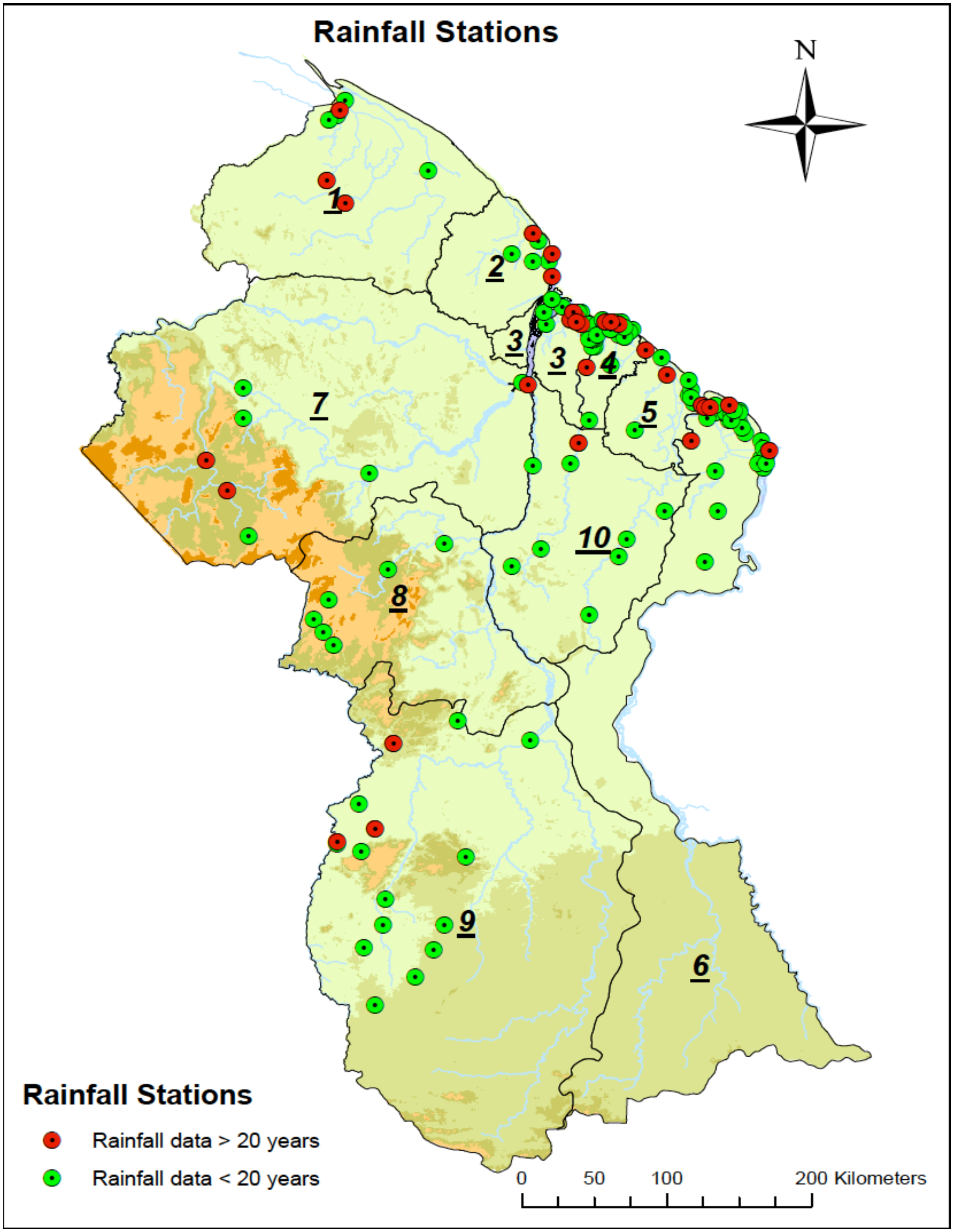


Figure 4.5 Rainfall Stations in Guyana
Source: (Hydromet, n.d.)

4.6 Empirical Results of Climate Change and Climate Variability in Guyana

4.6.1 Evidence from Descriptive Statistics

Based on the World Metrological Organization (WMO) Climate Normals approach, the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) is used to compute the long term (30-year) mean, standard deviation, and coefficient of variation (CV) of the average annual total rainfall, average annual minimum temperature, and average annual maximum temperature for Guyana. Climate Normals are three-decade averages of climatological variables such as rainfall and temperature (NOAA, 2018). It should be noted that the annual rainfall, minimum and maximum temperature data are aggregated for the entire country. Table 4.1 summarizes climate in Guyana over three historical 30-year periods and a more recent 25-year period.

Table 4.1 Climate Variability in Guyana (1901-2015)[a]

Major Climate Variable	Statistical Tool	1901 - 1930	1931 -1960	1961 -1990	1991-2015
Average Annual Total Rainfall (mm)	Mean	2,385.31	2,558.10	2,398.01	2,439.63
	Standard Deviation	266.15	427.27	369.14	404.92
	Coefficient of Variation (%)	11.16	16.70	15.39	16.60
Average Annual Minimum Temperature (°C)	Mean	21.41	21.53	21.63	21.97
	Standard Deviation	0.20	0.28	0.39	0.38
	Coefficient of Variation (%)	0.94	1.29	1.80	1.71
Average Annual Maximum Temperature (°C)	Mean	30.17	30.29	30.40	30.73
	Standard Deviation	0.20	0.27	0.39	0.36
	Coefficient of Variation (%)	0.66	0.88	1.29	1.17

[a] Computations are based on data obtained from the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) at East Anglia University for the period 1901-2015.

Table 4.1 indicates that the mean average annual total rainfall increased over the first two 30-year periods from 2,385mm (1901-1930) to 2,558mm (1931-1960). The 30-year period from 1961 to 1990 saw the mean average annual total rainfall decrease to 2,398mm. However, the most recent 25 years shows an increase in the mean average annual total rainfall over the previous 30 years. Analyzing rainfall patterns along the coastal plain of Guyana, Ramraj (1996) found that rainfall was heavier during 1941-1980 than the preceding 40 years. The standard deviation which measures the absolute variability and coefficient of variation (CV) which measures the relative variability followed a similar pattern.

In terms of temperature, there is evidence of change over three historical 30-year periods and a more recent 25-year period. The mean for both average annual minimum temperature and average annual maximum temperature increased gradually over the four periods. However, the standard deviation and CV increased in the first three 30-year periods but decreased slightly in the most recent 25 years. It is important to note that the relative variability in average annual minimum temperature is greater than that of average annual maximum temperature over the four periods. This indicates there is greater variation associated with average annual minimum temperature.

Although the Climate Normals (three-decade averages) of average annual total rainfall, average annual minimum temperature, and annual maximum temperature provide evidence of a changing climate in Guyana over the last 115 years, a closer examination of these changes over the years is warranted. To smooth-out any short-term fluctuations and highlight long-term trends, a 5-year moving average is used to compute the mean, standard deviation, and CV from Climate Research Unit (CRU) gridded time-series country dataset (CRU CY v.3.24.01).

The moving average is computed by taking the arithmetic mean of series of 5-year subsets starting with an initial subset and shifting forward by excluding the first value in the series and including the next value in the subset. For example, the 5-year moving average of average annual total rainfall for 1905 is computed by taking the mean of average annual total rainfall for 1901, 1902, 1903, 1904, and 1905 while the 5-year moving average of average annual total rainfall for 1906 is computed by taking the mean of average annual total rainfall for 1902, 1903, 1904, 1905, and 1906. This process is continued until the last 5-year subset.

By computing the 5-year moving average, the full dataset of 115 years is reduced to 111 years. Based on the 5-year moving average, the mean, standard deviation, and CV of average annual total rainfall, average annual minimum temperature, and annual maximum temperature for the last 111 years is presented in Appendix D. The absolute and relative variability of each climate variable is more apparent when these observations are plotted over time. This is accomplished in Figures 4.6 - 4.14.

Figure 4.6 provides a visual illustration of the changes in the average annual rainfall for Guyana. Although the average annual rainfall fluctuated over the last 111 years, the overall pattern indicates a slight upward trend. There are two distinct periods of changes in rainfall patterns. The average annual rainfall increased from 1927, peaked in 1956 before experiencing a steep decline that ended in 1961. From 1965 onward, the average annual rainfall began increasing once again despite several peaks and troughs along the way.

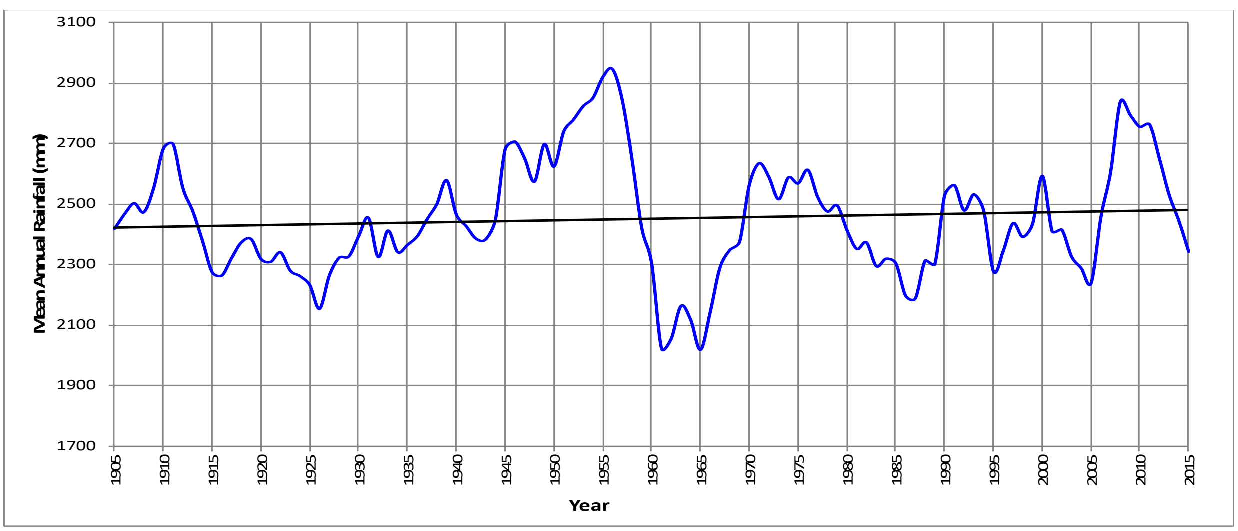


Figure 4.6 Moving average of mean annual rainfall for Guyana
Source: Author

The absolute variability in rainfall, as measured by the standard deviation, is shown in Figure 4.7. Given the increase in average annual rainfall, the standard deviation shows an upward trend over the entire period. In particular, the period 1975-2015 shows an increase in the dispersion of annual rainfall relative to the mean. This indicates that on average, annual rainfall has fluctuated more in the last four decades.

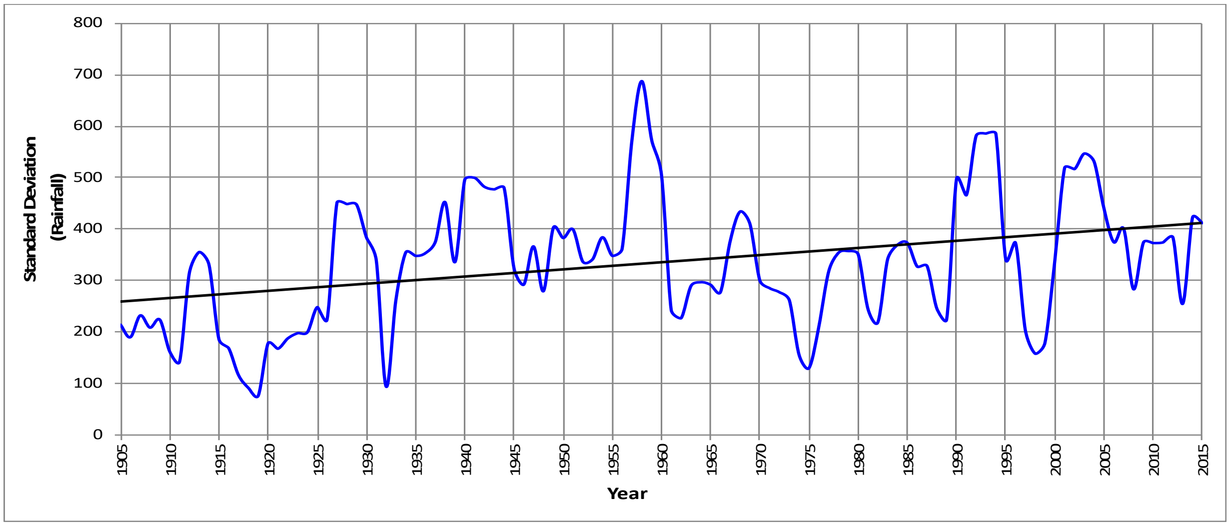


Figure 4.7 Standard deviation of mean annual rainfall for Guyana
Source: Author

Figure 4.8 depicts the coefficient of variation of annual rainfall. This measure of relative variability follows a similar pattern as that of the absolute variability reflected in Figure 4.7. Apart from a strong upward movement over the last 111 years, the degree of variation in annual rainfall has increased in the last four decades.

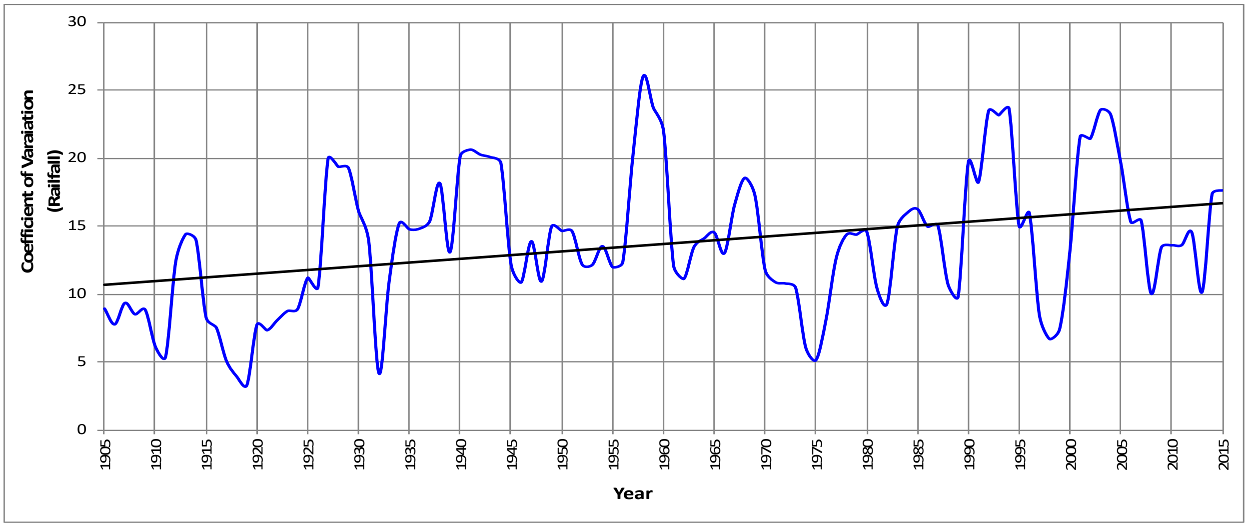


Figure 4.8 Coefficient of variation of annual rainfall for Guyana
Source: Author

Figure 4.9 illustrates the mean annual minimum temperature over the last 111 years. Despite several peaks and troughs, a strong upward trend is evident. Of significance is the increase in the mean annual minimum temperature observed over the period 1975-2001. While the last 15-year period has seen a downturn, on average the mean annual minimum temperature has been rising steadily in the last four decades, more so than at any other period of time.

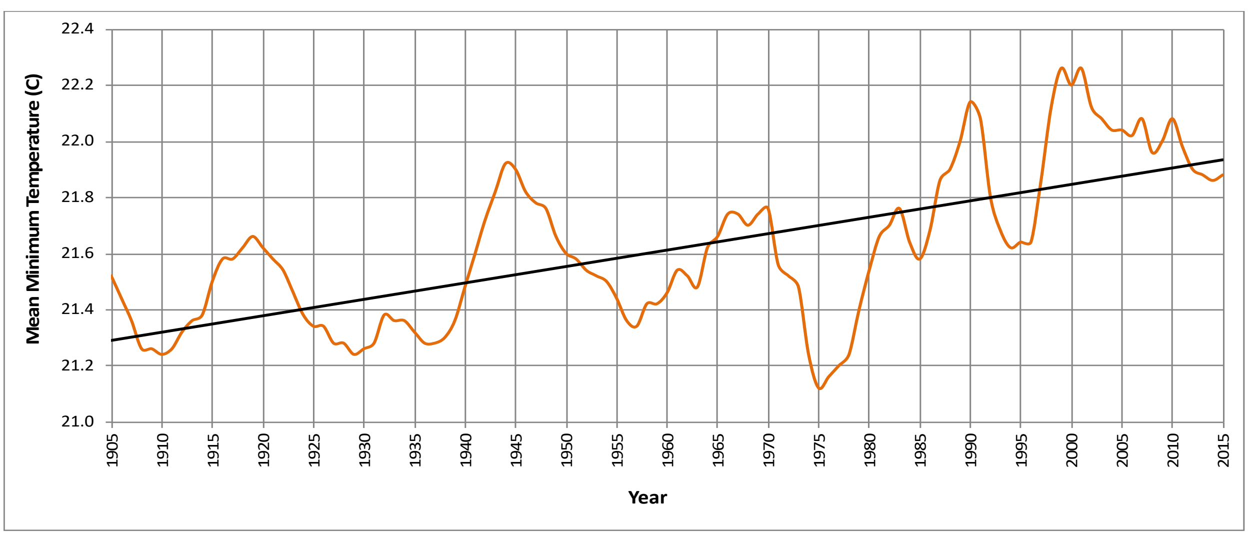


Figure 4.9 Moving average of mean annual minimum temperature for Guyana
Source: Author

The behavior of the absolute variability of the annual minimum temperature is depicted in Figure 4.10. Overall, there is an upward movement across the entire period. However, the period 1970-2015 indicates that there is greater variability in minimum temperature characterized by the increase in spread observed.

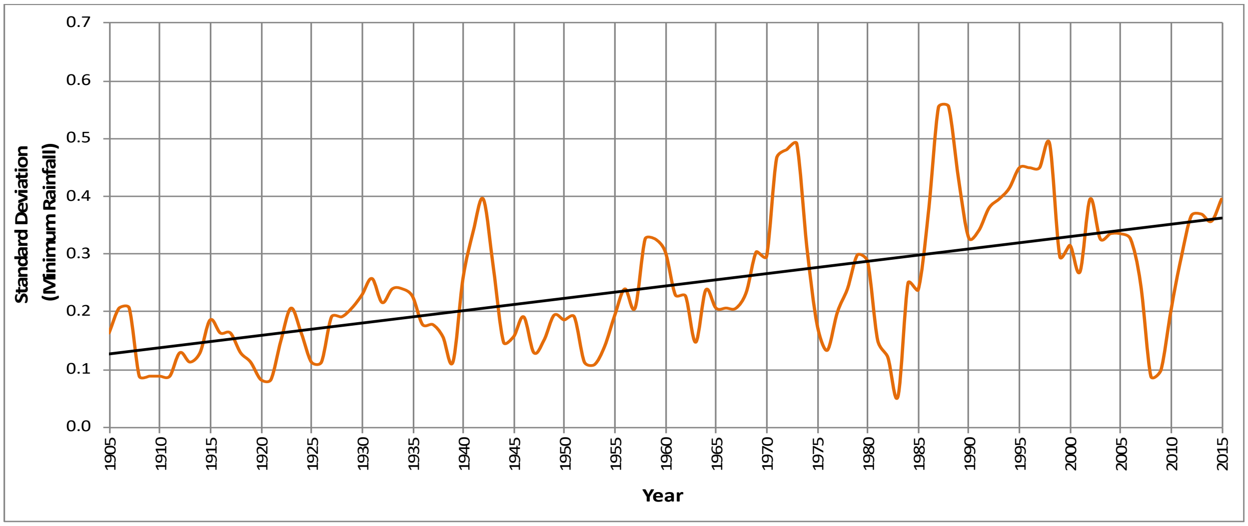


Figure 4.10 Standard deviation of mean annual minimum temperature for Guyana
Source: Author

The relative variability of the annual minimum temperature depicted in Figure 4.11 also indicates an increasing trend over the entire period. Between 1905-1970, the increase in the coefficient of variation of annual minimum temperature appears to be relatively smoother in comparison to later years. Thus, although increasing, the period 1970-2015 appears to be more dynamic.

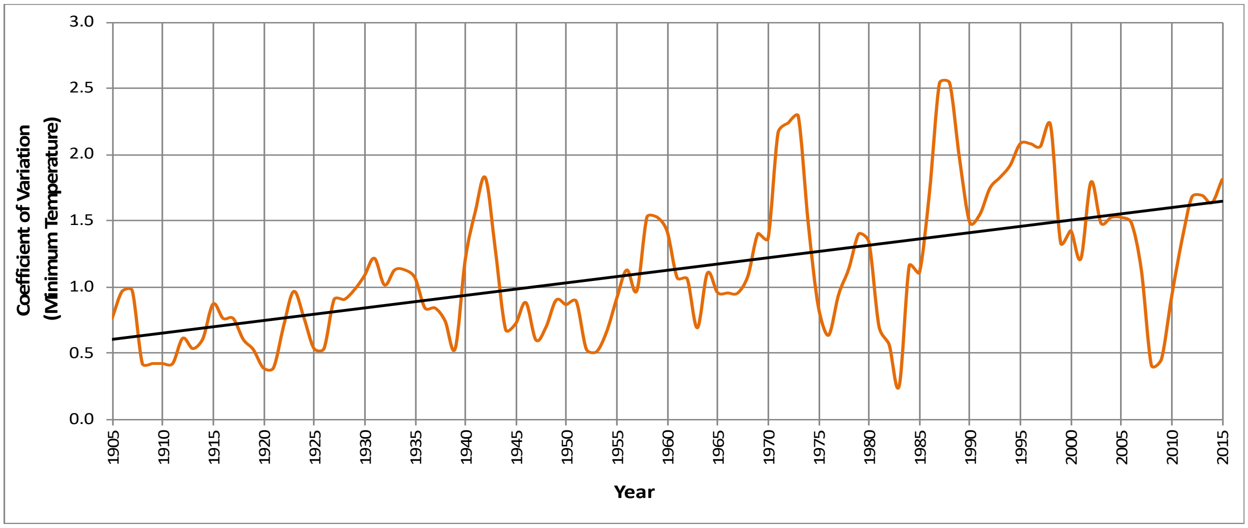


Figure 4.11 Coefficient of variation of annual minimum temperature for Guyana
Source: Author

The mean annual maximum temperature over the last 111 years is portrayed in Figure 4.12. The period 1905-1975 fluctuated significantly while exhibiting a slight increase in the overall average. However, from 1975 onwards, the mean annual maximum temperature shows a distinct upward trajectory coupled with a great spread. Analyzing data for Georgetown, Stephenson et al. (2014) found a significant increase in the diurnal temperature range from 1961 to 2010.

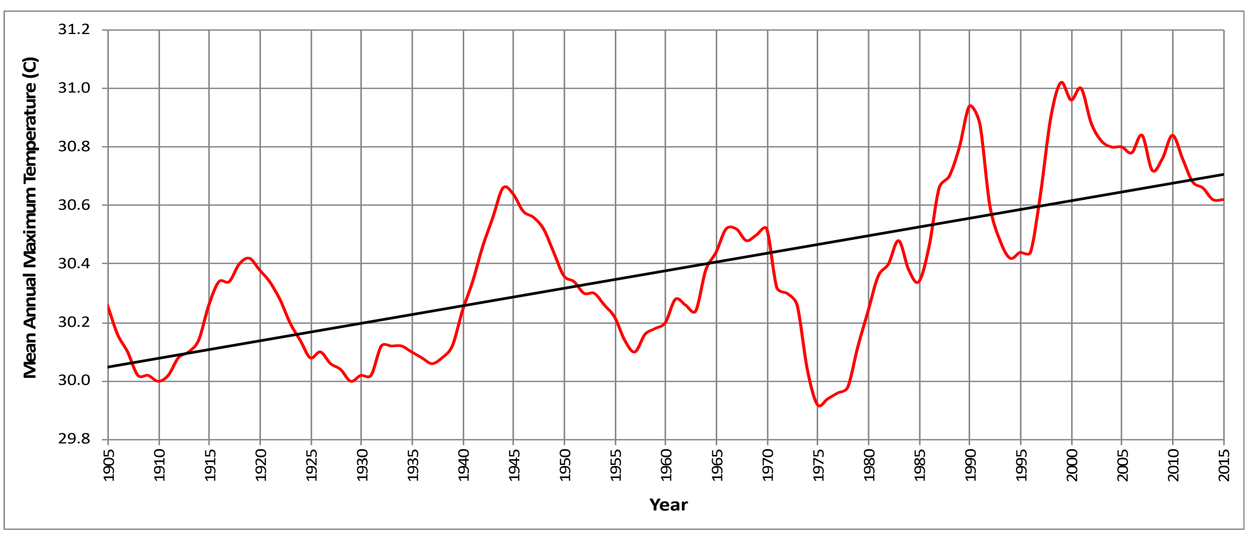


Figure 4.12 Moving average of mean annual maximum temperature for Guyana
Source: Author

The absolute variability of the annual maximum temperature is depicted in Figure 4.13. While there is an overall increasing trend, the period 1905-1970 reflects a smoother upward movement in comparison to the most recent 45 years. Thus, annual maximum temperature appears to be more dynamic variable between 1970-2015.

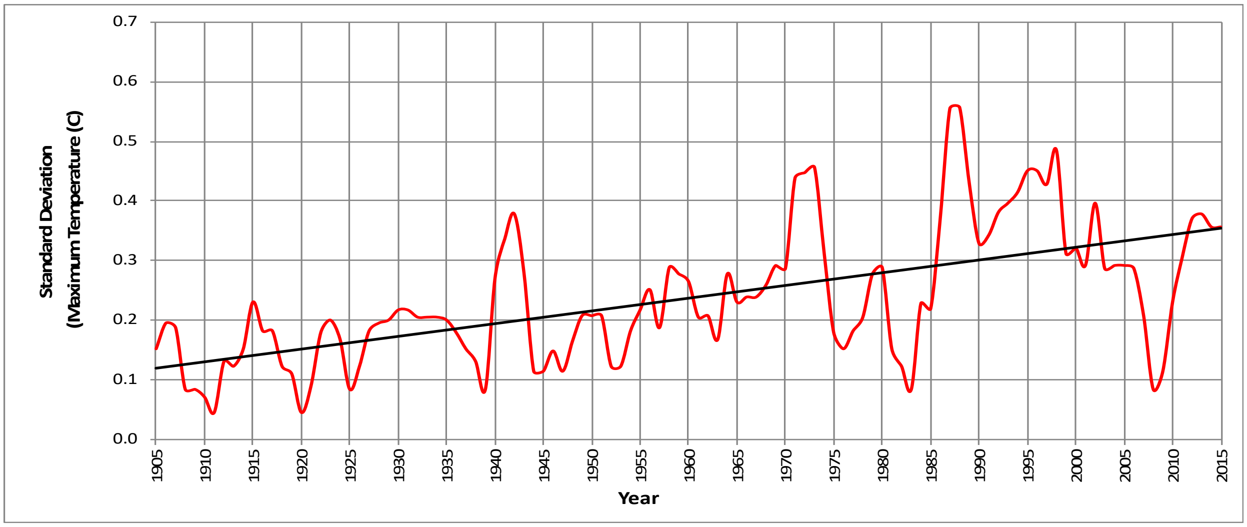


Figure 4.13 Standard deviation of mean annual maximum temperature for Guyana
Source: Author

The relative variability of annual maximum temperature illustrated in Figure 4.14 also exhibits similar characteristics as that of the absolute variability captured in Figure 4.13. The gradual increase in annual maximum temperature observed between 1905-1970 is followed by more erratic observations in the last four decades. Hence, significant variability is evident in the last 45 years despite the upward trajectory observed.

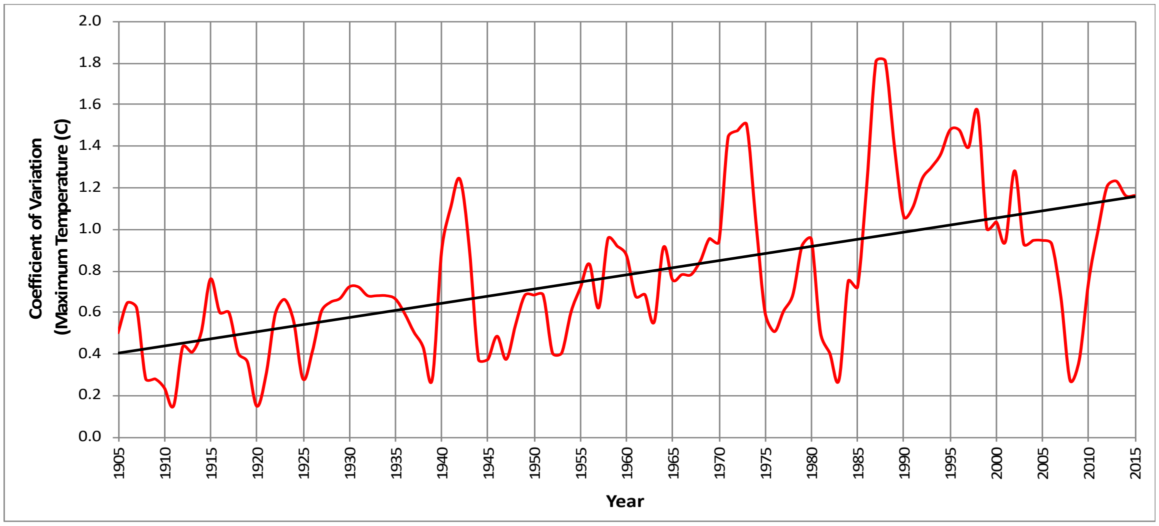


Figure 4.14 Coefficient of variation of annual maximum temperature for Guyana
Source: Author

4.6.2 Evidence from Linear Trend Model

Simple linear regression is subsequently employed to show any time trend in the mean, standard deviation, and coefficient of variation (CV) of annual rainfall, minimum and maximum temperature over the last 111 years. While changes through the full historical record may not be linear in nature, linear regression does provide some insight into the general tendency of the climate variables over the record.

4.6.2.1 Annual Rainfall

In equation [4.1], the dependent variable (Y_{Rain}) is the moving average of annual rainfall while in equation [4.2], the dependent variable (Y_{SDRain}) is the standard deviation of annual rainfall. In equation [4.3], the dependent variable (Y_{CVRain}) is the coefficient of variation of annual rainfall. In each equation, the time variable (t) is the year the variable was observed and is referred to as the trend variable. Its coefficient (β_1) indicates the direction of the trend.

$$Y_{Rain} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.1]$$

where,
Y_{Rain} = moving average of annual rainfall
t = year
ε_t = error term

$$Y_{SDRain} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.2]$$

where,
Y_{SDRain} = standard deviation of annual rainfall
t = year
ε_t = error term

$$Y_{CVRain} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.3]$$

where,
Y_{CVRain} = coefficient of variation of annual rainfall
t = year
ε_t = error term

The results of the linear regression for annual rainfall are presented in Table 4.2. There is no statistically significant time trend in the mean annual rainfall. However, there is a noticeable time trend in the standard deviation and coefficient of variation, both of which are statistically significant at the 95 percent probability level. Specifically, for each additional decade, the standard deviation and coefficient of variation of annual rainfall increases by 13.83mm and 0.55 percent, respectively.

Table 4.2 Trend Analysis of the Variability in Annual Rainfall

Independent Variable	**Dependent Variables**		
	Mean (Standard Errors)	Standard Deviation (Standard Errors)	Coefficient of Variation (Standard Errors)
Intercept	1,418.652 (1,110.726)	-2,375.316*** (679.124)	-93.809*** (27.622)
Year	0.527 (0.567)	1.383*** (0.346)	0.055*** (0.014)
Observations	111	111	111
R^2	0.008	0.1275	0.1220
F-value	0.86	15.93	15.15
Prob > F	0.355	0.0001	0.0002

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

4.6.2.2 Annual Minimum Temperature

In equation [4.4], the dependent variable (Y_{MinT}) is the moving average of annual minimum temperature while in equation [4.5], the dependent variable (Y_{SDMinT}) is the standard deviation of annual minimum temperature. In equation [4.6], the dependent variable (Y_{CVMinT}) is the coefficient of variation of annual minimum temperature. In each equation, the time variable (t) is the year the variable was observed and is referred to as the trend variable. Its coefficient (β_1) indicates the direction of the trend.

$$Y_{MinT} = \beta_0 + \beta_1 t + \varepsilon_t \quad [4.4]$$

where,
Y_{MinT} = moving average of annual minimum temperature
t = year
ε_t = error term

$$Y_{SDMinT} = \beta_0 + \beta_1 t + \varepsilon_t \quad [4.5]$$

where,
Y_{SDMinT} = standard deviation of minimum temperature
t = year
ε_t = error term

$$Y_{CVMinT} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.6]$$

where,
Y_{CVMinT} = coefficient of variation of minimum temperature
t = year
ε_t = error term

Table 4.3 summarizes the results of the linear regression for annual minimum temperature. For each additional decade, the mean, standard deviation, coefficient of variation of annual minimum temperature increases by 0.06 (ºC), 0.02 (ºC), and 0.1 percent, respectively. Thus, there is a noticeable time trend observed for the mean, standard deviation, and coefficient of variation all of which are statistically significant at the 5 percent level.

Table 4.3 Trend Analysis of the Variability in Annual Minimum Temperature

Independent Variable	**Dependent Variables**		
	Mean (Standard Errors)	Standard Deviation (Standard Errors)	Coefficient of Variation (Standard Errors)
Intercept	10.104*** (1.195)	-3.937*** (0.539)	-17.592*** (2.489)
Year	0.006*** (0.0006)	0.002*** (0.0003)	0.010 *** (0.001)
Observations	111	111	111
R^2	0.460	0.355	0.342
F-value	92.84	59.99	56.58
Prob > F	0.000	0.000	0.000

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

4.6.2.3 Annual Maximum Temperature

In equation [4.7], the dependent variable (Y_{MaxT}) is the moving average of annual maximum temperature while in equation [4.8], the dependent variable (Y_{SDMaxT}) is the standard deviation of annual maximum temperature. In equation [4.9], the dependent variable (Y_{CVMaxT}) is the coefficient of variation of annual maximum temperature. In each equation, the time variable (t) is the year the variable was observed and is referred to as the trend variable. Its coefficient (β_1) indicates the direction of the trend.

$$Y_{MaxT} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.7]$$

where,
Y_{MaxT} = moving average of mean annual maximum temperature
t= year
ε_t = error term

$$Y_{SDMaxT} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.8]$$

where,
Y_{SDMaxT} = standard deviation of mean maximum temperature
t= year
ε_t = error term

$$Y_{CVMaxT} = \beta_0 + \beta_1 t + \varepsilon_t \qquad [4.9]$$

where,
Y_{CVMaxT} = coefficient of variation of maximum temperature
t = year
ε_t = error term

Table 4.4 summarizes the results of the linear regression for annual maximum temperature. There is statistically significant time trend in the mean, standard deviation, and coefficient of variation of annual maximum temperature. For each additional decade, the mean, standard deviation, coefficient of variation of annual maximum temperature increases by 0.06 (ºC), 0.02 (ºC), and 0.07 percent, respectively.

Table 4.4 Trend Analysis of the Variability in Annual Maximum Temperature

Independent Variable	**Dependent Variables**		
	Mean (Standard Errors)	Standard Deviation (Standard Errors)	Coefficient of Variation (Standard Errors)
Intercept	18.577***	-3.955***	-12.7***
	(1.189)	(0.523)	(1.715)
Year	0.006***	0.002***	0.007***
	(0.001)	(0.0002)	(0.001)
Observations	111	111	111
R^2	0.475	0.371	0.362
F-value	98.56	64.19	61.80
Prob > F	0.000	0.000	0.000

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

4.6.3 Evidence from Two Sample T-test

A two-sample t-test was used to compare the mean, standard deviation, and coefficient of variation for the average annual total rainfall (mm), average annual minimum temperature (^{0}C), and average annual maximum temperature (^{0}C) between 1934-1974 and 1975-2015.

In terms of rainfall, there was no statistically significant evidence that mean annual rainfall changed between the periods 1934-1974 and 1975-2015 (t= 0.88, df = 40, $p>0.05$). There is no statistically significant evidence that the standard deviation of the mean annual rainfall changed between the periods 1934-1974 and 1975-2015 (t= 0.37, df = 40, $p>0.05$). Similarly, statistically significant evidence does not exist that the coefficient of variation of the annual rainfall changed between the periods 1934-1974 and 1975-2015 (t= 0.14, df = 40, $p>0.05$).

For minimum temperature, there is statistically significant evidence that the mean annual minimum temperature changed between the periods 1934-1974 and 1975-2015 (t= -5.72, df = 40, $p<0.05$). There is also statistically significant evidence that the standard deviation of the annual minimum temperature changed between the periods 1934-1974 and 1975-2015 (t= -2.78, df = 40, $p<0.05$). Similarly, statistically significant evidence exists that the coefficient of variation of the annual minimum temperature changed between the periods 1934-1974 and 1975-2015 ($t = -2.64$, $df = 40$, $p<0.05$).

With regards to maximum temperature, there is statistically significant evidence that the mean annual maximum temperature changed between the periods 1934-1974 and 1975-2015 ($t = -5.73$, $df = 40$, $p<0.05$). Furthermore, statistically significant evidence exists that the standard deviation of the annual maximum temperature changed between the periods 1934-1974 and 1975-2015 ($t = -2.92$, $df = 40$, $p<0.05$). As expected, there is also statistically significant evidence that the coefficient of variation of the annual maximum temperature changed between the periods 1934-1974 and 1975-2015 ($t = -2.82$, $df = 40$, $p<0.05$).

4.7 Future Climate Change Projections

Using an Atmosphere-Ocean General Circulation Model (AOGCM), McSweeney et al. (2010) projected for Guyana that the mean annual rainfall is expected to decrease by 4% to 8% by 2060s and 4% to 5% by 2090s with a proportionate increase in heavy precipitation events. The mean annual temperature is likely to increase by 0.4ºC to 2.0ºC by 2030s, 0.9ºC to 3.3ºC by 2060s, and 1.4ºC to 5.0ºC by 2090 with a significant increase in the number of hot days and nights projected (McSweeney et al. 2010). Table 4.5 summarizes the projected future rainfall and temperature for Guyana.

Table 4.5 Future Climate Scenarios for Guyana

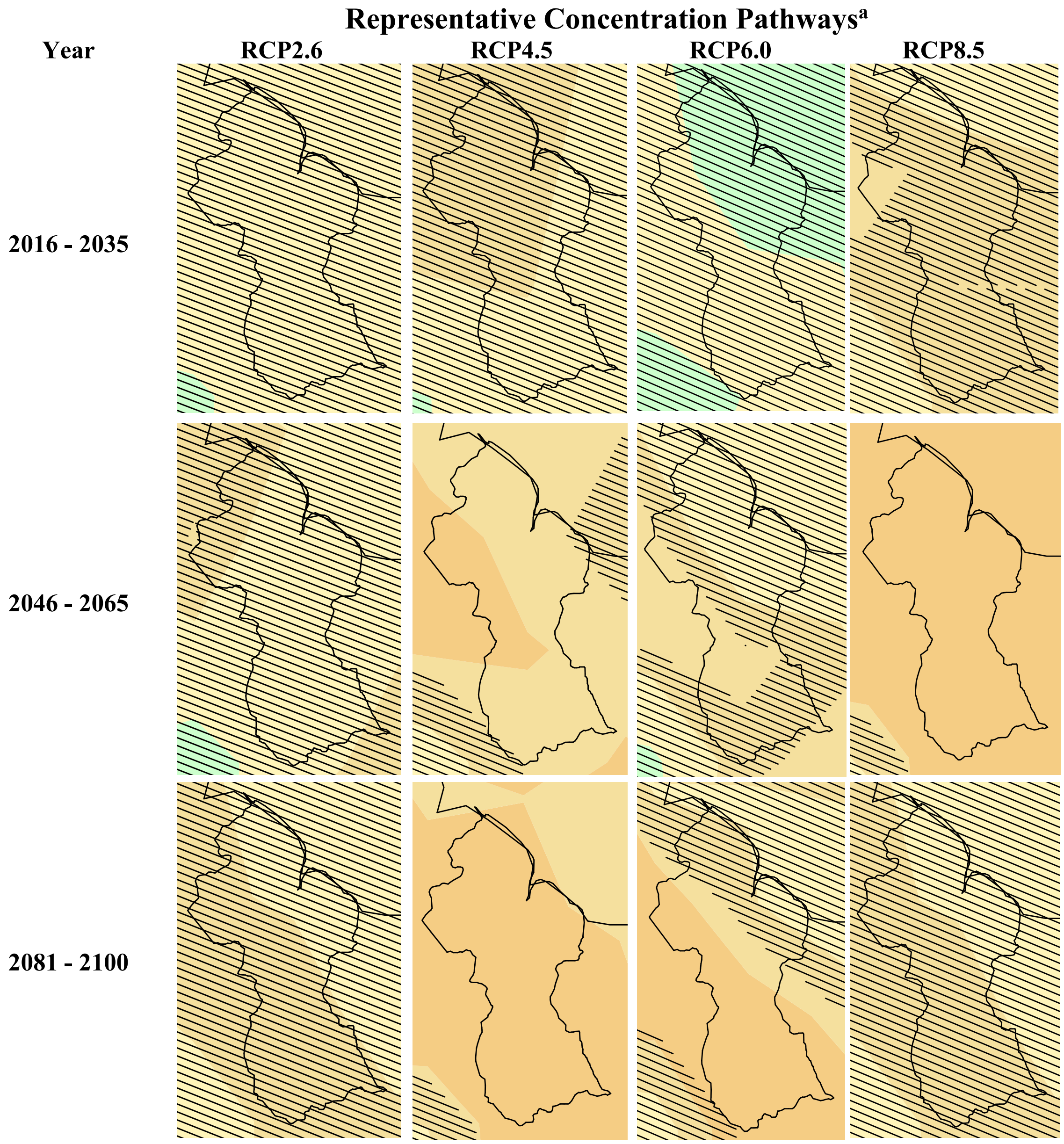
Climate Variable	2030s	2060s	2090s
Mean Annual Precipitation change	Median: 0 to -4% Min-Max: -29% to 14%	Median: -4% to -8% Min-Max: -41% to 13%	Median: -4% to -5% Min-Max: -63% to 20%
% of rainfall that falls as heavy precipitation events	No Data	Median: 1% to 2% Min-Max: -3% to 10%	Median: 2 to 3% Min-Max: -8% to 12%
Mean Annual temperature change	0.4ºC to 2.0ºC	0.9ºC to 3.3ºC	1.4ºC to 5.0ºC
Frequency of Hot Days	No Data	Median: 30% to 44% Min-Max: 18% to 56%	Median: 43% to 61% Min-Max: 19% to 79%
Frequency of Hot Nights	No Data	Median: 47% to 69% Min-Max: 33% to 90%	Median: 63% to 94% Min-Max: 49% to 99%

Source: McSweeney et al. 2010.

While McSweeney et al. (2010) provide insights into the future climate of Guyana, such projections were based on the earlier Special Report on Emission Scenarios (SRES) use by the Inter-governmental Panel on Climate Change (IPCC). To see how rainfall and temperature will change under the Inter-governmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCPs)[20] introduced in the fifth Assessment Report (AR5), projected rainfall and near surface temperature were plotted using the Climate Change Atlas function that forms part of the Royal Netherlands Meteorological Institute (KNMI) Climate Explorer web application. The projected changes in rainfall and near surface temperature are based on the General Circulation Model (GCM) Coupled Model Intercomparison Project (CMIP5) dataset which incorporates course-resolution models and time series averaged over specific regions or countries. The dataset uses only a single realization of each climate model and weighs all models equally with the only differing characteristic being the model parameter settings (KNMI 2018). Figure 4.15 and 4.16 illustrate projected changes in rainfall and near surface temperature for three future timeframes under each RCP. The base period is 1986-2005 and the hatching represents areas

[20] Representative Concentration Pathways (RCPs) is the most recent scenarios used by IPCC to reflect projections of atmospheric greenhouse gas (GHG) concentrations.

where the signal is smaller than one standard deviation of natural variability (KNMI 2018). While there appears to be little projected change in rainfall, projected changes in temperature are more apparent for Guyana.



[a] "RCP8.5 is a business-as-usual scenario with increasing greenhouse gas emissions over time, leading to high greenhouse gas concentration levels; RCP6.0 is a stabilization scenario in which emissions rise quickly up to 2060 and then decrease; RCP4.5 assumes quicker action to limit greenhouse gas emissions with emissions peaking in 2040 and declining strongly until 2080; and RCP2.6 describes an all-out effort to limit global warming to below 2°C with emissions decreasing sharply after 2020 and zero from 2080 onward" (Collins et al. 2013).

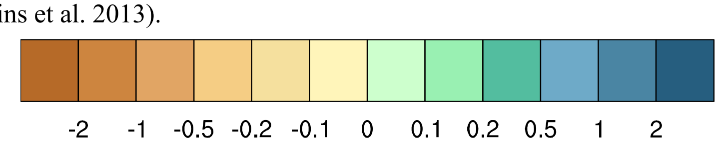
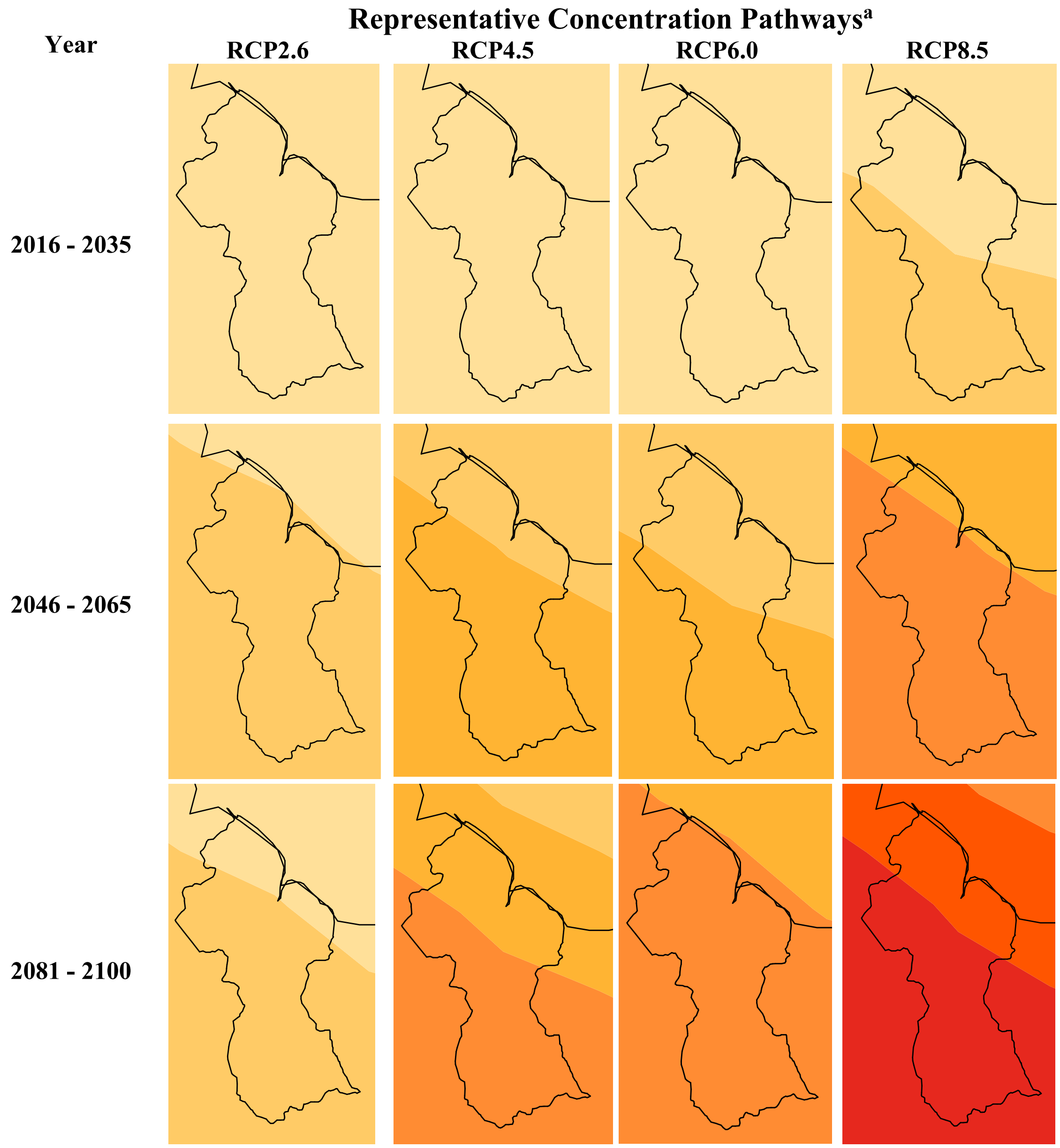


Figure 4.15 Projected change in precipitation (mm/day) relative to 1986–2005
Source: Author (as created through the KNMI website)



[a] "RCP8.5 is a business-as-usual scenario with increasing greenhouse gas emissions over time, leading to high greenhouse gas concentration levels; RCP6.0 is a stabilization scenario in which emissions rise quickly up to 2060 and then decrease; RCP4.5 assumes quicker action to limit greenhouse gas emissions with emissions peaking in 2040 and declining strongly until 2080; and RCP2.6 describes an all-out effort to limit global warming to below 2°C with emissions decreasing sharply after 2020 and zero from 2080 onward" (Collins et al. 2013).

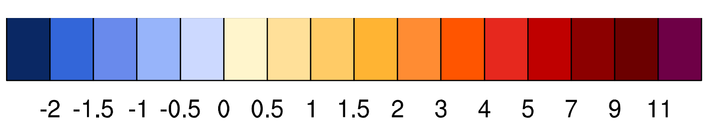


Figure 4.16 Projected change in near surface temperature (${}_0$C) relative to 1986–2005
Source: Author (as created through the KNMI website)

4.8 Conclusion

Three statistical methods were employed to show variability in average annual total rainfall and minimum and maximum temperature for Guyana over the last 115 years. Descriptive statistics, linear trend models, and two-sample t-tests provide strong evidence of shifts in minimum and maximum temperature. However, evidence supporting changes in rainfall over the same period remains tenuous and is supported by the projected change in precipitation for the remainder of the century as illustrated in Figure 4.15. Although descriptive statistics and linear trend models provide some evidence of changes in rainfall, the two-sample t-test failed to provide statistically significant evidence that rainfall changed. Regardless, even relatively minor changes in rainfall can have significant implications for rice cultivation.

While this is an interesting finding, one must be cognizant that the analysis was based on available aggregated rainfall data. As such, the distribution, intensity, and duration of rainfall are not captured through aggregated data. However, these variables are as important to agriculture and rice cultivation specifically, as the amount of rainfall itself. Given that the spatial variations in rainfall create three sub-climate zones in Guyana, rainfall changes in one sub-climate zone may offset rainfall changes in another sub-climate zone without drastically changing the aggregated annual rainfall for the country. For example, rainfall distribution may have shifted such that areas along the coastal sub-climate zone where rice is primarily cultivated received more rainfall while the interior savannahs sub-climate zone received less. The intensity of rainfall (more rainfall over a short period of time) may have also changed across sub-climate zones. As a result, more intense rainfall events may have led to excess water that inundate rice fields and overwhelm existing drainage infrastructure. Similarly, the duration of the traditional rainy season may have also changed. An extended wet season where rainfall starts early and finishes late may affect both sowing and harvesting.

Considering the importance of these three climatological variables to rice cultivation, Chapter 6 employs farm-level data to address the limitations of the aggregated data. It will also enhance our understanding of the changes in rainfall patterns perceived by small farmers and key informants across the five primary rice-producing regions in Guyana.

Chapter 5 Multivariate Analysis of Farm-level Data

5.1 Introduction

Climate averages and aggregated yield data provide important insights into the impacts of climate change on rice yields at the national and regional levels. However, climate averages mask individual extreme weather events and microclimates which can have important effects on yields (Lobell, Cahill, and Field 2007). Similarly, aggregated yield data conceals how individual farm households are affected by climate change. Moreover, climate variables alone are not the only determinant of agricultural yields. The heterogeneity in both farm-specific biophysical and socio-economic conditions across farm households (Antle, Stoorvogel, and Valdivia 2014; Claessens et al. 2012) signals the importance of controlling for other explanatory variables (Ochieng, Kirimi, and Mathenge 2016; De Salvo, Raffaelli, and Moser 2013).

Sarker (2012) notes that the impacts of climate change on crop production varies depending on non-climatic factors. In other words, explanatory variables such as soils, infrastructure, agricultural services, and other socio-economic variables (Mendelsohn and Dinar 2005) play a pivotal role in determining yields under a changing climate. As such, this chapter uses multiple regression to explore the effects of perceived changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds together with socio-economic, farm-level, and institutional factors on rice yields. Descriptive statistics of farmers' perception of changes in rainfall, temperature, extreme weather events, insects and pests, diseases, weeds, and the various socio-economic, farm-level, and institutional factors are presented. This is followed by a summary of farmers' responses regarding the quality of inputs and equipment. Results and discussion of the multivariate analyses are presented next. The chapter concludes with a summary of the key findings.

5.2 Small Farmers' Perceptions: Rainfall, Temperature and Extreme Weather, Insects and Pests, Diseases, and Weeds

Among the 189 small farmers interviewed, 182 (96.3%) perceived changes in rainfall; 170 (89.9%) perceived changes in temperature; 169 (89.4%) perceived changes in extreme weather events; 185 (97.9%) perceived changes in insects and pests; 73 (38.6%) perceived changes in diseases; and 168 (88.9%) perceived changes in weeds.

5.3 Socio-economic Characteristics of Small Farmers

Socio-economic characteristics include farmers' age, gender, education level, and sources of income. Based on the sampling methods applied (see Chapter 3) we assume these demographics are representative of the wider population of small farmers.

5.3.1 Age, Gender, and Education

The average age of small farmers in the sample population is 51 years with the youngest and oldest farmers being 20 and 89 years, respectively. Table 5.1 summarizes the age distribution of farmers interviewed.

Table 5.1 Age of Small Farmers

Age	No. of Farmers	%
Under 30 years	25	13.2
31 - 40 Years	24	12.7
41 - 50 years	37	19.6
51 - 60 years	53	28.0
61 - 70 years	38	20.1
Above 70 years	12	6.3
Total	**189**	**100.0**

Males accounted for approximately 97 percent of the sample population. Approximately 55 percent of the farmers attended primary school while 32 percent attended high school. Less than 10 percent of the farmers obtained a tertiary education while three farmers never attended school. Table 5.2 presents the education level reported by small farmers.

Table 5.2 Education Level of Small Farmers

Education Level	No. of Farmers	%
Primary	103	54.5
Community High School	8	4.2
High School	61	32.3
Technical/vocational	10	5.3
University	4	2.1
No schooling	3	1.6
Total	**189**	**100.0**

5.3.2 Primary and Secondary Sources of Income

Rice farming is the primary source of income for 93 (49.2%) farmers. However, 181 (95.8%) farmers reported other agricultural and/or non-agricultural sources of income. Table 5.3 captures the sources of income of farmers.

Table 5.3 Income Source of Small Farmers

Source of Income	No. of Farmers	%
Rice only	8	4.2
Rice and other agricultural	69	36.5
Rice and non-agricultural	60	31.7
Rice, other agricultural, and non-agricultural	52	27.5
Total	**189**	**100.0**

Other agricultural sources of income include cash crops[21], livestock, and agricultural labor while old age and National Insurance Scheme (NIS) pension, services (e.g., taxi and bus driver), and other off farm employment (e.g., mechanic and welder) were the main non-agricultural sources of income. Other agricultural and non-agricultural sources of income are reflected in Table 5.4 and 5.5, respectively.

[21] Vegetables including eggplants, bora (a type of long beans), spinach, peppers, green onions, etc.

Table 5.4 Other Agricultural Sources of Income of Small Farmers

Other Agricultural Sources of Income	No. of Farmers	%
Cash crops (e.g. peppers, spinach)	58	30.7
Livestock	57	30.2
Fruits	11	5.8
Fishery	3	1.6
Ground provisions	7	3.7
Other (e.g. laborer, tractor operator)	57	30.2

Table 5.5 Non-Agricultural Sources of Income of Small Farmers

Non-Agricultural Sources of Income	No. of Farmers	%
Pension (old age and NIS)	40	21.2
Service (e.g. taxi and bus driver)	21	11.1
Carpentry	8	4.2
Small business	8	4.2
Wholesale/ retail	5	2.6
Remittances	2	1.1
Other (e.g. mechanic, welder)	45	23.8

5.4 Farm-level Characteristics

Farm-level characteristics include the farm size, tenure status, farming experience, household participation, seasonal labor, ownership and rental of farming equipment, livestock, and soil type.

5.4.1 Farm Size and Tenure Status

The average farm size in the sample is 2.38 hectares. Farming plots ranged from 0.4 to 4.5 hectares with 59 (31.2%) farmers cultivating plots of three or more hectares. Table 5.6 provides a breakdown of farm sizes in the sample. While 146 (77.2%) farmers reported that the land was owned personally or by a family member, only 85 (44.9%) farmers reported having legal title to the land.

Table 5.6 Farm Size by Hectare

Hectare	No. of Farmers	%
0 – 0.9 Hectare	17	8.9
1 – 1.9 Hectares	48	25.4
2 – 2.9 Hectares	65	34.4
3 – 3.9 Hectares	33	17.5
4 – 4.9 Hectares	26	13.8
Total	**189**	**100.0**

5.4.2 Farming Experience, Household Participation, and Seasonal Labor

The average farmer had approximately 20 years of experience planting rice with 1.5 years being the least and 70 years being the most experience. Table 5.7 provides a breakdown of farmers' experience.

Table 5.7 Farming Experience of Small Farmers

Farming Experience	No. of Farmers	%
1 - 5 years	32	16.9
6 - 10 years	41	21.7
11 - 15 years	15	7.9
16 - 20 years	25	13.2
21 - 25 years	18	9.5
26 - 30 years	15	7.9
31 - 35 years	11	5.8
36 - 40 years	12	6.3
Above 40 years	20	10.6
Total	**189**	**100.0%**

Approximately one-third of the farmers reported that a family member helps with rice farming. The most common household members that help with rice farming are son(s), brother, and father. Despite household members helping out in the field, seasonal labor remains an important part of rice cultivation in Guyana. While land preparation and harvesting are done mechanically (e.g., tractors and combines), sowing, applying fertilizer, and spraying for weeds, insects and pests, and diseases are primarily done by seasonal laborers. As such, 162 (85.7%) farmers reported employing seasonal laborers to help with these tasks. For the other 27 (14.3%) farmers, employing part-time laborer is an additional cost that they avoid by doing the work themselves. As one farmer relate, “I do the work myself….if I had to pay [laborers], I would have nothing [profit] for myself”. Table 5.8 presents the tasks farmers employ laborers to perform.

Table 5.8 Tasks Performed by Seasonal Labor

Task	No. of Farmers	%
Sowing seedlings	161	99.4
Fertilizer application	141	87.0
Spraying chemicals	121	74.7
Sowing, fertilizer, spraying	120	74.1
Sowing and fertilizer	115	71.0
Drains and water tracks	9	5.6
Rogueing of weeds	8	4.9
Weeding	5	3.1
Drying	1	0.6

5.4.3 Equipment Ownership and Rental

Among the 189 small farmers interviewed, 161 (85.2%) indicated owning farming equipment. Of those that owned farming equipment, 145 (90.1%) own a manual spray can, 87 (54.0%) own a motor blower, 33 (20.5%) own a tractor, and 23 (14.3%) own a small pump. However, only a third of these farmers reported sharing their equipment, specifically the motor blower and spray can. In terms of equipment rental, 186 (98.4%) farmers rented a combine harvester while 162 (87.1%) rented a tractor.

5.4.4 Livestock Ownership

Eighty-six (45.5%) farmers owned one or more livestock. Of these farmers, 58 (67.4%) own cows, 37 (43.0%) own sheep, 12 (14.0%) own ducks, and 10 (11.6%) own goats. Other livestock own include fowls, broilers/layers, and pigs. Table 5.9 summarizes farmers that own livestock.

Table 5.9 Type of Livestock Owned

Livestock	No. of Farmers	%
Cows	58	67.4
Sheep	37	43.0
Ducks	12	14.0
Goats	10	11.6
Fowls	7	8.1
Broilers/layers	5	5.8
Pigs	3	3.5

5.5 Institutional Accessibility

Institutional accessibility refers to farmers access to extension services, weather information, credit, insurance, and adequate irrigation.

5.5.1 Farmers' Participation in Extension Training

Ninety-two (48.7%) farmers acknowledged participating in one or more rice extension training courses. Of these, 75 (39.7%) farmers indicated that the training they participated in was based on the six-point practice. In 2008, the extension department of the Guyana Rice Development Board introduced six improved management practices for rice cultivation which are primarily based on two earlier writings on rice cultivation in Guyana: Hints for Profitable Rice Farming by Madramootoo (1969) and Some Notes on Rice Cultivation by the Research and Extension Division of the Guyana Rice Board (GRB 1976). The improved practices include advice on planting in-season (time of sowing), reducing plant densities (seed rate), treating seeds before sowing (seed treatment), controlling weeds, using balance nutrition fertilizer, and managing water in the field. Farmers were also asked separately if they had heard of the six-point practice with 110 (58%) responding in the affirmative. However, 21 (19.1%) of these farmers had only heard of the six-point practice and could not elaborate on the specific practices involved. While some farmers may have heard of the six-point practice as a whole, they may not be practicing it or fully aware of the various components. As one farmer admitted, "I heard of it but don't know the details." On the other hand, 35 (31.8%) farmers stated that the six-point practice educates farmers on how to get better yields with 10 (9.1%) farmers declaring that the six-point practice works in that their yields had increased. Farmers also demonstrated their knowledge of the six-point practice by highlighting the specific components. Table 5.10 captures farmers' knowledge of the six-point practice.

Table 5.10 Small Farmers' Knowledge of the Six-Point Practice

Response	No. of Farmers	%
How to plant rice to get better yields	35	31.8
Balance nutrition (fertilizer)	28	25.5
Don't know	21	19.1
Treatment of seeds	17	15.5
Time of sowing	16	14.5
Seed rate	14	12.7
Increased yields	10	9.1
Weed control	8	7.3
Water management	8	7.3
Land preparation	6	5.5
Other	11	10.0

Using the list of six improve management practices, farmers were further asked to indicate which of the practices they had adopted. About half of the farmers fully adopted the six-point practice. In terms of specific practices being followed, all farmers reported that they controlled for weeds and approximately 97 percent engaged in water management and balance nutrition fertilizer. Almost 95 percent sowed in-season and 92 percent treated seeds or applied chemicals to the water in the field. Less than 60 percent of farmers reduced their seed rates. Some farmers noted that it is difficult to reduce seed rate because the land is low, and they are catering for potential losses due to flooding.

Other training courses farmers attended include paddy bug control, land preparation, fertilizer application, paddy grading, and markets for rice. Most of these training courses were done as part of farmer field schools, field visits, and field days. The Guyana Rice Development Board (GRDB) extension department was the primary source of the training courses.

5.5.2 Weather Information in Advance

One hundred and forty (74.1%) farmers indicated that they received weather information in advanced. Television was the most popular source of weather information which accounted for 99 (52.4%) farmers. Twelve (6.3%) farmers received weather information through the radio and 17 (9.0%) farmers reported multiple sources including the internet and farming almanac. Access to accurate and timely weather information can help farmers adjust farm management practices to mitigate the impacts of climate change.

5.5.3 Input Credit and Agricultural Insurance

One hundred (52.9%) farmers received fertilizer credit. Eighty-one (42.9%) farmers indicated that the miller was the source of the credit. Supplier/distributors and large farmers provided credit to nine (4.8%) and seven (3.7%) farmers, respectively. Farmers responded that they do not have agricultural insurance and suggested that such products may not even exist in Guyana. According to the World Bank (2010) there is currently no agricultural insurance provision in Guyana and no clear national policy framework to this effect. As a result, farmers have no knowledge, experience, or awareness of agricultural insurance products and the related costs, benefits, and constraints (WB 2010a).

5.5.4 Access to Irrigation and Pumping of Water

One hundred and fifty-eight (83.6%) farmers indicated that they had proper irrigation facilities. However, 74 (39.2%) farmers reported that they had to pump water to flood their fields. This was because there is no irrigation system in their area or the water levels in the irrigation canals were not high enough to accommodate gravity flow. In a few cases, some fields were too high to allow for gravity flow from the nearby irrigation canals. While irrigation was up to standard, drainage was a major problem according to these farmers.

5.5.5 Membership in an Agricultural Organization

Thirty-three (17.5%) farmers reported that they were members of the Rice Producer Association (RPA). The RPA is generally responsible for "the protection, promotion, and advancement of the interests of rice producers"(GRPAA, 1946). Sixteen (8.5%) farmers also noted that they were members of other agricultural organizations such as the water user association and credit society. As members of an agricultural organization, farmers may have greater access to information on climate change and farm management practices that can help them successfully adapt.

5.6 Inputs and Equipment

Inputs include seeds, fertilizers, insecticides, pesticides and labor while equipment include tractor and combine used for land preparation and harvesting, respectively. The quality of inputs and equipment is also important in determining yields.

5.6.1 Seed Variety

One hundred and twenty-five (66.1%) farmers planted GRDB 10 rice variety. GRDB 10 is popular because it is a high yielding variety with a shorter time to mature. Nineteen (10.0%) farmers planted multiple varieties. This is because they had more than one plot or they rotated varieties between the two seasons in order to hedge against expected climatic conditions. For instance, they planted GRDB 10 in the traditionally short rainy season (November-December/ spring crop) given this variety's tendency to lodge because of heavy rainfall and related flooding. In the traditionally long rainy season (May-June/ autumn crop) they would plant a sturdier variety such as the GRDB 12 or 14. Hence, the choice of seed variety is an adaptation strategy employed by small farmers which is further explored in Chapter 6.

In a few cases, farmers reported mixing varieties on the same field. One farmer contends that the mixing of varieties on the same field helps to prevent lodging since a sturdier variety (e.g., GRDB 12) serves as a brace for a weaker variety (e.g., GRDB 10) in the event of rainfall induced lodging. However, this practice is ill advised since different varieties have different maturity times. If farmers harvest before the longer of the two varieties mature, the harvested yields will contain green grains which will result in a lower grade received at the mill. On the other hand, if the farmer harvest after both varieties have matured, the variety with the shorter maturity time will likely be too ripe leading to moisture loss and brittle grains once it goes through the milling process. It is also important to note that 16 (13.8%) farmers are still planting old varieties such as G98-22-4, G98-196, Rustic, G98-135 and 33-3. Although these old varieties are not disease resistant, older farmers continue to plant them because they are reluctant to change and/or because some millers still request these varieties. Table 5.11 presents the rice varieties planted.

Table 5.11 Seed Variety Planted

Response	No. of Farmers	%
GRDB 10	125	66.1
Multiple	19	10.1
GRDB 14	11	5.8
G98 - 22-4	9	4.8
G98 - 196	7	3.7
Rustic	6	3.2
GRDB 12	3	1.6
G98 - 135	2	1.1
33-3	2	1.1
Other (Diwani and Brazilian)	5	2.6
Total	**189**	**100.0**

5.6.2 Quality of Inputs and Equipment

Farmers were also asked to rate the quality of inputs and equipment. A total of 166 (87.8%) farmers rated the quality of seeds as being good or higher. This may be attributed to the fact that 182 (96.2%) farmers indicated that they bought new seeds each or every other season. In comparison, farmers were more circumspect when it came to the quality of fertilizers, insecticides, and pesticides. Fertilizers received a rating of good or higher by 148 (78.3%) farmers while insecticides and pesticides received the same rating by 147 (77.8%) farmers. In terms of labor, 158 (83.6%) farmers responded that the quality of labor was good or higher with 27 (14.3%) farmers reporting that they did the work themselves. Equipment rental received a rating of good or higher by 159 (84.1%) farmers. Table 5.12 presents farmers rating of the main inputs involved in rice farming.

Table 5.12 Quality of Inputs and Equipment

Inputs and Equipment	No. of Farmers										
	Very Good	%	Good	%	Acceptable	%	Poor	%	Very Poor	%	Total
Seeds	55	29.1	111	58.7	16	8.5	6	3.2	1	0.5	189
Fertilizers	40	21.2	108	57.1	24	12.7	15	7.9	2	1.1	189
Pesticide and Herbicide	35	18.5	112	59.3	26	13.8	15	7.9	1	0.5	189
Labor	35	18.5	123	65.1	23	12.2	5	2.6	3	1.6	189
Equipment: Combine and Tractor	29	15.3	130	68.8	25	13.2	4	2.1	1	0.5	189

5.7 Yields and its Determinants: Multivariate Analyses

Ordinary Least Square (OLS) is used for statistical estimation. This method is employed to determine which socio-economic, farm-level, and institutional factors influence small farmers' yields. In the absence of farm-level climate data, farmers' perception of changes in rainfall, temperature, and extreme weather events are used as explanatory variables. In addition, changes in rainfall, temperature, and extreme weather events are expected to have a positive effect on the presence of insects, diseases, and weeds (Rosenzweig et al. 2001), which are assumed to negatively impact yields. It is assumed that farmers that perceived changes in these climate variables are also likely to experience changes in their yields and subsequently change their farm management practices. Some socio-economic, farm-level, and institutional factors included in the model are identified from the literature and described in detail in Chapter 3. Other socio-economic, farm-level, and institutional explanatory variables are added based on farming practices and conditions prevalent in Guyana. Furthermore, independent variables that control for regional differences in yield are included.

5.7.1 Estimation Procedure: Heteroskedasticity and Multicollinearity

In analyzing cross-sectional data, two issues usually arise: heteroskedasticity and multicollinearity (Greene 2012; Benhin 2008; Cameron and Trivedi 2005). Heteroskedasticity occurs when the error term exhibit non-constant variance (Wooldridge 2013). In other words, the variance of the error term changes depending on the value of one or more independent variables. This results in biased standard errors which leads to bias test statistics and confidence intervals. The Breusch-Pagan test was used for checking heteroskedasticity and robust standard errors are computed to deal with this issue.

Multicollinearity refers to the successive inclusion of additional variables that increases correlation among independent variables in a multiple regression model (Wooldridge 2013). The variance inflation factor (VIF) was used to detect the problem of multicollinearity. It shows how the variance of an estimator is inflated by the presence of multicollinearity (Gujarati, Porter, and Gunasekar 2012). The higher VIF, the greater the signs of multicollinearity.

5.7.2 Results and Discussion of the Multivariate Analysis

Equation [3.7] was estimated using multiple regression. Three specification scenarios are estimated. In scenario 1, the equation contains farmers' perceptions and those characteristics that are expected to influence the small farmers' yields based on the review of literature. The variables contained in the estimated equation for Scenario 1 are described under Chapter 3.3. Keeping the equation from Scenario 1, Scenario 2 introduces additional independent variables to the equation. It was reasoned that including farmer has secondary non-agricultural sources of income (SECNAG), farmer conducted a soil test (SOILTEST), household members participated in rice farming (HOUSEPART), farmer received adequate irrigation (ADEQIRRIG), and farmer fully implemented the six-point practice (SIXPOINT) would influence the amount of grains harvested.

According to Wooldridge (2013), while it may be appropriate to exclude certain independent variables from a model, including irrelevant independent variables in the equation has no effect on the unbiasedness of the intercept and other slope estimators. However, incorrectly excluding relevant independent variables can lead to inconsistency in the estimates (Wooldridge 2013). Building on Scenario 2, Scenario 3 included farmer employed seasonal labor (SEALAB), and farmer pumped water to flood field (PUMPWAT). These variables were added with the expectation that they would further enhance the model. Using the same scenarios, analyses are also conducted by season. Stata version 14 was used to generate the results. Table 5.13 present the definitions, mean, standard deviation, and frequency distribution for the independent variables used in the analysis; the results of the multivariate analyses are presented in Table 5.14 and 5.15.

Table 5.13 Definitions, Expected Signs, and Descriptive Statistics of Independent Variables

Variable	Variable Description	Measure	Expected Sign	Mean (Std. Dev.)/ Frequency n = 189
RAINCHNG	Perceived changes in rainfall	1=yes and 0=no	+	Yes = 96.3% No = 3.7%
TEMPCHNG	Perceived changes in temperature	1=yes and 0=no	+	Yes = 89.9% No = 10.1%
EXTREWEAT	Perceived changes in extreme weather events	1=yes and 0=no	+	Yes = 89.4% No = 10.6%
INSECCHNG	Perceived changes in insects and pests	1=yes and 0=no	+	Yes = 97.9% No = 2.1%
DISEACHNG	Perceived changes in diseases	1=yes and 0=no	+	Yes = 38.6% No = 61.4%
WEEDSCHNG	Perceived changes in weeds	1=yes and 0=no	+	Yes = 88.9% No = 11.1%
AGE	Age of the farmer	No. of years	+	50.6 (14.6)
GENDER	Gender of the farmer	1=male and 0=female	+	Yes = 97.9% No = 2.1%
EDUC	Education level of the farmer	0=no school 1=primary 2=high school 3=technical/ vocational 4=university	+	No school = 1.6% Primary = 54.5% High school = 36.5% Technical/vocational = 4.8% University = 2.6%
PRIMOCCU	Rice farming is the primary occupation	1=yes and 0=no	+	Yes = 50.8% No = 49.2%
FARMSIZE	Size of farm	No. of hectares	+	2.38 (1.07)
TENURE	Ownership of farm land	1=yes and 0=no	+	Yes = 44.9% No = 55.1%
FARMEXP	Experience of farmer	No. of years	+	20.3 (14.9)
TRACTOR	Owned a tractor	1=yes and 0=no	+	Yes = 17.5% No = 82.5%
OWNLIVE	Owned livestock	1=yes and 0=no	-	Yes = 45.5% No = 54.5%
EXTTRAIN	Participated in rice extension training(s)	1=yes and 0=no	+	Yes = 48.7% No = 51.3%

ADVWEATH	Access to advance weather information	1=yes and 0=no	+	Yes = 74.1% No = 25.9%
CREDIT	Access to input credit	1=yes and 0=no	+	Yes = 52.9% No = 47.1%
AGMEM	Membership in an agricultural organization(s)	1=yes and 0=no	+	Yes = 22.8% No = 77.2%
SECNAG	Non-agricultural income	1=yes and 0=no	+	Yes = 59.8% No = 40.2%
SOILTEST	Soil test was done	1=yes and 0=no	+	Yes = 28.0% No = 72.0%
HOUSEPART	Household member(s) help with rice farming	1=yes and 0=no	+	Yes = 34.9% No = 65.1%
ADEQIRRIG	Access to adequate irrigation	1=yes and 0=no	+	Yes = 83.6% No = 16.4%
SIXPOINT	Fully adopted the six-point practice	1=yes and 0=no	+	Yes = 49.7% No = 50.3%
LABOR	Seasonal labor was employed	1=yes and 0=no	+/-	Yes = 85.7% No = 14.3%
PUMPWAT	Pumped water	1=yes and 0=no	+/-	Yes = 39.2% No = 60.8%
REGION2	Farm located in region 2	Region=2	+/-	0.36 (0.48)
REGION3	Farm located in region 3	Region=3	+/-	0.16 (0.37)
REGION4	Farm located in region 4	Region=4	+/-	0.16 (0.37)
REGION5	Farm located in region 5	Region=5	+/-	0.16 (0.37)
REGION6	Farm located in region 6	Region=6	+/-	0.16 (0.37)

Table 5.14 Multivariate Analysis of Small Farmers' Yields[a]

Independent Variable	Predicted Relationship	Scenario 1	Scenario 2	Scenario 3
		Yields (MT/Ha)	**Yields (MT/Ha)**	**Yields (MT/Ha)**
		(Standard Errors)	(Standard Errors)	(Standard Errors)
INTERCEPT		5.278 *** (1.592)	6.038*** (1.589)	5.974*** (1.652)
RAINCHNG	+	-1.388** (0.703)	-1.207* (0.693)	-1.199* (0.700)
TEMPCHNG	+	0.349 (0.434)	0.164 (0.430)	0.180 (0.433)
EXTREWEAT	+	-0.444 (0.454)	-0.306 (0.445)	-0.316 (0.452)
INSECCHNG	+	0.672 (0.955)	0.385 (0.940)	0.346 (0.945)
DISEACHNG	+	-0.229 (0.259)	-0.223 (0.253)	-0.234 (0.254)
WEEDSCHNG	+	-0.256 (0.387)	-0.335 (0.379)	-0.340 (0.381)
AGE	+	-0.003 (0.012)	-0.005 (0.012)	-0.006 (0.012)
GENDER	+	1.384* (0.826)	1.346* (0.809)	1.376* (0.818)
EDUC	+	0.162 (0.115)	0.059 (0.116)	0.050 (0.119)
PRIMOCCU	+	-0.053 (0.267)	-0.064 (0.264)	-0.072 (0.270)
FARMSIZE	+	-0.076 (0.047)	-0.078 (0.048)	-0.087* (0.049)
TENURE	+	0.599** (0.252)	0.536** (0.249)	0.524** (0.250)
FARMEXP	+	0.009 (0.012)	0.003 (0.012)	0.004 (0.012)
TRACTOR	+	1.114*** (0.334)	1.078*** (0.334)	1.048*** (0.337)
OWNLIVE	-	-0.579** (0.246)	-0.581** (0.242)	-0.572** (0.243)
EXTTRAIN	+	-0.447* (0.257)	-0.510* (0.267)	-0.512* (0.268)
ADVWEATH	+	-0.194 (0.286)	-0.071 (0.282)	-0.049 (0.284)
CREDIT	+	0.216 (0.262)	0.204 (0.257)	0.212 (0.258)
AGMEM	+	0.628** (0.305)	0.531* (0.312)	0.525* (0.313)
SECNAG	+		0.570** (0.265)	0.547** (0.268)
SOILTEST	+		0.461 (0.292)	0.458 (0.293)
HOUSEPART	+		-0.424* (0.253)	-0.433* (0.255)
ADEQIRRIG	+		-0.518 (0.341)	-0.556 (0.357)
SIXPOINT	+		0.262 (0.248)	0.278 (0.250)
				0.313

LABOR	+/-			(0.348)
PUMPWAT	+/-			-0.022 (0.319)
REGION2	+/-	1.619*** (0.389)	1.477*** (0.393)	1.424*** (0.484)
REGION3	+/-	0.517 (0.437)	0.382 (0.448)	0.337 (0.490)
REGION4	+/-	2.183*** (0.422)	2.198*** (0.423)	2.185*** (0.497)
REGION5	+/-	0.471 (0.421)	0.346 (0.434)	0.305 (0.469)
No. of Observation[b]		188	188	188
R^2		0.359	0.410	0.413
F-value		3.99	3.95	3.69
Prob > F		0.000	0.000	0.000
Breusch-Pagan prob.		0.257	0.187	0.123
Variance Inflation Factor (VIF)		1.54	1.57	1.69

[a] REGION6 has been dropped from the analysis.
[b] One farmer could not recall his yields for 2016.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

In the baseline model specified (Scenario 1), several independent variables were found to have an important relationship with total rice yield measured in metric ton per hectare (TRYLDMTHA). It should be noted that this relationship suggests correlation and not causation. The statistically significant variables include small farmers perceived changes in rainfall (RAINCHNG), gender of farmer (GENDER), land tenure status (TENURE), tractor ownership (TRACTOR), livestock ownership (OWNLIVE), farmer participate in rice extension training (EXTTRAIN), and membership in an agricultural organization (AGMEM).

Perceived changes in rainfall (RAINCHNG) was negatively correlated with rice yields. In other words, rice yields were likely to be lower if a farmer observed changes in rainfall patterns. This may be due to the lack of resources to successfully adapt and/or ineffective adaptation practices under changing rainfall patterns. Additionally, farmers may not be able to adapt due to biophysical limits. For instance, farmers may not be able to pump out excess water if the drainage infrastructure is overwhelmed by excess rainfall.

There was a positive relationship between the gender of the farmer (GENDER) and yields. Specifically, higher yields were associated with male farmers. While this regression is not meant to explain causality, there are various possible reasons for this correlation. For one, male farmers are likely to have better access to inputs and information. Land tenure (TENURE) was positively correlated with rice yields. Farmers are more inclined to invest in their own land because property rights enhance the certainty of benefiting from capital and labor investments. This positive relationship was also found by other studies (e.g., Kurukulasuriya and Ajwad 2007; Charles 2009; Sarker 2012). Tractor ownership (TRACTOR) also has a positive relationship with rice yields. One possible explanation for this relationship, supported by qualitative responses during interviews, is that small farmers that own a tractor do not have to wait in line for their land to be prepared by a large farmer that owns machinery and equipment. As a result, small farmers can begin land preparation early thus allowing them the time to do additional dry land preparation, if needed. Dry land preparation can improve soil quality through the removal of straw and other vegetation, reduce infestation of pest and diseases and increase soil nutrient (GRB 1976). It also consumes less fuel and is important for controlling red rice, the major rice weed in Guyana. Also, being able to prepare their own land helps ensure that they sow within the suggested planting windows of May-June and December-January. Charles (2009) and Mishra, Sahu, and Sahoo (2016) found that tractor ownership had a strong positive relationship with net farm revenues.

Livestock ownership (OWNLIVE) has a negative relationship with rice yields. Livestock ownership among small rice farmers appears to be their main farming activity; in other words, farmers may be classified as small rice farmers but large livestock farmers. As noted in Table 5.9 above, 58 farmers own cows, 37 own sheep, 10 own goats. Of those that own cows, sheep and goats, 14 (24.1%) own ten or more cows, 18 (48.6%) own ten or more sheep, and 8 (80.0%) own ten or more goats. In Guyana, these are considered large livestock farmers. Kabubo-Mariara and Karanja (2007) found similar results, implying competition rather than complementarity between livestock and rice farming.

It was expected that small farmers that had access to and took advantage of training opportunities (e.g., field schools, field day, plot demonstrations, etc.) facilitated by district rice extension officers would benefit from the transfer of new information, technologies, and management practices that would help with adaptation under a changing climate. However, participation in rice extension training (EXTTRAIN) was negatively correlated with rice yields. This is an extremely curious and unexpected finding. One probable explanation is that the advice received by farmers that attended training sessions is not appropriate under current biophysical and climatic conditions. For example, farmers whose land is low and thus prone to flooding may suffer a decline in yields by reducing seed rates. Flooding may wash away seeds leading to even less seedlings remaining in the field to grow. On the other hand, the advice received may be poorly implemented thus causing more harm than good. For example, the use of balance nutrition fertilizer may be counterproductive if farmers fail to control weeds or engage in proper water management in the field. In short, farmers may need to apply extension advice holistically otherwise risk further losses. It is noteworthy that other studies (e.g., Charles 2009; Sarker 2012; Nyuor et al. (2016); Huong, Bo, and Fahad (2018) found the opposite—i.e., a positive relationship—for this variable.

In contrast to extension training, membership in an agricultural organization (AGMEM) has a positive relationship with rice yields. Small farmers that are members of one or more agricultural organizations may benefit from information sharing and farmer-to-farmer extension as it relates to new farming practices, agricultural technologies, and weather. Previous studies have reported mixed results for this variable. Wang et al. (2009) found that participation in a production association was advantageous to farmers while Sarker (2012) found it to be negatively correlated with net revenues.

Alternative model specifications were explored in scenarios two and three. Under scenario two, the equation was expanded to include secondary non-agricultural income (SECNAG), soil test (SOILTEST), household member(s) help with rice farming (HOUSEPART), access to adequate irrigation (ADEQIRRIG), and full adoption of the six-point practice (SIXPOINT). It was reasoned that including a variable measuring off-farm income would enhance farm household income levels and hence, the capacity to engage in additional farm management practices. A soil test would heighten awareness of soil health and quality which would help farmers make better farm management decisions at is relates to fertilizer application and water management which could increase yields. Similarly, other household members helping with rice farming were thought to enhance the quality of work performed in terms of sowing, spraying, and fertilizer application and continuous monitoring of the field for insects and pests, diseases, weeds. In addition, farmers that received adequate irrigation are more likely to benefit from better yields since water is readily available to start and finish the crop. Furthermore, farmers that fully adopted the six improved management practices were likely to experience higher yields. Secondary non-agricultural income has a positive relationship with yields. Sarker (2012) found that higher income levels were positively correlated with net revenue from rice farming. Household member(s) participation in rice farming has a negative relationship with yields. It is likely that household members that help with rice farming may not boast the skills and experience of seasonal laborers.

Building on Scenario 2, in Scenario 3 the equation was expanded to include the use of seasonal labor (LABOR) and farmer pumped water (PUMPWAT). It was thought that yields would increase through the use of seasonal labor to sow, apply fertilizer, and spray chemicals. In comparison to household participation, seasonal laborers have broad knowledge and experience from working on different plots. However, the quality of work performed by seasonal labor may lead to lower yields. For example, seasonal laborers may do a poor job applying fertilizer or spraying for insects and pests. Farmers that pump water to flood their fields may benefit from better yields in that they are able to engage in better water management. Alternatively, pumping water may be a sign of limited water availability in the irrigation canals which may affect yields. Although neither variable added were statistically significant, one previously included variable became significant. Farm size was negatively correlated with yields. One probable explanation is that larger farms are more difficult to manage especially as it relates to controlling insects and weeds. Similar findings were reported by Kabubo-Mariara and Karanja (2007) and Closset, Dhehibi, and Aw-Hassan (2015) while contrasting findings were reported by Charles (2009), Sarker (2012), Wood and Mendelsohn (2015), Nyuor et al. (2016), and Huong, Bo, and Fahad (2018).

In the three scenarios considered, two regional variables were positively correlated with yields. Region two (REGION2) and region four (REGION4) were both statistically significant at the 1% level. As such, farms located in these regions on average produce higher yields when compared to region six, which was dropped from the analysis. There are two possible explanations for this finding. In the sample, the average farm size in region two is 2.1 hectares which is representative of the population. In general, smaller farms are considered more efficient. Also, farmers are able to better manage water and control weeds and insects on small plots. Region four is the smallest in area under cultivation. Thus, the extension officer is able to provide good coverage of the area in terms of providing advice and guidance to farmers. In fact, the extension officer for region four was recently recognized as the first Extension Officer of Excellence in the Caribbean.

The F-value for all three scenarios implies that the models were statistically significant. The goodness of fit measured by the R^2 for scenario 1, 2 and 3 were 0.36, 0.41, and 0.41, respectively. For farm-level data, this is considered reasonable (Sarker 2012). Among the considered model, Scenario 3 is the preferred specification. Apart from no evidence of multicollinearity and heteroskedasticity, this specification encompasses the most complete list of independent variables and as such is likely to result in more consistent estimates.

Table 5.15 Multivariate Analysis of Small Farmers' Yield by Season[a]

Independent Variable	Predicted Relationship	Scenario 1		Scenario 2		Scenario 3	
		Spring Yields (MT/Ha)	**Autumn Yields (MT/Ha)**	**Spring Yields (MT/Ha)**	**Autumn Yields (MT/Ha)**	**Spring Yields (MT/Ha)**	**Autumn Yields (MT/Ha)**
		(Standard Errors)	(Robust Standard Errors)	(Standard Errors)	(Robust Standard Errors)	(Standard Errors)	(Robust Standard Errors)
INTERCEPT		3.228*** (0.875)	2.050** (0.803)	3.462*** (0.891)	2.576*** (0.776)	3.552*** (0.928)	2.422** (0.781)
RAINCHNG	+	-0.856** (0.386)	-0.532 (0.405)	-0.773** (0.389)	-0.434 (0.362)	-0.756* (0.393)	-0.443 (0.357)
TEMPCHNG	+	0.208 (0.238)	0.141 (0.394)	0.108 (0.241)	0.056 (0.380)	0.104 (0.243)	0.076 (0.380)
EXTREWEAT	+	-0.332 (0.250)	-0.112 (0.220)	-0.278 (0.249)	-0.028 (0.216)	-0.263 (0.254)	-0.053 (0.220)
INSECCHNG	+	0.211 (0.525)	0.462 (0.497)	0.095 (0.527)	0.290 (0.428)	0.096 (0.531)	0.250 (0.442)
DISEACHNG	+	-0.113 (0.142)	-0.117 (0.154)	-0.108 (0.142)	-0.114 (0.151)	-0.106 (0.143)	-0.128 (0.151)
WEEDSCHNG	+	-0.093 (0.213)	-0.162 (0.245)	-0.125 (0.212)	-0.209 (0.227)	-0.124 (0.214)	-0.217 (0.223)
AGE	+	0.001 (0.007)	-0.003 (0.008)	0.000 (0.007)	-0.005 (0.008)	0.000 (0.007)	-0.006 (0.008)
GENDER	+	0.549 (0.454)	0.835* (0.459)	0.564 (0.453)	0.782* (0.448)	0.545 (0.459)	0.831* (0.437)
EDUC	+	0.096 (0.063)	0.067 (0.067)	0.053 (0.065)	0.005 (0.066)	0.049 (0.067)	-0.001 (0.068)
PRIMOCCU	+	0.104 (0.147)	-0.157 (0.157)	0.099 (0.148)	-0.163 (0.149)	0.089 (0.152)	-0.161 (0.156)
FARMSIZE	+	-0.053** (0.026)	-0.023 (0.033)	-0.054** (0.027)	-0.024 (0.032)	-0.054* (0.028)	-0.034 (0.032)
TENURE	+	0.309** (0.138)	0.290* (0.156)	0.297** (0.140)	0.239 (0.155)	0.299** (0.141)	0.225 (0.153)
FARMEXP	+	0.001 (0.006)	0.008 (0.007)	0.001 (0.006)	0.005 (0.007)	-0.002 (0.007)	0.006 (0.008)
TRACTOR	+	0.659*** (0.183)	0.455** (0.228)	0.678*** (0.187)	0.400* (0.218)	0.678*** (0.189)	0.369* (0.222)
OWNLIVE	-	-0.236* (0.135)	-0.344** (0.143)	-0.222 (0.136)	-0.359** (0.141)	-0.221 (0.137)	-0.351** (0.140)
EXTTRAIN	+	-0.333** (0.141)	-0.113 (0.159)	-0.329** (0.149)	-0.181 (0.168)	-0.328** (0.150)	-0.184 (0 .165)
ADVWEATH	+	-0.016 (0.157)	-0.178 (0.185)	0.030 (0.158)	-0.102 (0.171)	0.029 (0.159)	-0.078 (0.168)
CREDIT	+	-0.016 (0.144)	0.232 (0.164)	-0.015 (0.144)	0.219 (0.161)	-0.018 (0.145)	0.229 (0.164)
AGMEM	+	0.242 (0.168)	0.386** (0.155)	0.226 (0.175)	0.304** (0.155)	0.226 (0.176)	0.299* (0.161)
SECNAG	+			0.243 (0.148)	0.327* (0.179)	0.249* (0.151)	0.298* (0.174)
SOILTEST	+			0.168 (0.163)	0.294** (0.150)	0.172 (0.165)	0.286* (0.151)
HOUSEPART	+			-0.244* (0.142)	-0.180 0.143	-0.246* (0.143)	-0.188 (0.143)

ADEQIRRIG	+			-0.131 (0.191)	-0.387** (0.182)	-0.151 (0.200)	-0.405** (0.196)
SIXPOINT	+			0.042 (0.139)	0.220 (0.157)	0.047 (0.141)	0.231 (0.157)
LABOR	+/-					0.003 (0.195)	0.309 (0.270)
PUMPWAT	+/-					-0.068 (0.179)	0.046 (0.172)
REGION2	+/-	0.619** (0.214)	0.999*** (0.250)	0.558** (0.220)	0.918*** (0.271)	0.499* (0.272)	0.924*** (0.298)
REGION3	+/-	0.114 (0.240)	0.403 (0.299)	0.067 (0.251)	0.315 (0.334)	-0.026 (0.275)	0.310 0.325)
REGION4	+/-	1.249*** (0.232)	0.934*** (0.265)	1.249*** (0.237)	0.948*** (0.289)	1.194*** (0.279)	0.991*** (0.312)
REGION5	+/-	0.251 (0.231)	0.219 (0.290)	0.205 (0.243)	0.141 (0.282)	0.169 (0.263)	0.136 (0.292)
No. of Observation[b]		188	188	188	188	188	188
R^2		0.326	0.290	0.336	0.348	0.356	0.357
F-value		3.45	3.51	3.13	3.52	2.90	3.30
Prob > F		0.000	0.000	0.000	0.000	0.000	0.000
Breusch-Pagan prob.		0.766	-	0.693	-	0.734	-
Mean Variance Inflation Factor (VIF)		1.54	1.54	1.57	1.57	1.69	1.69

[a] REGION6 has been dropped from the analysis.
[b] One farmer could not recall his yields for 2016.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Several variables were statistically significant in the baseline model (Scenario 1) for the spring season. Land tenure status (TENURE) and tractor ownership (TRACTOR) were positively correlated with yields while perceived changes in rainfall (RAINCHNG), size of farm (FARMSIZE), livestock ownership (OWNLIVE), and farmer participate in rice extension training (EXTTRAIN) were negatively associated with yields. For the autumn season, male farmers (GENDER), land tenure status (TENURE), tractor ownership (TRACTOR), and membership in an agricultural organization(s) (AGEM) had a positive relationship with yields. However, livestock ownership (OWNLIVE) was negatively correlated with yields.

Under scenario 2, spring yields were positively correlated with land tenure status (TENURE) and tractor ownership (TRACTOR). The size of farm (FARMSIZE), perceived changes in rainfall (RAINCHNG), farmer participate in rice extension training (EXTTRAIN), and household member(s) help with rice farming (HOUSEPART) had a negative relationship with yields. For the autumn season, male farmers (GENDER), tractor ownership (TRACTOR), and membership in an agricultural organization(s) (AGEM), secondary non-agricultural income (SECNAG), and soil test (SOILTEST) were positively correlated with yields. Livestock ownership (OWNLIVE) and adequate irrigation (ADEQIRRIG) were negatively associated with yields.

For scenario 3, spring yields were positively correlated with land tenure status (TENURE), tractor ownership (TRACTOR), and secondary non-agricultural income (SECNAG). Perceived changes in rainfall (RAINCHNG), size of farm (FARMSIZE), and farmer participate in rice extension training (EXTTRAIN) were negatively associated with yields. Autumn yields were positively correlated with male farmers (GENDER), tractor ownership (TRACTOR), membership in an agricultural organization(s) (AGEM), and soil test (SOILTEST) while livestock ownership (OWNLIVE) and adequate irrigation (ADEQIRRIG) were negatively associated with yields. For both seasons under the three scenarios considered, region two (REGION2) and region four (REGION4) were both statistically significant regional variables and had a positive relationship with yields when compared to region 6.

The F-value for both seasons under each of the three scenarios implies that the models are statistically significant. The goodness of fit measured by the R^2 under each scenario is considered reasonable. While there were no evidence of multicollinearity and heteroskedasticity for the spring season, the Breusch-Pagan test showed signs of heteroskedasticity in the autumn season. As such, robust standard errors were computed to ensure unbiased test statistics and confidence intervals.

5.8 Conclusion

The chapter employed multiple regression to determine the impacts of various socio-economic, farm-level, and institutional factors on rice yields. Three model specifications were used to estimate annual and seasonal yields. Overall, the models estimated were statistically significant. The variance inflation factor (VIF) showed little evidence of multicollinearity. However, robust standard errors were computed to address concerns of heteroskedasticity in the autumn season.

Across the three models specified, several variables were found to be statistically significant for annual and seasonal yields. Gender of farmer, land tenure status, tractor ownership, membership in an agricultural organization(s), secondary non-agricultural income, and farms located in regions two and four were found to be positively correlated with yields. Perceived changes in rainfall, farm size, livestock ownership, farmer participate in rice extension training, and household members help with rice farming were found to have a negative relationship with yields.

In the spring season, land tenure status, tractor ownership, and secondary non-agricultural income were positively correlated with yields. Perceived changes in rainfall, farm size, livestock ownership, farmer participate in rice extension training, and household member(s) help with rice farming were found to have a negative relationship with yields. In comparison, male farmers, land tenure status, tractor ownership, membership in an agricultural organization(s), secondary non-agricultural income, and soil test have a positive relationship with autumn yields. Livestock ownership and adequate irrigation were found to have a negative relationship with yields. Farms located in regions two and four also have a positive association with yields for both seasons. The spring season appears to have more factors that are negatively correlated with yields while the autumn season have more factors that are positively associated with yields. This finding is important because it highlights important differences between the two seasons which can be used to inform policy decisions.

The results presented are based on small farmers across the five main rice-producing regions in Guyana. As such, caution needs to be taken in generalizing the results across all farmers and for specific regions. Regardless, the results support several of the expected relationships and findings in the literature.

Chapter 6 Farmers' Perceptions, Impacts, and Adaptation

6.1 Introduction

Farmers have been coping with year-to-year fluctuation in climate since time immemorial. Yet, climate change poses a different kind of threat as it is expected to hasten the need for and scale of adaptation (Parry et al. 2009). Any response to climate change, however, begins with farmers' perception of the environmental changes and the observed impacts occurring in and around their farms. Perceptions (cognitive processes) of climate change are important factors in determining whether farmers are likely to undertake adaptive measures (Niles, Lubell, and Haden, 2013; Haden et al. 2012) Additionally, a better understanding of farmers' perceptions, impacts, and ongoing adaptation measures is crucial for informing policies aimed at promoting successful adaptation strategies among small farmers[22].

To learn about farm-level perceptions, impacts, and adaptation, responses were solicited from both small farmers and key informants[23]. It was valuable to talk to both small farmers and key informants given the different perspectives each group offers. While small farmers provide an own-farm perspective, key informants are better positioned to comment on larger patterns seen across many farms. In addition, responses from key informants may help validate information gather through small farmers. A detailed discussion of the method used for collecting this data is presented in Chapter 3.

This chapter begins with an overview of small farmers' understanding of climate change or global warming. An analysis of small farmers' perceptions, impacts, and

[22] Farmers that cultivate 4.45 hectares (11 acres) or less in rice each season.

[23] Key informants comprise of district rice extension officers, an experience farmer (+25 years of experience), a rice miller, and senior staff (Chief Scientist/Plant Breeder, Plant Pathologist, Agronomist, Entomologist, and the Rice Extension Manager) at the Burma Rice Research Station in Guyana. Please refer to Chapter 3 – Data and Methods for additional information.

responses in relation to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds is presented next. This is supported by responses from key informants. The adaptation practices implemented and small farmers' ability to pay for these changes in farming practices are explored. The planting season affected, and the coping strategies employed by small farmers to mitigate the impact of losses attributed to crop failure and the high cost of inputs, low market prices, poor grades, and/or late payments by millers are discussed. Barriers and limits to adaptation are examined next. The chapter concludes with an inquiry of the service and support provided to farmers by district rice extension officers employed by the Guyana Rice Development Board (GRDB).

6.2 Small Farmers' Understanding of Climate Change

Earth's climate is changing at an unprecedented rate (Jay et al. 2018). Yet, for many people across the world, an understanding of climate change may still be a novelty. For developing countries like Guyana, emphasis on climate change education may be low on the list of priorities. However, knowledge and awareness of climate change is an important step in understanding if and/or how people are likely to respond to changes in environmental conditions attributed to climate change. As such, small farmers were asked to describe their understanding of climate change and what it meant to them. It should be noted that this was an open-ended question; farmers were not given an explicit list of possible impacts to choose from among, but rather simply asked to describe their understanding.

Of the 189 small farmers interviewed, 168 (88.9%) noted that they have heard of climate change or global warming. When asked what climate change means to them, 64

(38.1%) responded that climate change refers to a change in weather patterns. Sixty-seven (39.9%) specifically stated that climate change meant a change in rainfall or more heavy rainfall events while a similar number stated a change in temperature. A further 21 (12.5%) small farmers acknowledged that climate change meant more disasters, including drought and flooding while 20 (11.9%) referenced sea level rise or ice melting. Eleven (6.5%) small farmers responded that climate change has a negative effect on farming and livestock. Other responses by small farmers include heavy winds, increase humidity, greenhouse effect, pollution, and colder climate. Despite hearing about climate change, 18 (10.7%) small farmers did not know what it really meant. Table 6.1 summarizes small farmers' understanding of climate change.

Table 6.1 Meaning of Climate Change to Small Farmers

Meaning of Climate Change	No. of Farmers	%
Change in rainfall/ heavy rain	67	39.9
Change in temperature (hot and cold)	67	39.9
Weather pattern change	64	38.1
Disaster (including drought and flooding)	21	12.5
Sea level rise/ ice melting	20	11.9
No idea	18	10.7
Affects farming/ livestock	11	6.5
Other (heavy wind, greenhouse effect, pollution, etc.)	26	15.5

Although small farmers may not fully understand how the climate is changing, the majority had a good understanding of the changes in atmospheric conditions related to climate change. This is not surprising given that farmers have access to newspapers, radio, and/or television where national and international information and trends about climate change are frequently reported and/or discussed. The establishment of Guyana REDD+ Investment Fund (GRIF) in 2010 which supported Guyana's Low Carbon Development Strategy (LCDS), would have also caused information on climate change to be circulated in the local media.

It is also likely that district rice extension officers attached to the Guyana Rice Development Board (GRDB) have shared information with farmers regarding weather pattern changes in an effort to help them adapt. In short, small farmers' ability to identify specific environmental conditions attributed climate change was both affirming and expected given the likely multiple sources of information available in Guyana. The next several sections explore small farmers' and key informants' awareness, impacts, and responses to perceive changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds.

6.3 Changes in Rainfall

Changes in rainfall patterns may pose serious challenges for small farmers. As the main source of soil moisture, rainfall is probably the most important factor determining agricultural yields (Motha 2011). Thus, the frequency, intensity, timing, and duration of rainfall (Guan et al. 2015), may have direct impacts on yields, field conditions, irrigation systems, and transportation infrastructure. As such, responses were solicited from small farmers and key informants regarding their perceptions of changes in rainfall patterns. Specific changes in rainfall, the related impacts, and changes in farm management practices in response to observed changes are discussed below.

6.3.1 Perceptions of Changes in Rainfall

Changes in rainfall patterns were perceived by 182 (96.3%) small farmers and 28 (100.0%) key informants. When asked about specific changes observed[24], 106 (58.2%)

[24] This was an open-ended question; participants were not given a specific list of changes to choose from.

small farmers and 12 (42.9%) key informants reported an increase in total rainfall in and out of season. Additionally, 80 (44.0%) small farmers and 12 (42.9%) key informants observed an increase in out-of-season rainfall alone. However, only nine (4.9%) small farmers observed rainfall increased during the traditional rainy seasons.

In a related response, small farmers and key informants also observed that weather patterns had shifted. Specifically, 43 (23.6%) small farmers and 14 (50%) key informants reported that there are "no more seasons" due in part to extended rainy seasons. The distinction between the wet and dry seasons seems to have faded since rain starts early and ends late as reported by 19 (10.4%) small farmers and 13 (46.4%) key informants. One small farmer related, "we normally expect rain in May-June but now you don't get rain….rain is out of season as rainfall patterns have shifted….the total amount of rain you get is similar but out of season."

While increases in rainfall in and/or out of season were the most popular responses by small farmers, changes in rainfall intensity was the number one response by key informants. Twenty-three (82.1%) key informants and 56 (30.8%) small farmers reported an increase in rainfall intensity. An important consideration regarding changes in rainfall relates to its intensity. That is, the amount of rainfall over a specific time period. More rainfall over a shorter time span has greater intensity and usually spells disaster for rice farmers. This is because farmlands are below sea level and draft[25] relies on the change in tidal flow to facilitate the movement of excess water from inundated fields via drainage canals and eventually into a river and/or the Atlantic Ocean. Given that tides change every six hours, kokers [sluices] cannot be opened if intense rainfall occurs during high tide.

[25] Draining of the land via the trenches and canals.

Factoring in existing drainage capacity and a poorly maintained drainage infrastructure, more rainfall over a short period of time would easily overwhelm the current drainage system even during the low tide.

Small farmers and key informants also reported that unlike years past, rainfall has become more unpredictable. As evidence of the mercurial nature of rainfall patterns in recent years, 25 (13.7%) small farmers and eight (28.6%) key informants noted that it is difficult to predict the rain. In the words of one small farmer, “yo kyant predict de weather any mo” [you can’t predict the weather anymore] while another mentioned, “it is not that rain has stopped falling, it is you don't know when it will fall.” In other words, rain falls when it is least expected. This may explain why the analysis of precipitation patterns discussed in Chapter 4 shows little aggregate change, yet farmers are reporting consequential shifts - it is not the average precipitation that is shifting substantially, but rather the patterns of when and with what intensity.

Furthermore, 15 (8.2%) small farmers indicated that in recent years, rainfall fluctuated between seasons and/or years. That is, in some seasons and/or years, rainfall appeared to follow historical patterns while in other seasons and/or years it increased or decreased in and out of season. One small farmer noted, “Sometimes yo get mo rain in de small crop than de big crop.” In other words, rainfall during the spring crop (November – April) or short rainy season sometimes exceeds that of autumn crop [May-October] or long rainy season. This is a key observation in that historically, more rainfall occurred during the long rainy season (May-June). Rama Rao et al. (2012) found that rainfall variability was greater during the secondary rainy season [December-January] than the primary rainy season [May-July].

Excess rainfall (in comparison to the historical norm) was reported by 12 (6.6%) small farmers while another six (3.3%) mentioned that they had experienced flooding in recent years. It must be noted that excess rainfall, poorly maintained drainage, and the tidal flow collectively impact the magnitude of flooding. However, small farmers in some areas noted that even with well-maintained drainage, flooding still occurs because of the intensity of rainfall events. The sheer volume of water coupled with inadequate infrastructure to discharge excess water leads to an overflow of the waterways. As a result, there is no outlet for water in inundated rice fields to flow since often times the water in the field and in the nearby trenches and canals are at the same level.

While the majority of the respondents reported some degree of change in rainfall, 15 (8.2%) small farmers observed a decrease in rainfall while six (3.3%) reported a lack of rainfall due to drought. This is not surprising given that Guyana experienced drought as recent as 2015-2016 (NAPG, 2016). Other notable observations by small farmers and key informants include the existence of microclimates where rainfall patterns in one area differed from adjacent areas; the number of rainy days had increased; and there were cloudier/overcast conditions. Table 6.2 summarizes small farmers' and key informants' perception of changes in rainfall.

Table 6.2 Changes in Rainfall Reported by Small Farmers and Key Informants

Perceptions	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Rainfall increased (in and out of season)	106	58.2	1	12	42.9	4
Rainfall increased (out of season)	80	44.0	2	10	35.7	5
Rainfall intensity increased	56	30.8	3	23	81.2	1
No more seasons/ weather patterns shifted	43	23.6	4	14	50.0	2
Unpredictable rainfall	25	13.7	5	8	28.6	6
Early/late rainfall	19	10.4	6	13	46.4	3
Rainfall fluctuated between seasons	15	8.2	7	-	-	-
Less/no rainfall	15	8.2	8	-	-	-
Excess rainfall	12	6.6	9	1	3.6	7
Rainfall increased (in-season)	9	4.9	10	-	-	-
Drought (lack of rainfall)	6	3.3	11	-	-	-
Flooding	6	3.3	11	1	3.6	7
Other	4	2.2		5	17.9	

Although the responses between small farmers and key informants are not exactly alike, both groups have perceived similar changes in rainfall patterns. An important observation is the increase in rainfall intensity observed by both small farmers and key informants. It provides a different perspective on the changes in rainfall patterns not captured through the analysis of aggregated rainfall data presented in Chapter 4. In Chapter 4 it was reported that although there was some evidence that rainfall has changed, such evidence was not statistically significant.

However, the increase in rainfall intensity captured through farm-level and key informant interviews shed new light on the changes in rainfall patterns. Changes in the rate and timing of heavy downpours may be masked when looking at average annual rainfall. As such, it is plausible that despite the lack of statistical significance in the changes of average annual rainfall, changes in the intensity on an hourly, daily or weekly timeframe still pose a significant risk to small farmers. Hence, this finding underscored the importance of talking to small farmers and key informants since such details are usually lost in aggregated data analyzed in Chapter 4.

6.3.2 Perceived Impacts of Changes in Rainfall

Small farmers and key informants were also asked how the observed changes in rainfall affected the quality and quantity of rice yields. Among the 182 (96.3%) small farmers that observed changes in rainfall patterns, 37 (20.3%) specifically stated that yields decreased. In terms of specific impacts, both small farmers and key informants stated that changes in rainfall affected harvesting. Ideal conditions for harvesting call for dry dams [access roads] and fields. However, 89 (48.9%) small farmers and 24 (85.7%) key informants reported that poor dams, wet fields [during harvesting], and lodged plants [plants that fell down] hindered harvesting, thereby reducing the quality and quantity of yields. Rain leading up to and during harvesting leaves access dams in poor condition. This is because the dams are made primarily of mud, which makes traversing especially difficult for heavy-duty machinery such as tractors and combine harvesters. Even if some farmers are able to access their fields, the machinery often leaves large potholes in the aftermath, which makes access difficult for farmers that harvest their fields later in the season. Figure 6.1 illustrates the condition of an access dam in Region 6.

Figure 6.1 Poor condition of access dam
Photo credit: Author

Wet fields make it difficult for combine harvesters to maneuver seamlessly. This leads to combine operators (usually large farmers) often refusing to harvest parts of the field that are too wet for fear that the machine will become stuck in the mud. As a result, rice plants/grains in wet parts of the field are left un-harvested, thereby lowering the yields of small farmers. In addition to wet fields, out of season rainfall also causes the plants to lodge or fall down in the field. As rice grains mature and approach harvesting, the plants become drier and weaker. The weakened plant stacks absorb water more easily causing the plants to fall down. This makes it difficult for the combine harvester to collect the grains as it passes through parts of the field that contains fallen plants. Thus, lodged plants are left un-harvested thereby reducing the overall yields. Figure 6.2 illustrates harvesting under wet and dry field conditions.

Figure 6.2 Harvesting under wet (left) and dry (right) field conditions
Photo credit: Davindra Singh – District Rice Extension Officer

Restricted or delayed access to fields causes the rice grains to over ripen. Over ripen rice grains contain lower moisture content thus reducing the yield weight received by small farmers at the mills. Millers also penalize farmers in terms of the price they receive for paddy that are too dry. This is because the grains become brittle when it is too dry and as it passes through the various stages of milling results in broken or damaged grain that is less valuable. Even when small farmers are able to successfully harvest the rice in the fields, damaged dams can make it difficult to transport the harvested grains from the fields to the mills.

Poor farm to market roads makes access to fields and transport of yields more difficult and costlier. Farmers are forced to use grain carts which is an additional cost to bring the harvested yields out of the field. Grain carts limited capacity means that they are only used to collect and transport the grains from fields and empty into a larger capacity tractor-trailer which then transports the grains to the mill. As a result, farmers incur additional cost associated with renting a grain cart and the increase fuel required to make multiple trips to and from the field and for off-loading the grains. Figure 6.3 depicts harvesting and direct transport of grains from farm to market and a grain cart that is required to act as an intermediary between harvesting and final transport to the mill under poor farm to market road conditions.

Figure 6.3 Combine harvester and transport truck (left) and grain cart (right)
Photo credit: Author

In some cases, extremely poor farm-to-market roads force farmers to use boats to bring their yield out from the fields. This entails additional time and costs since the capacity of boats is typically much smaller than trucks or grain carts and requires more labor to load and off-load the boats. Access roads that are destroyed during harvesting also causes more difficulty in terms of access to the fields when sowing begins in the following season.

A total of 80 (44.0%) small farmers and 19 (67.9%) key informants reported that rainfall during the reproductive or flowering stage "beats-off" [knocks-off] the flowers and/or pollens of the plants. This results in lower pollination rates and at harvest, more "wind paddy". Wind paddy refers to a husk with little or no grain material inside

(Madramootoo 1974). From a physiological perspective, cloudy or overcast conditions during this stage may also cause the flowers to remain close further limiting pollination rates. Lower pollination rates result in more wind paddy or unfilled grains, hence lower yields.

Excess rainfall during sowing or early stages of growth also affects yields. A total of 58 (31.9%) small farmers and five (17.9%) key informants reported that excess rainfall led to flooding that negatively impacted seedlings and young rice plants. During the sowing stage, flooding causes some seedlings to float-off with the receding water. On the other hand, seedlings that remain submerged for an extended period eventually rot. Flooding also kills young rice plants that remain submerged for an extended period. One small farmer related, "Floods caused the young rice plants to melt [dissolve]." All three cases lead to a reduction in plant population in parts of the field. The end result is lower yields at harvest time.

The change in rainfall pattern also affected the timely application of fertilizer, herbicides, and pesticides as reported by 13 (7.1%) small farmers and 14 (50%) key informants. The inability to apply fertilizer at the prescribed time means that the plants are deprived of necessary nutrients needed for healthy growth. In cases where fertilizer was applied on time, sudden rainfall led to increase run-off thus depriving the plants of nutrients. On the other hand, the untimely control of weeds means increased competition for nutrients and space while delayed spraying for insects result in damaged plants and/or grains. In cases where small farmers were able to apply fertilizer and spray for weeds and insects on time, unexpected downpours wash away the fertilizer and chemicals thus leaving the plants malnourished and unprotected from insects and weeds. Consequently, the quality and quantity of rice yields decreased.

Land preparation was also reportedly affected by changes in rainfall patterns. As such, 12 (6.6%) small farmers and 13 (46.4%) key informants reported that the changes in rainfall patterns affected proper land preparation. Rainfall leading up to sowing prevents farmers from performing a dry plow as part of proper land preparation. Farmers that decide to wait in order to perform the dry plow usually end up planting out of season which causes them to harvest in the rain. As such, the land is usually prepared under wet conditions which is costlier in terms of fuel consumption by tractors. Regardless, land preparation under such conditions is considered less effective.

Given that rice fields are lightly flooded during wet land preparation, limited rainfall affects final land preparation which in turn impacts yields because the land is not properly irrigated prior to sowing. If the field is wet during harvesting, the combine harvester usually destroys the land by leaving deep ditches as it traverses the field. This makes leveling the land costlier and more difficult for the next season. Inability to properly level the land means that some parts of the field develop furrows resulting in uneven water distribution. Uneven water levels across the field makes it difficult for seedlings to grow through parts of the field that contain deeper water. As a result, plants grow sparsely in and around these troughs resulting in lower plant population and by extension, lower yields. Figure 6.4 illustrates an unleveled field, which resulted in uneven water distribution.

Figure 6.4 Unlevelled field resulting in uneven water distribution
Photo credit: Author

Despite the various impacts discussed above, 15 (8.2%) small farmers were unsure or noted that they were not affected. These farmers noted that their land is higher and thus the changes in rainfall did not really affect them because they were able to get the water out of the field. Other impacts of changes in rainfall patterns reported by small farmers and key informants include an increase in pests, diseases and weeds, lack of sunshine or more cloud cover, fertilizer run-off, grain discoloration due to wet grains at harvest, and early harvest to avoid the onset of rain led to green grains and poor quality. Table 6.3 summarizes the impact of changes in rainfall patterns reported by small farmers and key informants.

Table 6.3 Impacts of Changes in Rainfall Reported by Small Farmers and Key Informants

Impacts	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Affected harvesting (poor dams, wet field, plant lodges)	89	48.9	1	24	85.7	1
Knocked-off flower/pollen; lower pollination/ more unfilled grains	80	44.0	2	19	67.9	2
Flooded field/ affected seedling/ young plant	58	31.9	3	5	17.9	5
Reduced yields	37	20.3	4	-	-	-
Unsure/ no impact	15	8.2	5	-	-	-
Affected timely application of fertilizer and chemicals	13	7.1	6	14	50.0	3
Affected land preparation	12	6.6	7	13	46.4	4
Pests/ weeds increased	5	2.7	8	4	14.3	6
Lack of sunshine/more cloud cover	-	-	-	2	7.1	7
Fertilizer run-off	-	-	-	2	7.1	7
Other	14	7.7		5	17.9	

While the impacts of perceived changes in rainfall reported by both small farmers and key informants appear similar, a few notable differences exist in the responses reported. Impacts regarding timely application of fertilizer and chemicals were emphasized among key informants. Given their training, knowledge, and experience, key informants may have a better understanding of the importance of timely application of fertilizer and chemicals since applying fertilizer and chemicals outside of the prescribed windows may be ineffective and/or counter-productive to plant development. Key informants also see the impacts of untimely application of fertilizer and chemicals across different fields.

Impacts on land preparation were also highlighted by key informants as a major concern. The agronomic importance of good land preparation as it relates to water and weed management may also be better understood by key informants. Additionally, small farmers often rely on large farmers to prepare their lands. As a result, they may not be well informed regarding how changes in rainfall patterns affect land preparation. An important impact that was raised by key informants relates to fertilizer runoff due to flooding. Fertilizer run-off not only deprives plants of nutrients but also results in the pollution of waterways and the fertilization of weeds in these waterways. Again, small farmers may not be aware of these environmental impacts.

On the other hand, the flooding of young seedlings/plants was underscored by small farmers. Key informants may not view this as a very important impact since damages caused by flooding during the early stages can be overcome by farmers re-sowing their fields. However, the additional costs associated with re-sowing fields coupled with the risk of out of season harvesting are important considerations for small farmers. Despite these differences, it is apparent that both small farmers and key informants are observing similar impacts due to the perceived changes in rainfall.

6.3.3 Responses to Perceived Changes in Rainfall

Given the observed changes in rainfall patterns and the related impacts, small farmers and key informants were asked to describe any changes in farm management practices undertaken. Responses depended on the growth stage of the crop. Of the 182 (96.3%) small farmers that observed changes in rainfall patterns, 57 (31.3%) noted that they adjusted the planting dates based on water availability in the irrigation canals. In comparison, only two (7.1%) key informants noted that farmers adjust planting dates. Since rice is irrigated, the planting dates of farmers in most parts of the country depend on the release of water into the irrigation canals from major conservancies that store rainwater for agricultural use. The release of water is based on a time run system where each farming section receives water for a short period (e.g., two days) before water is made available to the next section. A culvert system is used to restrict the flow of water beyond the receiving section thus allowing water levels to build up so that farmers can open inlet pipes and allow gravity flow to flood their fields. This is also the reason why six (3.3%) small farmers and four (14.3%) key informants mentioned that planting is done in blocks within the season. That is, farmers in each section plant together based on water availability within the traditional sowing season of May-June and December-January.

Regardless of the existing water management system however, 24 (13.2%) small farmers and 13 (46.4%) key informants noted that planting was done early in each season. These farmers noted that they paid for water to be pumped into their fields instead of waiting on the release of water through the irrigation system. Early planting provides two benefits in response to changes in rainfall patterns. It helps ensure that rice plants reach a certain height by the time rainfall steps in. This gives plants a better chance of survival under inundated conditions. It also helps farmers avoid harvesting in the rain since early sowing would lead to early harvest. Figure 6.5 shows early sowing in region 2 - Pomeroon Supenaam in May 2018.

Figure 6.5 Early sowing in region 2 - Pomeroon Supenaam
Photo credit: Author

Despite the benefit of planting early, six (3.3%) small farmers and three (10.7%) key informants reported planting late because water was not available early and/or they were not able to pay for pumping. In response to excess rainfall that led to flooding, 14 (7.7%) small farmers reported that they maintained drainage often at their own expense and time and/or added more outlets to their fields to facilitate the faster draining of flood waters. This was supported by eight (28.6%) key informants. Similarly, 11 (6.0%) small farmers indicated that they opened existing outlets to drain their fields and/or waited for the water to recede. This practice was also mentioned by two (7.1%) key informants. Figure 6.6 shows a farmer cleaning a drainage canal of vegetation and an example of an outlet pipe that is used for draining fields.

Figure 6.6 A farmer cleaning a drainage canal (left) and drainage outlet pipe (right)
Photo credit: Author

Pumping out excess water from the field was reported by 11 (6.0%) small farmers and eight (28.6%) key informants. It is important to note that opening of outlets, maintaining drainage, and pumping-out water are only effective when the water level in the drainage canals is lower than that of the field. Furthermore, nine (4.9%) small farmers replanted parts of the field that were damaged because of flooding.

Fourteen (50.0%) key informants stated that farmers planted different varieties. In particular, they rotated varieties between seasons. For instance, farmers may plant a high yielding but lodge-prone variety (e.g., GRDB 10) in the spring crop because less rainfall is expected and a sturdier variety (e.g., GRDB 14) in the autumn crop when more rainfall is expected based on historical norms. However, only five (2.7%) small farmers reported planting different varieties between the seasons.

Six (21.4%) key informants noted that farmers are also preparing and/or maintaining farm-to-market roads to ensure easy access to their fields during sowing and harvesting. In order to counteract flooding due to excess rainfall, farmers also build-up the embankments around their fields as reported by four (14.3%) key informants. This helps to keep overflowing irrigation and drainage canals from inundating their fields while also allowing them to pump out water effectively.

While many small farmers reported making changes to their farming practices, 27 (14.8%) reported that they did nothing. As one small farmer opined, "what can we do? That's God's work." In other words, he was emphasizing that there is nothing farmers can do about excess rainfall especially when the crop is already planted. Other responses by farmers include leveling the land, partition of land to improve water management, increasing seed density, using stickers when spraying chemicals, spraying chemicals more frequently, applying more fertilizer, drying the field earlier, farmer-to-farmer extension, investing in equipment and pooling resources, using the Internet to check weather forecast, using a boat to access field, and monitoring the field closely. Table 6.4 presents the various responses to perceive changes in rainfall undertaken by farmers.

Table 6.4 Responses to Perceived Changes in Rainfall

Responses	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Adjusted planting date (based on water availability)	57	31.3	1	2	7.1	9
Did nothing	27	14.8	2	-	-	-
Planted early	24	13.2	3	13	46.4	2
Maintained drainage and added drains	14	7.7	4	8	28.6	3
Drained the field/ waited for water to recede	11	6.0	5	2	7.1	9
Pumped-out water	11	6.0	6	8	28.6	3
Re-planted field	9	4.9	7	1	3.6	11
Pumped-in water	8	4.4	8	-	-	-
Planted late	6	3.3	9	3	10.7	8
Planted in blocks	6	3.3	9	4	14.3	6
Planted different rice variety	5	2.7	11	14	50.0	1
Maintained access roads	-	-	-	6	21.4	5
Raised embankment/meres	-	-	-	4	14.3	6
Other	7	3.8		8	28.6	

Although similarities between the responses of small farmers and key informants are evident, there are notable differences. One possible explanation is that key informants are reporting on the responses by farmers in general and not small farmers specifically. For instance, the maintenance of farm-to-market roads, maintenance of drainage, raising of embankments, and pumping out of water are most likely undertaken by large farmers that own equipment and/or could afford to pay out of pocket. Due to economies of scale, the additional effort and/or costs is a worthwhile investment for these farmers. Regardless, small farmers still benefit since they also use the same farm-to-market roads and drainage canals.

Key informants also stressed the planting of different varieties as being a major response by farmers. However, this response appears to be less popular among small farmers. Small farmers may be more resistant to change. As a result, they may continue to plant older varieties that they know about regardless of advice received from district rice extension officers. Additionally, small farmers may have accepted the risk of planting older high yielding varieties even though such varieties may be more sensitive to climate change. Furthermore, unlike large farmers that own multiple plots, most small farmers have a single plot of land. Thus, they are not able to hedge against risk by planting different varieties on different plots, which prevents them from seeing first-hand the potential of other varieties under a changing climate.

Another observable difference is the emphasis on planting early reported by key informants. This may be more appropriate for farmers with their own equipment. Small farmers' ability to plant early depends on whether their land is prepared early. Given that most small farmers rely on large farmers for land preparation, it is very difficult for small farmers to plant early since large farmers prioritize their own land preparation. Even if small farmers are able to sow early, their harvest will be delayed if their neighbors' fields are not ready for harvest. This is because combine operators will not enter an area to harvest a single field. This delays the harvest which could have negative consequences on the quality and quantity of yields because of over-ripen grains.

It is also important to note that while some small farmers responded that they did nothing, this may not be an accurate reflection of farm-level behavior. Perhaps, small farmers may have viewed their actions as being routine and ongoing even as they do gradually shift practices overtime. Actions such as maintaining drains in and around the field, draining the field, and planting in blocks can be considered regular farm management practices. However, the intensification of such actions may be even more important under a changing climate.

6.4 Changes in Temperature

Changes in temperature may also impact small farmers' yields. Temperature affects the rate of plant development (Hatfield and Prueger 2015) with temperature tolerance also varying by development stage (R. Wassmann et al. 2009). As such, small farmers and key informants were asked whether they had observed any changes in temperature in the last five years. Specific changes in temperature, the related impacts, and changes in farm management practices in response to observed changes are discussed below.

6.4.1 Perceptions of Changes in Temperature

Changes in temperature were perceived by 170 (89.9%) small farmers and 27 (96.4%) key informants interviewed. When asked how temperature has changed[26], 167 (98.2%) small farmers and all key informants indicated that the days have become hotter or more heated [sic]. As one key informant recalled, "field work used to be quite pleasant. You can go out without an umbrella in the sun and you won't feel the heat or you won't feel your skin burning. But for the last five years, that has changed; it is not the same. You have to go with a hat, an umbrella, a long sleeve shirt. The kind of sweating [perspiration] you do now is far more that you use to do 10, 15 years ago."

[26] This was an open-ended question; participants were not given a specific list of changes to choose from.

While seven (4.1%) small farmers mentioned that there has been an increase humidity, 14 (51.9%) key informants revealed that the days in particular were more humid. Five (2.9%) small farmers indicated that the temperature has been hot and cold. That is, days have gotten hotter while some nights and early mornings have become colder. Another three (1.8%) small farmers indicated that the atmosphere has become breezier and colder. Other responses by small farmers include hot days followed by rainfall and more dew in the mornings.

In addition, 12 (44.4%) key informants indicated that the temperature was hotter during the day and parts of the night while five (18.5%) reported colder nights. Hot days and cold nights resulted in more morning dew as reported by eight (29.6%) respondents. According to one respondent, "dew in the morning creates ideal conditions for fungal diseases." Table 6.5 summarizes the observation of small farmers and key informants with regards to changes in temperature.

Table 6.5 Changes in Temperature Reported by Small Farmers and Key Informants

Perceptions	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Hotter/more heated	167	98.2	1	27	100.0	1
Higher humidity	7	4.1	2	14	51.9	2
Hot days and cold nights	5	2.9	3	-	-	-
Breezy and cold	3	1.8	4	-	-	-
Hotter days and partial nights	-	-	-	12	44.4	3
More dew	-	-	-	8	29.6	4
Cold nights	-	-	-	5	18.5	5
Other	6	3.5		-	-	

In Chapter 4, descriptive statistics, a linear trend model, and a two-sample t-test used to analyze gridded temperature data for Guyana all showed increases in both maximum and minimum temperature over the last 111 years. In particular, the trend appeared to be increasing in the last two decades. Small farmers' and key informants' observations of hotter or more heated days and nights are consistent with the results and trends presented in Chapter 4. In addition to hotter days and nights, higher temperatures also increase humidity since more water vapor is needed to achieve saturation in the atmosphere. Thus, the more humid conditions that were perceived by both small farmers and key informants would be expected.

General temperature trends aside, small farmers alluded to some days being hot and nights cold. Such observations may be attributed to sunny days followed by rain in the evening and/or throughout the night and early morning. More so, such conditions are most likely in areas further inland or where homes benefit from significant tree canopy. A few small farmers also perceived that some days are breezy and cold. Such conditions are usually perceived during rainy days which are sometimes accompanied by heavy winds. While both small farmers and key informants agreed that the days have been hotter, key informants reported that nights were also hotter. This occurs primarily in the dry months and is exacerbated by traditional building materials.

6.4.2 Perceived Impacts of Changes in Temperature

The perceived impacts of changes in temperature on the quality and quantity of yields was also solicited from both small farmers and key informants. Among small farmers, 62 (36.5%) reported that the increase in temperature resulted in their fields drying out faster. Fields drying out faster was confirmed by 21 (77.8%) key informants. Higher temperature during the day causes the water in the fields to evaporate at a faster rate. In uneven fields, high areas are the first to suffer from evaporation since the water levels are usually lower.

Regardless of faster evaporation of water, 39 (22.9%) small farmers and four (14.8%) key informants indicated that the change in temperature had no impact on yields. As one small farmer related, “as long as you get water to add back to the field, yields are not affected.” In fact, eight (4.7%) small farmers reported that they harvested higher yields under hotter conditions. In addition, seven (4.1%) small farmers and three (11.1%) key informants noted that the heat was better for rice plants. These respondents link higher temperature to more sunlight and less rainy and/or overcast conditions. They argue that more sunlight is better especially during the reproductive or flowering stage since it facilitates higher pollination rates and deters the arrival of insects and pests. This results in more filled grains and hence higher quality and quantity yields. Welch et al. (2010) found that higher maximum (minimum) temperature raised (reduced) rice yields.

The temperature-sunlight nexus also enhances harvesting conditions through the timely preparation of farm-to-market roads which allows for easier and timely access to fields and transport of yields to the mills. Thus, yields increase because harvesting is expedited thereby limiting opportunities for losses due to lodging of plants. Additionally, the temperature-sunlight link helps the fields to dry faster in preparation for harvesting. Dried fields ensure that the combine harvester can traverse the entire field thus harvesting the majority of the grains. Fields that are completely harvested due of ideal conditions produces higher yields.

Despite some farmers reporting favorable yields under higher temperature conditions, 20 (11.8%) small farmers and four (14.8%) key informants reported that yields decreased. In addition, the quality of grains under increasingly hot conditions were highlighted. Chalky[27] and unfilled grains were reported by six (3.5%) and five (2.9%) small farmers, respectively. In general, small farmers argued that the increase in temperature hastened the evaporation of water in the field. This lack of water slowed plant growth and as a result plants did not produce to their potential. The lack of adequate water during the grain filling stage produced chalkier and/or unfilled grains. According to Qiu et al. (2015), chalky grains are more prone to breakage during milling and thus reduces the amount of whole grains. As a result, the overall quality and quantity of yields are lower. In cases where water was available in the field, 16 (9.4%) small farmers noted that plant growth was negatively affected because the water became too hot. Hotter water in the field served as a form of heat stress on the plants.

Twenty-eight (16.5%) small farmers and 13 (48.1%) key informants reported that the increase in temperature contributed to more pest and/or diseases. Blast[28] and brown spot[29] were two diseases referenced. It is contended that hot days followed by cold nights created ideal conditions for funguses like blast and brown spot which diminish the quality and quantity of grains harvested. Even though the majority of small farmers reported one or more impacts, 18 (10.6%) did not know or had little idea of how the perceived changes in temperature affected yields.

Three (11.1%) key informants also perceived that the increase in daytime temperature made working in the field tougher. They asserted that farmers are not able to

[27] Grains that contain loosely packed starch granules with air spaces between them (Qiu et al. 2015).
[28] Blast is a fungal disease that attacks all stages of plant growth and all parts of the rice plant located above the ground (Cheaney and Jennings 1975).
[29] Brown spot is a fungal disease that attacks seedlings, leaves, and developing grains (Cheaney and Jennings 1975).

spend extended periods of time tending to their fields because of higher temperatures during the day. As such, farmers have to settle with visiting their fields for a few hours after dawn and a few hours before dusk each day. Similarly, the hotter climate affected the availability of field labor and the quality of work they performed since working in the sweltering heat is not an undertaking field labor are eager to perform. Other impacts observed by key informants include surfacing of salt in the land and lower weight of paddy grains. Table 6.6 presents the impacts of changes in temperature as reported by small farmers and key informants.

Table 6.6 Impacts of Changes in Temperature

Impacts	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Dried out water in field	62	36.5	1	21	77.8	1
No impact on yields	39	22.9	2	4	14.8	3
Pests and/or diseases increased	28	16.5	3	13	48.1	2
Reduced yields	20	11.8	4	4	14.8	3
Don't know/ no idea	18	10.6	5	-	-	-
Water in field hotter/ affected plant growth	16	9.4	6	-	-	-
Higher yields	8	4.7	7	-	-	-
Heat was better for rice plants	7	4.1	8	3	11.1	5
Chalky and damaged grains/ lower quality	6	3.5	9	-	-	-
Unfilled grains/ wind paddy	5	2.9	10	2	7.4	7
Killed plants	3	1.8	11	-	-	-
Makes working on the farm harder	-	-	-	3	11.1	5
Other	8	4.7		5	18.5	

The top four impacts of perceived changes in temperature reported by small farmers and key informants are similar; large proportions in both groups reported the water in the filed dried out, no impact on yields, pest and diseases increased, and reduced yields. However, differences in the responses between the two groups exist. Some small farmers may not know or understand how temperature increases are affecting rice yields. Assuming adequate water is available to replenish fields, the effects of heat stress may be minimal and/or go unnoticed. In addition, key informants made no reference to heat stress caused by water in the field becoming hotter. Assuming small farmers are able to add water to help cool the field and plants, this may not be as impactful as reported by some small farmers.

Although not highlighted by key informants, small farmers reported that higher temperatures are responsible for chalky and damaged grains. High temperatures have been found to impact grain yield and quality in rice (Shi et al. 2016; Nevame et al. 2018). It should be noted that the association of higher yields and increased temperature alluded to by small farmers is much more complex. While it is possible that temperature increase resulted in higher yields, this depends on the development stage of the plants; the heat tolerance of plants varies depending on the growth stage (Wahid et al. 2007). While the threshold temperature for grain yield in rice is approximately 34 degrees Celsius (Morita et al. 2004), Lanning et al. (2011) found that high temperatures during the grain filling stage can cause severe damage to grain quality.

6.4.3 Responses to Perceived Changes in Temperature

Data collected through the farm-level surveys suggest that small farmers' response to changes in temperature has been limited. Assuming water was available in the irrigation system, 92 (54.1%) small farmers responded by managing the water in the field. This entailed replenishing the water in the field primarily through mechanical pumping and/or keeping extra water in the field as a hedge against water loss due to evaporation. Fields that are low however are better placed to respond to increased temperature since water available in the irrigation system can be easily accessed. Adding additional water to the field was also confirmed by 22 (81.5%) key informants. Forty (23.5%) small farmers reportedly did nothing. The general sentiment among these farmers is that you cannot do anything about the heat. In the absence of a heat tolerant rice variety, there is very little farmers can do since low land rice requires adequate water supply all the way through the grain filling stage.

Interviews with key informants provided additional insights regarding responses to change in temperature. Hot days and cold nights create ideal conditions for fungal diseases. While only five (2.9%) small farmers reported spraying fungicide, eight (29.6%) key informants reported that farmers increase preventative spraying of fungicide to neutralize the threat of diseases like blast and brown spot. Furthermore, five (18.5%) key informants related that farmers are planting different rice varieties and using balance nutrition fertilizer. The use of short duration varieties ensures less water is needed while balance nutrition fertilizer provides plants with more nutrients so that they can fend off the threat of diseases. The risk of fields drying out faster also resulted in farmers monitoring their fields more frequently as reported by four (14.8%) key informants. Given that farmers do not usually reside in close proximity to their farms, increase field visits help ensure faster response to water loss in the fields.

Other responses by small farmers and key informants include lowering the seed rate, leveling the field, and using stickers[30]. A lower seed rate at sowing ensures that the plants in the field is less clustered thus allowing air to past through especially during hot days. The more aerated the field, the less likelihood of fungal diseases. Another response by farmers involved the leveling of their fields. A level field allows for better water management since farmers can maintain an even water level across the field at sowing.

[30] A sticking agent that helps synthetic chemicals to remain on the plants after application.

This prevents some areas of the field from drying out faster than others. Farmers are also using stickers to apply chemicals. Since hot days and cold nights result in more morning dew, the plants are usually covered with water in the morning. Thus, the use of stickers to apply insecticide and fungicide helps ensure greater effectiveness against insects and diseases. Table 6.7 summarizes farmers' response to changes in temperature.

Table 6.7 Responses to Perceived Changes in Temperature

Responses	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Added water to field	92	54.1	1	22	81.5	1
Did nothing	40	23.5	2	-	-	-
Increase preventative spraying	5	2.9	3	8	29.6	2
Planted different varieties	2	1.2	4	5	18.5	3
Balanced nutrition fertilizer	-	-	-	5	18.5	3
Increase monitoring of fields	-	-	-	4	14.8	5
Other	4	2.9		7	25.9	

For the most part, small farmers and key informants reported similar responses to perceived changes in temperatures. Depending on the soil type, location, and elevation of their fields, it is likely that some small farmers made no changes. Farms that contain pure clay soil holds water longer while those located close to the source of irrigation water and/or that are relatively low may not face difficulties in accessing water.

However, doing nothing may be exceptional since it is likely that all farmers are doing something even if it is increasing the otherwise routine work in and around their fields. This was evident in the responses from some key informants that farmers have increased monitoring of their fields. The routine nature of field visits may not seem important or worth mentioning by small farmers. In reality however, increased monitoring provides multiple benefits such as early detection with regards to water deficits and insect infestation.

Key informants also indicated that more farmers are using balanced nutrient fertilizer. While some small farmers may be using balanced fertilizer, this may be more prevalent among larger farmers considering the costs. For small farmers that barely make ends meet, the immediate costs of balanced fertilizer may not outweigh the benefits at harvest. Additionally, fertilizer credit provided by some millers may be too costly and oftentimes restricts small farmers from selling their grains elsewhere.

6.5 Changes in Extreme Weather Events

Extreme events are typified by precipitation, temperature, and/or wind speed phenomena above (or below) the upper (lower) observed threshold values of what is considered normal weather (IPCC 2012). In crop agriculture, such events can cause physical damage and affect the timing and conditions of field operations (Powell and Reinhard 2015). In Guyana, extreme weather events such as excess rainfall, flooding, drought, and wind storms, pose unique challenges for small farmers. As such, small farmers and key informants were asked to describe any observed changes in extreme weather events in the last five years. Specific changes in extreme weather events, the related impacts, and changes in farm management practices in response to the observed changes are discussed below.

6.5.1 Perceived Changes in Extreme Weather Events

Observed changes in extreme weather events were reported by 169 (89.4%) small farmers and 27 (96.4%) key informants. When asked to describe how extreme weather events have changed[31], 136 (80.5%) small farmers and 23 (85.2%) key informants noted that the occurrence of excess rainfall led to more flooding. In addition, 56 (33.1%) small farmers and 16 (59.3%) key informants reported an increase in heavy winds. Some small farmers observed that heavy winds either occurred independent of or in concert with heavy rainfall. While the agricultural belt along the Atlantic coast of Guyana normally experience a northeastern trade wind, it appears that the combination of rainfall and heavy winds have become more noticeable.

Moreover, 110 (65.1%) small farmers experienced a drought in the last five years. One small farmer stated, "meh had to pay people fa pump wata because ah drought and den when de drought done de rain tek off and duck out the whole place" [he paid for water to be pumped into his field because of drought only to experience flooding soon after]. In comparison, 20 (74.1%) key informants reported an increase in drought. Table 6.8 summarizes extreme weather events observed by small farmers and key informants.

Table 6.8 Changes in Extreme Weather Events Reported by Small Farmers and Key Informants

Perceptions	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Excess rainfall/ flooding	136	80.5	1	23	85.2	1
Drought	110	65.1	2	20	74.1	2
Heavy winds	56	33.1	3	16	59.3	3
Other (high temperature)	1	0.6		-	-	

As Table 6.8 suggests, the perceived changes in extreme weather events reported by small farmers and key informants are very similar. These observations are also supported by independent observations. For instance, in the last two decades Guyana has

[31] This was an open-ended question; participants were not given a specific list of changes to choose from.

experienced floods (2005, 2006, 2008, 2010, 2011, 2013, 2014, and 2015) and droughts (1997-1998, 2009-2010, and 2015-2016) (NAPG 2016). Therefore, there is little doubt that the observations by small farmers and key informants with regards to flooding and drought are not misplaced.

While greater emphasis is placed on reports of flooding and drought, heavy winds especially as it relates to agriculture in general and rice specifically is often overlooked and/or ignored. This is because heavy winds are not likely seen as a separate threat but as part of heavy downpours where flooding due to excess water is of greater concern. Heavy winds are often only acknowledged if there is a human toll and/or property damage. For example, in April 2018 a "freak storm" comprising of heavy winds and rainfall resulted in five injuries, and damage to four homes and power lines in region 2 (Seulall 2018). As such, the observation of heavy winds is a key finding of this research and its impacts will be explored in the next section.

6.5.2 Perceived Impacts of Changes in Extreme Weather Events

Given their observations, small farmers and key informants described the various impacts of extreme weather events on the quality and quantity of yields. Twenty-four (14.2%) small farmers specifically mentioned that extreme weather events as a whole led to lower yields. During the early growth stage, flooding hinders plant establishment and/or submerges young plants. However, farmers are able to re-sow the field albeit at an additional cost and at the risk of reaping outside the traditional harvesting window. Flooding during the later growth stages, however, is more detrimental especially after the maturation stage where grains are fully developed and curve towards the ground. During this stage flood waters make plants weak thus resulting in lodging. In parts of the field where lodging occurs, grains oftentimes go unharvested because it is difficult for a combine harvester to reach the plants especially if the field is wet.

As it relates to drought, the lack of adequate water diminishes grain filling potential which leads to less solid grains at harvest and overall lower weight at the mill. In extreme drought conditions, the lack of water in the irrigation or drainage canals mean that farmers are unable to pump water into their fields to save the crop. Regardless, seven (4.1%) small farmers reported that there was little or no impact on yields and five (3.0%) small farmers reported that they received better yields during drought. It is likely that these small farmers were located in areas close to the irrigation source and thus were able to access adequate water to pump into their fields despite experiencing drought.

In terms of specific impacts, 57 (33.7%) small farmers and seven (25.9%) key informants reported that excess rainfall and associated flooding that occurs during the early vegetative growth stage uproots and/or kills young submerged plants in lower parts of the field. In unleveled fields, lower parts are more affected by flooding since the water is deeper. Although some rice varieties are more water tolerant than others, younger plants cannot survive being waterlogged for an extended period of time (usually less than a week). As a result, farmers are often faced with the prospects of lower plant population or a thinning of plants in deeper sections of the field that remain submerged for extended periods. Flooding also delays sowing and tillering[32] which usually extends the growing period resulting in harvesting occurring out of season in wet conditions. In extreme cases, the entire field maybe loss because flood waters took longer to recede. Figure 6.7 illustrates

[32] Establishment of the vegetative branch of the rice plant composed of roots, culm, and leaves (GRDB 2009).

the aftermath of a field that was under water for several days which resulted in the entire field being loss.

Figure 6.7 A rice field after flood waters receded
Photo credit: Author

Thirty-four (20.1%) small farmers and eight (29.6%) key informants reported that during the grain filling (milk and dough) stages, the lack of water due to drought resulted in more unfilled and/or chalky grains. This is usually uncovered when paddy is taken to the mill for sale. At the mill, samples are taken to first determine the extent of dockage for unfilled grains and other contents that are not purely rice paddy. Thus, harvested fields that contain higher quantities of unfilled grains result in a higher percent being deducted which results in lower yields.

Twenty-two (13.0%) small farmers and 13 (48.1%) key informants stated that heavy winds caused rice plants to lodge in the field and depending on the cultivated variety results in re-germination. As noted above, lodge plants are difficult to harvest and are often left in the field thus reducing the quantity of grains harvested. Furthermore, some rice varieties tend to re-germinate on the plant if it becomes wet thus resulting in lower overall quality if such grains are included in the harvest. Figure 6.8 illustrates lodging caused by heavy winds.

Figure 6.8 Heavy winds caused lodging of rice plants
Photo credit: Author

Excess rainfall and related flooding also affected timely harvesting as mentioned by 13 (7.7%) small farmers. Favorable harvesting conditions necessitate dry grains and field. Any attempt to harvest under wet conditions has a direct impact of the amount of grains harvested since wet parts of the field are left unharvested. Additionally, wet grains contain more moisture and farmers are forced to engage in an additional step of drying the grains which increases the cost of production. As such, farmers prefer to allow the grains and field to dry before attempting to harvest. However, delay harvesting means that grains are not taken out at their optimal level of maturity which may also result in lower quality grains.

Apart from delaying the harvest, excess rainfall causes farm-to-market roads to deteriorate which makes timely access to the fields and transporting the harvest more difficult and costlier. As noted above, harvesting under wet conditions is less efficient since combine harvesters are usually unable to harvest all parts of the field. Combine owners/operators are also reluctant to traverse their machinery in parts of the field that is extremely wet for fear that the machinery will become stuck in the mud leading to damages and/or high repair and maintenance costs. Even if combine operators are willing to maneuver in wet fields, the mud unearthed by the tracks are inadvertently thrown on unharvested grains along the outside of the tracks. This result in these grains being loss.

Nine (5.3%) small farmers reported that drought and flooding resulted in crop failure or loss of part of field while four (2.4%) small farmers highlighted that excess rainfall and/or flooding affected the timely application of and effectiveness of fertilizer and pesticides. Other impacts reported by small farmers include lower pollination rates due to excess rainfall; seedlings float off with receding flood waters; more weeds entering the field because of overflowing irrigation and drainage canals during flooding.

Key informants provided additional insights regarding the impacts of extreme weather events. As such, five (18.5%) key informants disclosed that drought led to saltwater infiltration in the irrigation system. In some areas, the irrigation system flows directly into the Atlantic Ocean and thus is susceptible to saltwater entering the system which is exacerbated by the absence of freshwater due to drought. Other impacts reported include soil erosion due to flooding; increase insects and pests because of excess rainfall; and lower pollination rates because of excess rainfall. Table 6.9 presents the impacts reported by small farmers and key informants.

Table 6.9 Impacts of Changes in Extreme Weather Events

Impacts	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Submerged/ uprooted/ killed young plants - Excess rainfall/flooding	57	33.7	1	7	25.9	3
Stunted growth/ wind/chalky grains - Drought	34	20.1	2	8	29.6	2
Reduced yields	24	14.2	3	-	-	-
Lodged plants - Heavy winds/flooding	22	13.0	4	13	48.1	1
Affected harvesting - Excess rainfall/flooding	13	7.7	5	-	-	-
Crop failure/ Loss partial field - Drought and flooding	9	5.3	6	-	-	-
No/ slight impact on yields	7	4.1	7	-	-	-
Better yields - Drought	5	3.0	8	-	-	-
Affected fertilizer and pesticides application and effectiveness - Excess rainfall/flooding	4	2.4	9	-	-	-
Saltwater infiltration - Drought	-	-	-	5	18.5	4
Delayed sowing/ delayed tillering - Flooding	-	-	-	2	7.4	5
Other	6	3.6		4	14.8	

While the impacts of extreme weather events reported by small farmers and key informants are similar, there are some notable differences in the ranking and specific impacts. According to small farmers, the primary impact is the damage of young plants due to excess rainfall and associated flooding. However, key informants felt that lodging attributed to heavy winds and flooding are more noteworthy. This may be due to farmers' inability to effectively respond and/or recover once mature plants are lodged. As noted above, farmers at least have the option of re-sowing if damages occur in the early stages.

An important impact of extreme weather events is soil erosion. However, only one key informant reported this impact. A plausible explanation is that because farmers are increasing the use of fertilizer, the true impact of soil erosion may not be felt. Additionally, only key informants mentioned saltwater infiltration due to drought. In general, small farmers are aware of the risk of saltwater and in farming areas where there are greater risks, they often call upon the district rice extension officer to test the salinity level of the water in the irrigation canals before irrigating their fields.

6.5.3 Responses to Perceived Changes in Extreme Weather Events

Over the last five years, farmers engaged in several responses in relation to extreme weather events. Under drought conditions, 58 (34.3%) small farmers and 13 (48.1%) key informants reported that pumping water into the field was a major response. This is assuming water was available in the irrigation canals. It must be noted that farmers whose fields are located along the main irrigation canals and close to the source of the water are at an advantage during dry spells. This is because they have first access to pump the limited water available in the system. Farms located further down the line are less likely to benefit.

In response to flooding, 31 (18.3%) small farmers and ten (37.0%) key informants noted that excess water was pumped out of the field. Another response reported by 23 (13.6%) small farmers and five (18.5%) key informants is the creation of additional or clearing existing drainage to allow for the smooth flow of flood waters based on the tidal change. Farmers are also maintaining drainage through self-help or at their own expense. However, making drainage and pumping excess water out are only effective if the particular field is high and/or drainage system can accommodate the excess water.

Additionally, ten (5.3%) small farmers and three (11.1%) key informants noted that the replanting of fields and/or sowing more seeds is being done in response to flooding. Nine (5.3%) small farmers and four (14.8%) key informants reported that farmers just waited for the tide change to drain the field. In other instances, farmers are coordinating with the koker [sluice] attendants to ensure timely opening of the sluice doors to allow excess water to recede.

Despite the different adaptation responses, 43 (25.4%) small farmers and two (7.4%) key informants noted that nothing could be done about extreme weather events. In particular, these respondents disclosed that during the drought, there is no water to pump into the fields or only saltwater was available. With regards to flooding, pumping out water is difficult because everywhere was flooded and the drainage canals were overflowing. As such, there was nowhere for the water to retreat. Figure 6.9 illustrates a flooded rice field and overflowing drainage canal almost at the same water level.

Figure 6.9 Drainage canal (right) overflowing rice field (left)
Photo Credit: Davindra Singh – District Rice Extension Officer

Although small farmers maintained that there was nothing they could do about heavy winds, two (7.4%) key informants noted that some farmers are planting trees to serve as windbreakers to reduce the risk of plants lodging. While the planting of trees is a good idea in theory, the mere size and layout of farms would require significant investment in trees to be effective. As such, this response is likely to be impractical and/or prohibitively costly for small farmers.

Key informants also provided additional insights regarding adaptation to extreme weather events. Ten (37.0%) key informants noted that farmers planted different varieties and improved water management. Specifically, farmers plant short duration varieties to avoid harvesting in the rain or sturdier varieties that can withstand lodging caused by excess rainfall and heavy winds. In terms of water management, farmers are dividing their field into smaller plots to help ensure an even distribution of water across the field. This is also facilitated by leveling their lands during land preparation. They are also building up meres and embankments to help keep flood waters out.

Other responses to extreme weather events alluded to by small farmers and key informants include using boats to access fields because access roads were in a poor state; increase seed rate to compensate for losses due to flooding; abandoning the field; planting early to avoid bad weather; adding more outlets to drain inundated fields faster; and using balance nutrition fertilizer so that plants become sturdier to withstand flooding and lodging. Table 6.10 presents farmers' responses to extreme weather events.

Table 6.10 Responses to Perceived Changes in Extreme Weather Events

Responses	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Pumped water into field - Drought	58	34.3	1	13	48.1	1
Did nothing	43	25.4	2	2	7.4	8
Pumped water out of field - Flooding	31	18.3	3	10	37.0	2
Created/cleared drainage - Flooding	23	13.6	4	5	18.5	5
Replanted/ sowed more seeds - Flooding	10	5.9	5	3	11.1	7
Co-ordinate with sluice attendant/ waited on tide to drain - Flooding	9	5.3	6	4	14.8	6
Planted different variety – Flooding and heavy winds	-	-	-	10	37.0	2
Improved water management - Drought	-	-	-	10	37.0	2
Planted trees – Heavy winds	-	-	-	2	7.4	8
Other	14	8.3		8	29.6	

The responses to extreme weather reported by key informants mesh well with those reported by small farmers. However, two noticeable differences are evident. Key informants noted that farmers are planting different rice varieties to combat flooding and heavy winds. While small farmers have indicated planting different varieties, they may not view this as a direct response to flooding or heavy winds. From a small farmer's perspective, planting different varieties may be more in response to the promise of higher yields. Key informants also mentioned farmers are improving water management in response to drought. These farmers are likely to be large farmers with the resources and equipment to undertake water management. Unlike small farmers, large farmers often own pumps used for irrigation, and tractors and implements needed for leveling the field and building embankments and meres.

6.6 Changes in Insects and Pests

Climatic conditions play an important role in the distribution, development, and population dynamics of insects (Lamichhane et al. 2015). According to Walthall et al. (2012), higher temperatures and changes in rainfall patterns will alter environmental conditions that will affect insect population and distribution. Deutsch, Tewksbury, and Tigchelaar (2018) note that warming increases the population growth and metabolic rates of insects. As such, small farmers and key informants were asked whether they had observed any changes in insect and pest populations and impacts over the last five years. Specific changes, the related impacts, and changes in farm management practices in response to the observed changes are discussed below.

6.6.1 Perceived Changes in Insect and Pest Populations and Impacts

One hundred and eighty-five (97.9%) small farmers and all key informants interviewed indicated that early, mid, and/or late season pests have changed. Early season pests include the water weevil (*Helodytes foveolatus*), leaf miner (*Hydrellia sp.*), caterpillar

(*Spodoptera frugiperda*), and snail (*Pomacea sp.*) while mid-season pests include the caterpillar (*Spodoptera frugiperda*) and stem borer (*Rupela albinella*). The major late season pests are the paddy bug[33] (*Oebalus poecilus*) and plant hopper (*Tagosodes orizicolus*).

When asked to describe the insects and/or pests that have changed[34], 51 (27.6%) small farmers and ten (35.7%) key informants noted that water weevil increased while 12 (6.5%) small farmers and six (21.4%) key informants indicated an increase in root worm. The root worm is the larvae of the water weevil. Increases in snail was reported by 49 (26.5%) small farmers and 15 (53.6%) key informants while caterpillar increase was reported by 48 (25.9%) small farmers and nine (32.1%) key informants.

An increase in the leaf miner or heart worm was reported by 42 (22.7%) small farmers and nine (32.1%) key informants. It is interesting to note that 20 (10.8%) small farmers and five (17.9%) key informants reported seeing slugs in their fields for the first time in the last five years. Key informants noted that the appearance of slugs is relatively new, and much is not yet known about this pest. Increases in the stem borer moth was reported by 15 (8.1%) small farmers and four (14.3%) key informants.

The major rice pest in Guyana is the paddy bug. As such, 181 (97.8%) small farmers and 23 (82.1%) key informants noted increase presence of paddy bugs rice fields. One small farmer bellowed, “in meh whole life of 61 years, I neva see paddy bugs like dis …paddy bug increased 1,000 fold” [in his entire life he had never observed so many paddy bugs like he did in the 2018 spring season]. However, three (10.7%) key informants noted

33 Also referred to as bush bug, gandhi, or stink bug.
34 This was an open-ended question; participants were not given a specific list of changes to choose from.

that paddy bug infestation fluctuates from season to season depending on the prevailing climatic conditions.

Small farmers also stated that flies, some of which they could not identify are appearing for the first time in their fields. Other pests reported by small farmers and key informants include birds, wild ducks, grasshoppers, rats, plant hopper, and beetles. According to small farmers, these insects and pests are becoming more common in their rice field than ever before. Figure 6.10 illustrates the major pests observed by farmers. Despite an overwhelming majority of small farmers indicating that insects and pests have increased, five (2.6%) small farmers and two (7.1%) key informants reported a decrease in insects and pests. It is contended that increase chemical control of pests over the years have resulted is less pests being observed.

Figure 6.10 Paddy bug (top left), snail (top right), adult water weevil (center left), water weevil larvae (center right), caterpillar (bottom left) and leaf miner (bottom right)
Source: Rice Farmer's Manual (GRDB 2009)

Apart from the insects and pests noted above, according to one key informant, two new pests have shown up in rice fields in Guyana. In the last two seasons, the brown planthopper (*Nilaparvata lugens*) was observed in rice fields where there was 80 and in one case 90 percent damage recorded. The other pest is the rice leaffolder (*Cnaphalocrocis medinalis*) which was previously never recorded in Guyana. Figure 6.11 depicts the brown planthopper and rice leaffolder. Table 6.11 summarizes the changes in insects and pests reported by small farmers and key informants.

Figure 6.11 Brown planthopper (left) and leaffolder (right)
Source: International Rice Research Institute (IRRI)

Table 6.11 Changes in Insects and Pests Reported by Small Farmers and Key Informants

Perceptions	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Paddy bug increased	181	97.8	1	23	82.1	1
Water weevil increased	51	27.6	2	10	35.7	3
Snail increased	49	26.5	3	15	53.6	2
Caterpillar increased	48	25.9	4	9	32.1	4
Leaf miner/ heart worm increased	42	22.7	5	9	32.1	4
Slug increased	20	10.8	6	5	17.9	8
Flies increased	16	8.6	7	-	-	-
Stem borer moth increased	15	8.1	8	4	14.3	9
Root worm increased	12	6.5	9	6	21.4	6
Insects and pests decreased	5	2.7	10	2	7.1	11
Grasshopper increased	-	-	-	6	21.4	6
Paddy bug fluctuated	-	-	-	3	10.7	10
Birds and wild ducks increased	-	-	-	2	7.1	11
Rat/ rodent increased	-	-	-	2	7.1	11
Other insects/pests increased	14	7.6		7	25.0	

Changes in insect and pest populations observed by small farmers and key informants are similar. However, an important observation by a few key informants is that paddy bug infestations are correlated with changes in rainfall patterns. They asserted that in seasons and/or years with heavy rainfall, paddy bug infestation is more severe. One possible explanation is that wetter conditions disturb paddy bugs' natural habitat and/or food supply which leads to the invasion of rice fields.

While changes in weather patterns may be indirectly responsible for the observed changes in insects and pests, consideration should also be given to a few other factors. The cultivation of uncertified rice varieties originating from neighboring Brazil and Suriname may also be playing a role in the spread of insects and pests. Guyana's porous national borders are conducive to smuggling, which has facilitated the introduction of uncertified varieties into the rice sector; insects and diseases may be accompanying these foreign varieties.

The increased use of insecticides and pesticides may also be playing a role in the proliferation of some insects and pests. Continuous and intensive use of chemicals may lead to some insects becoming immune to synthetic control. As a result, the use chemicals may have become less effective in controlling insects in recent years. Additionally, the increased use of chemicals may also be harming beneficial insects. Thus, natural control of harmful insects may have been weakened.

An increase in weeds may also be contributing to the proliferation of insects and pests. Serving as temporary hosts, it is plausible that weeds may have helped sustain insects and pests until the rice plants approaches the graining filling stage. Given the observations of small farmers and key informants, climate change alone may not be responsible for the changes in insects and pests. It is likely that a combination of these factors may have also played an important role.

6.6.2 Perceived Impacts of Changes in Insects and Pests

Small farmers and key informants were also asked to describe how the observed changes in insects and pests affected the quality and quantity of yields harvested. Eighty-seven (47.1%) small farmers noted that the increase in insects and pests led to lower yields. In terms of specific impacts, 116 (62.7%) small farmers and 22 (78.6%) key informants stated that the increase in paddy bug infestations resulted in damaged grains which reduced the quality and quantity of grains harvested. During the milk[35] and dough[36] stages of plant growth, paddy bugs suck the sap from the developing grains which results in malformation

[35] The stage in grain development when the grains yield a milk-white substance (Madramootoo 1974).
[36] The stage in grain development when crushed grains yield a white, floury substance (Madramootoo 1974).

and discoloration of the grains. In severe cases there are more wind or unfilled grains as reported by 18 (9.7%) small farmers. The damages caused by paddy bugs result in lower yields, reduce quality, and brittleness that lead to increased breakage during milling (GRDB, 2009).

According to 17 (9.2%) small farmers and 13 (46.4%) key informants, the increase in snail and water weevil resulted in damage seedlings and/or young plants. The adult water weevil feeds on the radicle[37] of the sprouting seeds and on the leaves of young plants while the root worm (water weevil larvae) feeds on the young roots and root tips (Madramootoo 1974). Snails feed on young and emerging rice plants thus affecting plant establishment in the field (GRDB, 2009). According to one key informant, snails, water weevil and root worm "reduces plant population per square foot." Lower plant population across the field leads to lower yields at harvest.

Eleven (5.9%) small farmers and nine (32.1%) key informants alluded to the damages caused by caterpillar and slugs. While caterpillars consume plant leaves, slugs strip the leaves of chlorophyll which reduces the plants ability to generate food through photosynthesis. The inability to generate food slows the growth of the plants and in some cases causes the plants to die. Ten (5.4%) small farmers and four (14.3%) key informants reported that the increase in leaf miner affected plant growth and in severe cases, killed the plants. Leaf miners burrow into leaves and feed on the plant tissues (Madramootoo 1974). This affects the establishment of tillers[38] which causes stunted growth and in severe cases, delays panicle[39] initiation. The overall impact is lower yields and uneven plant growth

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[37] Embryotic root of the plant.

[38] Secondary shoots that surround the main stem (Madramootoo 1974).

[39] The terminal shoot of the rice plant that produces the grain (GRDB 2009).

across the field. Uneven plant growth also contribute to lower quality as some grains will mature later which results in increase green grains in the harvest.

Five (17.9%) key informants also pointed out that root worm feeds on the roots while four (14.3%) noted that the increase in stem borer damaged the plant stems. By tunneling into the plant stems, stem borers restrict the passage of nutrients to the grains. Key informants also described the impacts of other pests. At sowing, birds and wild ducks consume exposed seedlings while birds shell the paddy grains closer to harvesting. Rats damage the plants and feed on the grains. Table 6.12 presents the various impacts caused by changes in insects and pests.

Table 6.12 Impacts of Changes in Insects and Pests

Impacts	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Damaged grains - Paddy bug	116	62.7	1	22	78.6	1
Reduced yields	87	47.0	2	-	-	-
Unfilled grains/ wind paddy - Paddy bug	18	9.7	3	-	-	-
Damaged seedlings/ young plants - Snail and water weevil	17	9.2	4	13	46.4	2
Consumed plant leaves/ reduced photosynthesis - Caterpillar and Slug	11	5.9	5	9	32.1	3
Affected plant growth/ killed plants – Leafminer	10	5.4	6	4	14.3	5
Damaged plant roots - Root worm	-	-	-	5	17.9	4
Damaged the stem – Stem borer	-	-	-	4	14.3	5
Other	9	4.9		5	17.9	

While similarities between the responses of small farmers and key informants are evident, two notable exceptions are noted. Specifically, key informants made no reference to reduced yields. The failure to control insects and pests in a timely manner may have led to reduced yields among small farmers. However, the extent of the losses may not be serious enough to warrant the attention of key informants. In addition, key informants made no mention of unfilled grains due to paddy bug. It is likely that these farmers may have detected the infestation problem late and as a result the damage was already done.

6.6.3 Responses to Perceived Changes in Insects and Pests

The use of synthetic chemicals was the primary mechanism reported by small farmers in response to the observed changes in insects and pests. As such, 168 (90.8%) small farmers and 21 (75%) key informants noted that in recent years there have been an increase in preventative spraying to address the increase in insects and pests population and prevalence. As one small farmer relates, "before, I use to spray two or three times each season, now I am spraying five or six times and sometimes more depending on the infestation of paddy bugs." Another small farmer declared "if you don't spray, you get nothing" [he has to spray for paddy bugs, otherwise there is no grains to harvest].

The use of different chemicals and rotation of chemicals were also reported by seven (3.8%) small farmers and eight (28.6%) key informants. Farmers rotate chemicals in order to prevent insects and pests from becoming immune to a particular insecticide or pesticide. They are not only rotating among different brands of chemicals but also between systemic and contact treatment approaches. Systemic chemicals attack the different development stages while contact chemicals only affects individual insects and pests that come into contact. Figure 6.12 illustrates farmers checking and spraying for paddy bugs, respectively.


Figure 6.12 Farmer sweeping (left) and spraying for paddy bugs (right)
Photo credit: Author

Twenty-two (11.9%) small farmers and 18 (64.3%) key informants noted that farmers engage in seed treatment while five (2.7%) small farmers and 11 (39.3%) key informants stated that farmers are treating the water in the field. Seed treatment protects against early season pests such as snails and water weevil. However, since seed treatment is usually done at home, some farmers prefer treating the water in the field because it is safer in terms of preventing their livestock from accidentally consuming chemically treated seeds. Key informants noted that if farmers treat seeds, there is no need to also treat the water. Regardless, more conservative farmers engage in both seed and water treatment.

Four (2.2%) small farmers reported that they dried the field to expose root worms to the elements. This practice was confirmed by three (10.7%) key informants. In response to early season insects and/or pests that went undetected and caused extensive damage, farmers usually re-sow the field or transplant plants from other parts of the field. This was reported by two (1.1%) small farmers and three (10.7%) key informants.

While only three (1.6%) small farmers reported engaging in better sanitation of their field and its surroundings, 16 (57.1%) key informants noted farmers are engaging in this practice. Sanitation involves removing the host plants (e.g., wild rice) of insects and pests from the field and spraying the weeds and bushes that grow on the meres, dams, and embankments that surrounds their respective plots. Figure 6.13 depicts weeds on an embankment of a rice field that was sanitized with a contact chemical.

Figure 6.13 Weeds on the embankment of a rice field sanitized
Photo credit: Author

Key informants also offered two additional insights into farmers' behavior. Seven (25.0%) key informants noted that farmers are engaging in block sowing and spraying in order to effectively address paddy bug infestation. Block sowing entails farmers in a specific farming section planting together so that all the fields are at a similar growth stage. This makes controlling for paddy bugs more effective in that all the farmers in a particular block would also apply insecticide at the same time. The uniform application of pesticide across the block reduces the risk of paddy bugs swapping between neighboring fields to take refuge.

Five (17.9%) key informants also noted that farmers are monitoring their fields more closely, especially during grain formation (milk and dough stage). Early detection of insects and pests in the field allows farmers to respond sooner in that failure to do so may result in the entire field being loss in a matter of days. Only one small farmer reported increase monitoring of his field.

Other responses by farmers reported by key informants include mechanized spraying and reduce walking distance while applying chemicals to ensure better coverage; use of scarecrows and air guns to keep birds and wild ducks away; and applying chemicals early in the morning and late in the afternoon when insects and pests are more active. Farmers are also engaging in some cultural practices such as burning tires, boiling and spraying neem leaves[40], and planting neem trees around the fields. In addition, farmers are doing more research and learning about the beneficial insects in an effort to tackle insects and pests more effectively and efficiently. Table 6.13 presents responses to changes in insects and pests as reported by small farmers and key informants.

Table 6.13 Responses to Perceived Changes in Insects and Pests

Responses	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Preventative spraying/ sprayed more	168	90.8	1	21	75.0	1
Treated seeds	22	11.9	2	18	64.3	2
Rotate/ use different chemicals (contact and systemic)	7	3.8	3	8	28.6	5
Treated water in field	5	2.7	4	11	39.3	4
Drain field/ fresh water	4	2.2	5	3	10.7	8
Remove host plants/ sanitize field; surroundings (meres, dams, embankments, etc.)	3	1.6	6	16	57.1	3
Re-sow/ transplant from other fields	2	1.1	7	3	10.7	8
Block sowing/ spraying	-	-	-	7	25.0	6
Increase monitoring	1	0.5	8	5	17.9	7
Other	2	1.1		11	39.3	

[40] The neem tree's (*Azadirachta indica*) bitter leaves and bark is used as an insect repellant.

Farmers are engaging in a myriad of adaptation practices in reaction to perceived changes in insects and pests. Preventative spraying and seed treatment were the most popular adaptation responses reported by small farmers and key informants. While preventative spraying of chemicals and seed treatment may be effective, they also pose a serious threat to the environment. In addition to killing insects and pests, synthetic chemicals contaminate soil, water, turf, and other vegetation (Aktar, Sengupta, and Chowdhury 2009). As such, other non-targeted organisms such as birds, fish, and beneficial insects are harmed, resulting in loss of biodiversity.

It is interesting to note that key informants highlighted that improved sanitation in and around the field is a major response to insects and pests. It is likely that this practice is very popular among small farmers. However, the routine nature of this practice may have caused small farmers to downplay its importance. Similarly, block sowing and increased monitoring reported by key informants may be so common among small farmers that they did not bother to mention.

6.7 Changes in Diseases

Increased concentrations of CO_2 in the atmosphere coupled with changes in temperature and rainfall patterns are predicted to have a direct impact on the incidence and severity of diseases in agricultural crops (Gautam, Bhardwaj, and Kumar 2013). As such, small farmers and key informants were asked to describe any noticeable changes in diseases affecting their fields. Specific changes in diseases, the related impacts, and changes in farm management practices in response to the observed changes are discussed below.

6.7.1 Perceived Changes in Diseases

Seventy-three (38.6%) small farmers and 23 (82.1%) key informants observed changes in diseases. When asked how diseases have changed[41], 34 (46.6%) small farmers reported an increase in brown spot (*Cochilobolus miyabeans*). In comparison, 22 (95.7%) key informants reported an increase in brown spot. Key informants may have a better idea of this shift as they see many fields. Also, the difference in observation may be due to small farmers referring to brown spot as leaf blast and thus reported observe changes in brown spot as a form of blast.

Twenty-eight (28.8%) small farmers highlighted an increase in blast (*Pyricularia grisea*). However, only four (17.4%) key informants highlighted an increase in blast associated with older rice varieties such as the Rustic and 22-4. Despite the newer varieties of rice being blast resistant, some farmers continue to plant the older varieties that are susceptible to blast. In some districts, farmers continue to plant older varieties that are not blast resistant because they are reluctant to change and/or because some millers still request the older varieties. Withstanding this observation, 12 (16.4%) small farmers related that blast has decreased. Figure 6.14 illustrates brown spot and blast, respectively.

[41] This was an open-ended question; participants were not given a specific list of changes to choose from.

Figure 6.14 Brown spot (left) and blast disease (right)
Source: International Rice Research Institute (IRRI) and Rice Farmer's Manual (GRDB 2009)

Thirteen (17.8%) small farmers also reported an increase in brown or red tip. However, this observation may actually be attributed to iron toxicity rather than disease. Iron toxicity occurs in acidic, flooded soils with a pH general below 5.5 (Cheaney and Jennings 1975). Only three (4.1%) small farmers noticed an increase in sheath blight (*Rhizoctonia solani*) and sheath rot (*Sarocladium oryzae*). In comparison, 14 (60.9%) and 11 (47.8) key informants noticed an increase in sheath blight and sheath rot, respectively. Sheath blight and sheath rot are fungal diseases that causes lesions on the lower and uppermost leaf sheaths, respectively (GRDB 2009). Figure 6.15 depicts sheath blight and sheath rot.

Figure 6.15 Sheath blight (left) and sheath rot (right)
Source: International Rice Research Institute (IRRI)

Interestingly, five (21.7%) key informants highlighted an increase in false smut which was not mentioned by small farmers perhaps because this disease does not pose a major threat to their yields at present. Other observations by small farmers and key informants include an increase in black tip on the grains and kernel smut. Table 6.14 presents changes in diseases seen by small farmers and key informants.

Table 6.14 Changes in Diseases Reported by Small Farmers and Key Informants

Perceptions	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Brown spot increased	34	46.6	1	22	95.7	1
Blast increased	21	28.8	2	4	17.4	5
Brown/ red tip increased	13	17.8	3	-	-	-
Blast decreased	12	16.4	4	-	-	-
Sheath blight increased	3	4.1	5	14	60.9	2
Sheath rot increased	3	4.1	5	11	47.8	3
False smut	-	-	-	5	21.7	4
Other	4	5.5		3	13.0	

Although small farmers and key informants appear to perceive changes in diseases similarly, observations by key informants as it relates to sheath blight and sheath rot are different. Contextualizing the perceived increase in sheath blight and sheath rot, one key informant hypothesized that the appearance of these funguses may be linked to the predominant cultivation of blast resistant varieties by farmers. The cultivation of blast resistant varieties eases the application of fungicide. However, the same fungicide that treats blast may also control other fungal diseases like sheath blight and sheath rot.

6.7.2 Impacts of Perceived Changes in Diseases

To understand how grain quality and quantity were affected by the observe changes in diseases, both small farmers and key informants were asked to describe the various impacts observed. Diseases usually restrict the flow of nutrients and water to the grains and if untreated it is likely to kill the plants as reported by 11 (15.1%) small farmers and six (26.1%) key informants.

In terms of specific impacts, 35 (47.9%) small farmers and four (17.4%) key informants reported that the observed changes in diseases affected plant growth either through damaging the plants and/or stunting the growth. In particular, sheath blight reduces yields by restricting the uptake of nutrients thus leading to stunted growth while sheath rot deforms the panicle. This delays the maturity of the plants and/or diminished the yield potential.

The restriction on nutrient uptake also contributed to the quality and quantity of yields. Eleven (15.1%) small farmers and nine (39.1%) key informants noted that there were more wind paddy or unfilled grains while poor grain quality or damaged grains were reported by seven (9.6%) small farmers and seven (30.4%) key informants.

Although not mentioned specifically by small farmers, 14 (60.9%) key informants pointed out that the increase in brown spot, in particular, reduced the plants ability to effectively manufacture food through photosynthesis. Since plants depends on its leaves to manufacture food, damaged chlorophyll caused by brown spot impedes the plants ability to absorb energy from sunlight. Six (8.2%) small farmers noted that they were not sure or did not know how the change in diseases affected their yields while another three (4.1%) small farmers claimed that yields had increase due to the reduction in blast. Table 6.15 summaries the impacts reported by small farmers and key informants.

Table 6.15 Impacts of Changes in Diseases

Impacts	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Damaged plant/ stunted growth	35	47.9	1	4	17.4	5
Wind paddy/ sterile grains	11	15.1	2	9	39.1	2
Reduce plant population/ rot plants	11	15.1	2	6	26.1	4
Poor grain quality/ damage grains	7	9.6	4	7	30.4	3
Not sure/ don't know	6	8.2	5	-	-	-
Yields increased	3	4.1	6	-	-	-
Reduce food manufacture through photosynthesis	-	-	-	14	60.9	1
Deform panicle	-	-	-	3	13	6

While the impacts of perceived changes in diseases reported by both small farmers and key informants are similar, two responses by key informants standout. Reference to the role of photosynthesis in the manufacture of plant food and deformation of the panicle should come as no surprise given the agricultural education and experience of the majority of key informants. Although some farmers may understand these impacts, articulating them may have been difficult at the time of interview.

6.7.3 Responses to Perceived Changes in Diseases

Given the observed changes and related impacts reported, farmers reportedly engaged in several adaptation practices. To mitigate the impact of diseases, 49 (67.1%) small farmers and 21 (91.3%) key informants reported preventative spraying of fungicide and/or rotating chemicals as the major response. That is, farmers are spraying multiple times for fungus regardless of whether they exist in the fields. They are also rotating among different chemicals. Although, some farmers planted blast disease resistant varieties, they still apply fungicide as a precaution. As one small farmer noted, "prevention is better than cure."

Four (5.5%) small farmers and 11 (47.8%) key informants reported increased use of balance nutrition fertilizer and/or less nitrogen-based fertilizer. It is argued that balance nutrition fertilizer and less nitrogen-based fertilizer enable the plants to become healthier in order to fend off the threat of diseases. According to one key informant, nitrogen-based fertilizer weakens the plants making them more susceptible to diseases.

Eight (11.0%) small farmers interviewed did nothing and/or accepted the losses. Considering the cost of purchasing fungicides and labor to spray the field, these farmers may have felt it is not worth the cost especially if the disease was already widespread and/or detected late. Other responses by small farmers included drying the field, using a blast resistant variety, and burning the forage left behind in the field after harvest. By burning the forage, any pathogens that is still lingering is destroyed before the start of land preparation for the next season.

Interviews with key informants provided additional insights regarding farmers' adaptation to changes in diseases. Farmers are also reducing the seed rate as highlighted by 14 (60.9%) key informants. From a disease mitigation perspective, less plants per square foot enhances the uptake of nutrients, water and sunlight making plants healthier and more resistant to diseases. It also enhances air flow through the field which disrupts ideal conditions for diseases to develop and spread. Farmers are also planting blast resistant varieties as indicated by five (21.7%) key informants. However, blast resistant varieties are still susceptible to other diseases such as brown spot, sheath blight, and sheath rot.

Additionally, farmers are improving sanitation in and around their fields as mentioned by four (17.4%) key informants. By removing host plants such as wild rice from within the field and clearing meres and embankments of weeds and bushes, farmers are disrupting the environment that is conducive to diseases. Other responses by farmers reported by key informants include reducing water level in the field; dry land preparation; sow better quality seeds; and burning forage after harvesting. Table 6.16 presents farmers' responses to observed changes in diseases as reported by small farmers and key informants.

Table 6.16 Responses to Perceived Changes in Diseases

Responses	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Preventative spraying of fungicide / rotate chemicals	49	67.1	1	21	91.3	1
Did nothing/ accepted loss	8	11.0	2	-	-	-
Applied balance nutrition fertilizer/ reduce urea	4	5.5	3	11	47.8	3
Reduce seed rate	-	-	-	14	60.9	2
Plant different varieties	-	-	-	5	21.7	4
Improved sanitation of field	-	-	-	4	17.4	5
Other	6	8.2		8	34.8	

Preventative spraying of fungicide and the application of balanced nutrient fertilizer were the most popular answers by both small farmers and key informants. However, key informants offered three additional responses that warrant a closer examination. Historically, farmers have sown more seeds. However, one of the six improved management practices introduced by the Guyana Rice Development Board (GRDB) calls for farmers to sow less seeds. Small farmers specifically may be less inclined to reduce seed rate because of the belief that more is better. In other words, they may be trying to maximize yields by sowing more seeds with the expectation that more plants will result in more grains. In addition, the elevation of fields may warrant sowing more seeds; fields that are low are more susceptible to flooding which causes some seedlings to float away once flood waters recede. As such, sowing more seeds may help to mitigate potential losses arising from the risk of flooding.

While planting different varieties may help stem the proliferation and spread of diseases, emphasis on maximizing yields may influence small farmers' decisions on what variety to plant. Small farmers are more likely to continuously plant a high yielding variety (e.g. GRDB 10) instead of shifting to varieties that limit the occurrence and spread of diseases but yield less grains. Additionally, small farmers do not have the means to diversify. Unlike large farmers with multiple plots, which allows for the diversification of risk through lower seed rates and planting different varieties, most small farmers have a single plot. It is also possible that small farmers did not mention planting different varieties because they do not consider planting different varieties as a means of responding to the threat of diseases. It is also likely that small farmers did not mention improved sanitation of fields since this may be seen as routine ongoing work.

6.8 Changes in Weeds

Changes in atmospheric CO_2, temperature, and rainfall also impact the spatial and temporal distribution and proliferation of weeds (Rosenzweig et al. 2001; Peters, Breitsameter, and Gerowitt 2014). Their genetic diversity and physiological plasticity allows weeds to respond and adapt quickly to environmental changes (Varanasi, Prasad, and Jugulam 2016). According to Rosenzweig et al. (2001), humid conditions increase the proliferation of weeds which compete with crops for soil nutrients, light, and space. As a result, the quality and quantity of crop agricultural yields may also be affected leading to economic loss. As such, small farmers and key informants were asked whether they had observed any changes in weeds in the last five years. Specific changes in weeds, the related impacts, and changes in farm management practices in response to the observed changes are discussed below.

6.8.1 Perceived Changes in Weeds

Of the 189 small farmers interviewed, 168 (88.9%) observed changes in grass, sedge, and broadleaf weeds present in their rice fields. Similarly, 25 (89.3%) key informants acknowledged that weeds found in rice fields have changed. In Guyana, grasses include schoonord (*Echinochloa sp.*), muraina [42] (*Ischaemum rugosum*), birdseed (*Echinochloa colonum*), and monkeytail (*Echinochloa crus-galli*); sedges include jhussia[43] (*Fimbristylis miliacea*), and water sedge (*Cyperus difformis*); and broadleaf weeds include soapbush (*Sphenoclea zeylanica*), wild clove (*Ludwigia spp.*), and duckweed (*Sagittaria*

[42] Also known as rock-steady.
[43] Also known as masala and matchstick grass.

guyanensis) (GRDB, 2009). Additionally, red rice[44] (*Oryza sativa L.*) is a major weed that impacts the quantity and quality of rice yields.

When asked which weeds have changed[45], 114 (67.9%) small farmers and 18 (72.0%) key informants noted that red rice has increased. Red rice is believed to have originated from the continual crossing between wild species or as a result of breeding within domestic varieties (Mackill, Coffman, and Garrity 1996; Holm et al. 1997). As one key informant noted, "the shift in weather pattern affects proper land preparation which is one of the main reasons for the red rice problem." However, four (16.0%) key informants acknowledged that red rice was on the decline. This is primarily due to various adaptation measures undertaken by farmers over the years. Thus, it is not abnormal that some farmers have been able to control red rice.

One hundred and four (61.9%) small farmers and 17 (68.0%) key informants indicated an increase in duckweed. Duckweed is an aquatic weed with submerged and floating heart-shaped leaves (GRDB 2009). Figure 6.16 depicts red rice rising above the cultivated variety and duckweed displacing rice plants as it spreads.

[44] Also known as overhead, wild rice, and jharanga.

[45] This was an open-ended question; participants were not given a specific list of changes to choose from.

Figure 6.16 Red rice (left) and duckweed (right)
Photo credit: Author

Increases in jhussia was also reported by 60 (35.7%) small farmers and six (24.0%) key informants. A prolific seed producer that germinates year round, jhussia serves as an alternate host for diseases, insects, and nematodes (Galinato, Moody, and Piggin 1999). Thirty-two (19.0%) small farmers and five (20.0%) key informants also noticed an increase in monkeytail. In lowland direct-seeded rice like in Guyana, monkeytail is detrimental because of its rapid growth, competitiveness, and ability to multiply quickly (Holm et al. 1977). Jhussia and monkeytail are illustrated in Figure 6.17.

Figure 6.17 Jhussia (left) and monkeytail (right)
Source: Rice Farmers' Manual (GRDB 2009)

Additionally, 29 (17.3%) small farmers and two (8.0%) key informants reported an increase in muraina grass. Highly competitive with rice, muriana is an annual grass that emerges later than other weeds and thrives in lowland direct-seeded rice cultivation (Holm et al. 1977) It also serves as an alternate host of diseases, insects, and nematodes (Galinato, Moody, and Piggin 1999). The late emergence often means that this weed avoids weed control which is usually done 16-25 days after sowing or before the first application of urea fertilizer.

Twenty-one (12.5%) small farmers and three (12.0%) key informants observed an increase in sedges. Water and umbrella sedges high plant densities forms a thick vegetative cover in fields containing young plants (Holm et al. 1977). Figure 6.18 illustrates muraina and water sedge. Nineteen (11.3%) small farmers and two (8.0%) key informants reported an increase in hasser string grass. Eight (4.8%) small farmers and three (12.0%) key informants also noticed an increase in soap bush.

 

Figure 6.18 Muraina (left) and water sedge (right)
Source: Rice Farmer's Manual (GRDB 2009)

Other weeds that small farmers noticed an increase include tanner grass, antelope grass, wild clove, turkey claw, and busy-busy. Despite the increase in different weeds reported, 19 (11.3%) small farmers and four (16.0%) key informants stated that weeds have decreased while nine (4.8%) small farmers mentioned that weeds varied from season to season. Table 6.17 summarizes the changes in weeds observed by small farmers and key informants.

Table 6.17 Changes in Weeds Reported by Small Farmers and Key Informants

Perceptions	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Red rice increased	114	67.9	1	18	72.0	1
Duckweed increased	104	61.9	2	17	68.0	2
Jhussia increased	60	35.7	3	6	24.0	4
Monkey tail increased	32	19.0	4	5	20.0	5
Muraina increased	29	17.3	5	2	8.0	8
Water /umbrella sedge increased	21	12.5	6	3	12.0	6
Hasser string grass increased	19	11.3	7	2	8.0	8
Soap bush increased	8	4.8	8	3	12.0	6
Schoonord grass increased	3	1.8	9	7	28.0	3
Weeds decreased	19	11.3		4	16.0	
Weeds varied by season	9	5.4		-	-	
Other	13	7.7		3	12.0	

The changes in weeds observed by small farmers and key informants are similar especially as it relates to red rice and duckweed. However, there are a couple observable differences in the responses reported. For instance, the increase in schoonord grass was observed by more key informants than small farmers. One explanation is that the effect of schoonord grass on small farmers maybe marginal at present. As such, small farmers may have placed greater emphasis on major weeds such as red rice and duckweed that have greater impacts on the quality and quantity of yields. Alternatively, small farmers may have been proactive in managing schoonord grass.

The observed decrease in weeds may be attributed to an increase and/or continuous control with herbicides. Additionally, overall improvement in agronomic practices may have eventually led to the suppression of weeds over time. Changes in weather patterns from year-to-year may also influence the presence of weeds. For instance, duckweed proliferates under wet conditions so in seasons and/or years where there is increase rainfall, it is likely that duckweed will increase and vice versa. Flooding due to excess rainfall may have also contributed to the dissemination of seeds of different weeds. Given that combine harvesters work multiple fields, it is also likely that weeds may have been carried from one field to another.

6.8.2 Impacts of Perceived Changes in Weeds

Small farmers and key informants were also asked to describe how the observed changes in weeds affected the quality and quantity of yields. As such, 79 (47.0%) small farmers indicated that grasses, sedges, and broadleaf weeds reduced the plant population in the field because they compete directly with rice plants. Specifically, 30 (17.9%) small farmers and 22 (88.0%) key informants noted that weeds compete for space, water, nutrients, and sunlight. In the words of one small farmer, “weeds grow fast…tek ova de field and choke de rice” [weeds grow vigorously, spread quickly to all parts of the field, and prevent the rice plants from growing]. Lower plant population leads to lower yields as reported by 63 (37.5%) small farmers.

Thirty-eight (22.6%) small farmers and eight (32.0%) key informants related that red rice (Figure 6.19) reduced the quality of the harvest which results in poor grades and prices received at the mills. Red rice grains carry a red pericarp or pigmentation which usually requires additional milling to remove thus resulting in more broken grains (Holm et al. 1977). As a result, farmers whose harvest contains more red rice receives a lower overall grade for their grains at the mill. In addition, four (2.4%) small farmers and seven (28.0%) key informants related that because most weeds grow taller, they canopy the rice plants which leads to lodging. That is, the taller weeds fall over on the rice plants causing the plants to fall down.

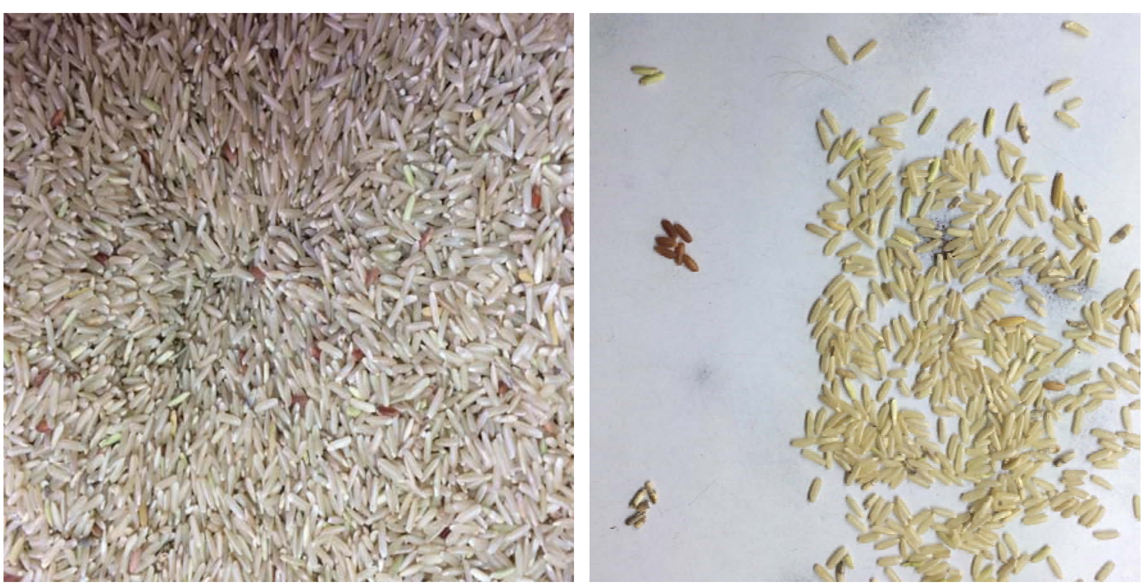

Figure 6.19 Red rice grains after milling
Photo credit: Author

Although not mentioned by small farmers, three (12.0%) key informants highlighted that the increase weeds observed in recent years served as a host for insects and diseases. For example, since red rice matures earlier, it serves as a surrogate for paddy bugs to feed on until the pure variety matures. Table 6.18 presents the impacts of changes on weeds reported by small farmers and key informants.

Table 6.18 Impacts of Changes in Weeds

Impacts	**Small Farmers**			**Key Informants**		
	No.	%	Rank	No.	%	Rank
Reduced plant population	79	47.0	1	-	-	-
Lowered yields	63	37.5	2	-	-	-
Reduce quality of yields	38	22.6	3	8	32.0	2
Compete for nutrients, space, fertilizer, and sunlight	30	17.9	4	22	88.0	1
Canopied/lodged rice plants	4	2.4	5	7	28.0	3
Hosts for insects and diseases	-	-	-	3	12.0	4
Other	6	3.6		-	-	

In general, impacts reported by small farmers and key informants are similar with two main exceptions. While small farmers noted that weeds reduced plant population and lowered yields, key informants did not mention either impact. One possible explanation is that the true impacts of weeds on yields may be marginal given that farmers are likely taking actions to control weeds before irreversible damage occurs.

6.8.3 Responses to Perceived Changes in Weeds

The observed changes in weed pressure saw several responses from farmers to prevent losses in yields, higher cost of production, and preservation of grain quality. The primary response by farmers involves the increase application of herbicides. As such, 128 (76.2%) small farmers and 22 (88.0%) key informants reported an increased in the application of herbicide to control weeds in recent years. Although herbicides are expensive, it is widely available to farmers. Farmers also mix and/or rotate among different herbicides available on the market or based on the recommendation of the district rice extension officer.

In addition, 11 (6.5%) small farmers and 13 (52.0%) key informants reported that farmers are improving water management in an effort to suppress weeds. Maintaining a lightly flooded field until the cultivated rice covers the field helps to suppress weeds. Lands that are high in some areas and low in others make it difficult to maintain equal water depth across the entire field. As a result, farmers are splitting larger fields into smaller plots so that they can maintain uniform water levels across each plot and better manage water resources as a whole. Although maintaining water in the field helps to suppress most weeds, this response actually helps duckweed to spread. This is because duckweed thrives under lightly flooded field conditions. Hence, five (3.0%) small farmers noted that they drained the field in response to duckweed.

Given that red rice shares similar genetic characteristics as cultivated varieties, conventional application of synthetic chemicals is not appropriate since these chemicals will also control the cultivated varieties. As such, both small farmers and key informants have indicated a couple novel strategies that are being used to control of red rice. Since red rice matures earlier and are usually taller than cultivated rice varieties, 23 (13.7%) small farmers and 17 (68.0%) key informants reported the use of the rope and stick method to burn red rice plants with a contact chemical.

The stick method involves wrapping a piece of cloth to the end of a stick and moistening it with the chemical. Farmers then walk through the field bringing the dampened end into contact with the red rice plants. In fields where red rice infestation is widespread, the rope method is more efficient. This involves two persons pulling a tight rope soaked in the chemical across parts of the field that contains red rice. Figure 6.20 shows red rice plants chemically burnt using the rope and stick method.

Figure 6.20 Red rice plants controlled using the rope and stick method
Photo credit: Author

Another method used by farmers to control red rice involves rogueing. Rogueing involves clearing the field of all plants other than the cultivated variety (Madramootoo 1974). As such, 17 (10.1%) small farmers and 15 (60.0%) key informants reported the use of water[46] and/or dry[47] rogueing to control red rice. Since red rice usually germinates before cultivated varieties, it is easier to identify and distinguish from cultivated varieties. Hence, farmers walk through the field and physically cut and/or remove the red rice plants. Figure 6.21 shows a field that was water rogued and free from weeds while Figure 6.22 captures a farmer using a grass knife [sickle] to dry rogue non-cultivated varieties from his

[46] Rogueing that takes place during the vegetative but before the flowering stage.
[47] Rogueing that takes place before harvesting.

field. In both cases, the individual farmers were seed paddy producers. Thus, producing good quality seeds entails sanitizing fields of weeds.

Figure 6.21 Water rogued rice field
Photo credit: Author

Figure 6.22 A farmer engaged in dry rogueing
Photo credit: Author

Key informants offered additional insights into farmers' responses to the observed changes in weeds. Although not mentioned by small farmers, 12 (48.0%) key informants noted that farmers in general are engaging in the flood and grow-out method. This method of red rice control entails flooding the field after harvesting to encourage red rice plants to germinate. Once red rice plants have established, farmers either spray with a chemical and/or plows the weeds back into the ground.

As part of land preparation, farmers are ensuring that their fields are level. As such, eight (32.0%) key informants reported that farmers are engaging in better land preparation. This entails both dry and wet land preparation and leveling the field to allow for better water management. Figure 6.23 shows a farmer leveling his field by dragging a log across the puddled surface. A level land helps ensure consistent water depth across the field. This allows farmers to grow the seedlings through water as reported by four (16.0%) key informants.

Figure 6.23 A farmer leveling the land prior to sowing
Photo credit: Author

Moreover, four (16.0%) key informants stated that farmers are using better quality seeds. Clean and certified seeds are usually free from red rice and other weeds. Other responses by farmers in general include using a higher seed rate to help suppress weeds; using different varieties; and burning the field after harvest to destroy any red rice seeds on the surface or in seed banks just below the surface. Table 6.19 presents farmers' response to changes in weeds as reported by small farmers and key informants.

Table 6.19 Responses to Perceived Changes in Weeds

Responses	Small Farmers			Key Informants		
	No.	%	Rank	No.	%	Rank
Sprayed more herbicide	128	76.2	1	22	88.0	1
Burnt with chemical	23	13.7	2	17	68.0	2
Dry and water rogued	17	10.1	3	15	60.0	3
Improved water management	11	6.5	4	13	52.0	4
Dried field	5	3.0	5	-	-	-
Flood/ grow-out method	-	-	-	12	48.0	5
Better/ additional land preparation	-	-	-	8	32.0	6
Used better quality seed	-	-	-	4	16.0	7
Grow through water	-	-	-	4	16.0	7
Other	14	8.3		6	24.0	

The top four responses reported by both small farmers and key informants are similar. However, additional insights offered by key informants may be beyond the reach of small farmers. While the flood and grow-out method may be an effective control against red rice, it may be prohibitively costly for small farmers that lack financial resources and/or equipment to engage in this additional land preparation activity. Hence, they are less likely to engage in this practice. Similarly, better land preparation means additional dry land preparation. Since small farmers rely on large farmers for land preparation, large farmers may not be available when needed. And even if they are available, small farmers may be reluctant to incur the additional costs.

While good quality seeds produced by the rice research center are available to all farmers, preference is often shown to large farmers since they buy in larger quantities. As such, small farmers whose seed needs are much smaller may not be able to access them. Additionally, the cost to transport a few bags of seeds from the research center to different parts of the country is prohibitively high. While some small farmers may be able to secure seeds through large farmers, the great majority of them purchase seeds from local farmers in the area which may not consistently be of good quality.

6.9 Changes to Farming Practices

In order to capture any additional responses to changes in climatic and non-climatic conditions, small farmers were read a general list of practices and asked to identify which practices they have implemented in the last five years. All small farmers in the sample population reported making changes to their farming practices in the last five years. Considering the increase in insects and weeds observed, it is not surprising that 183 (96.8%) small farmers increased the quantity and frequency of herbicides and pesticides used. One hundred and eighty-two (96.3%) small farmers reported using different rice varieties and/or rotate varieties between seasons depending on the expected weather conditions. For instance, the majority of small farmers are planting the newer high yielding and blast resistant varieties. As noted above, this is one of the reasons for increases in yields. Additionally, in the autumn season when excess rainfall is usually expected, some farmers plant a variety that can withstand lodging.

One hundred and eighty-two (96.3%) small farmers reported buying new seeds each or every other season. This is in contrast to the historic practice where many farmers retained seeds from their harvest to replant. Good quality seeds help to ensure better germination. They are also likely to be sanitized of weeds, insects and pests, and diseases all of which facilitates better yields. One hundred and seventy (89.9%) small farmers also treat their seeds for early season pests such as water weevil and snail. Seed treatment help to ensure that seedlings remain viable and plant population remain high. Ninety-seven (51.3%) small farmers also applied insecticide to the water in the field instead of or in addition to seed treatment. In general, farmers with livestock are more likely to apply the chemicals to the water in the field in order to prevent their livestock from accidentally consuming harmful treated seeds.

Given the lack of predictability in rainfall patterns, 169 (89.4%) small farmers reported adjusting their planting dates while 137 (72.5%) pumped water. Although rice in Guyana is irrigated, the release of water into the irrigation canals depend of rainfall that replenishes the water conservancies or reservoirs. As such, farmers adjust their planting dates based on the early or late release of water. However, the lack of in-season rainfall usually results in the water level in the irrigation canals not being high enough to allow for gravity flow into the fields. As such, farmers resort to pumping water to start land preparation and subsequent sowing. It must be noted that in some areas of the country where there is no irrigation system, farmers are forced to pump water. However, if there is adequate rainfall at the time of sowing, less water is required to be pumped into the field.

One hundred and sixty-four (86.8%) small farmers increased the quantity and frequency of fertilizer application. In an effort to increase yields and combat the adverse weather conditions, more farmers are using balance nutrition fertilizer on their fields. Farmers that had a soil test done also adjusted the type and quantity of fertilizer used. Ninety-seven (51.3%) small farmers also reduced the plant density in their field. By sowing less seeds, fewer plants compete for water and nutrients. This allows for increase yields since plants are able to absorb the necessary nutrients.

Although reduce plant densities are expected to generate better yields, 32 (16.9%) small farmers indicated that they sowed more seeds. Farmers in flood prone areas caters that some seedlings will die or float off. As such, they sow more seeds to compensate for potential loss of seedlings. Twenty-three (12.2%) small farmers reported leaving their land unplanted for one of the seasons. This was due the lack of water to start the crop (drought) or late harvesting which did not allow enough time for re-sowing. As one small farmer related, it was better to skip the crop and plant the next crop on time than to waste resources planting late and risk harvesting in the rain. Table 6.20 presents the various adaptation practices small farmers adopted.

Table 6.20 Adaptation by Small Farmers

Adaptation	No. of Farmers	%
Increase herbicide and pesticide application (quantity and frequency)	183	96.8
Use different rice varieties	182	96.3
Buy new seeds each season	182	96.3
Treat seeds for insects	170	89.9
Changing sowing/ planting dates	169	89.4
Increase fertilizer application (quantity and frequency)	164	86.8
Pump water	137	72.5
Reduce plant densities	97	51.3
Sprayed water in field	97	51.3
Sow more seeds	32	16.9
Leave land idle	23	12.2
Rent out land to large farmers	4	2.1
Rice variety rotation	3	1.6
Exited rice cultivation and seek off-farm employment	1	0.5
Other (block planting, patching, etc.)	14	7.4

As Table 6.20 suggests, small farmers are engaging in a many different adaptation practices. One can reasonably expect this to continue in the near future. However, it is also likely that some small farmers will need to accelerate the adoption of these adaptive measures under a changing climate. For instance, increase drought will force more small farmers to pump water. If adequate water is not available, a greater number of small farmers may need to leave their land idle, rent out their land, or stop planting rice altogether.

6.10 Seasonal Changes and Impacts on Yields

Given the observed changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds, 89 (47.1%) small farmers indicated that the autumn season was most affected while 68 (36.0%) small farmers referenced the spring season. Twenty-seven (14.3%) small farmers reported that both seasons were affected by the observed changes. Regardless, 135 (71.4%) small farmers reported an increase in yields while 24 (12.7%) reported lower yields in the last five years. Despite changes in climatic conditions, increases in yields may be attributed to farmers engaging in better agronomical practices because of climatic changes and planting new high yielding varieties. Since farmers are engaging in a wide range of adaptation practices, this would also help mitigate the negative externalities created by climate change. Furthermore, 16 (8.5%) small farmers noted that there was no change in yields while 14 (7.4%) stated that yields fluctuated from season to season.

6.11 Crop Failure and Coping Strategies

Climate shocks such as drought, flooding, poor or excess rainfall, and high temperature increase stress on agricultural crops, oftentimes lead to crop failure. Mendelsohn (2007) defines crop failure as the complete loss of crops on a farm. However, crop failure may also encompass poor yields relative to expectation. Adverse weather conditions reduce soil quality, drain soil nutrients, and/or limit the access to soil nutrients during critical growth stages (Coulibaly et al. 2015). Non-climatic factors such as weed infestation and pest and disease outbreaks may also cause crop failure and are inextricably influenced by climatic conditions.

Given the link between crop failure and changes in weather patterns, small farmers were asked whether they experienced crop failure in the last five years. Ninety-eight (51.8%) small farmers stated that they suffered losses to their entire or partial field due to excess rainfall that led to flooding, lack of water due to drought and/or paddy bug infestation that was detected too late. Of these small farmers, 52 (53.1%) reported that losses occurred in the spring season while 33 (33.7%) suffered crop failure in the autumn season. Four (4.1%) small farmers noted that they have experience crop failure in both seasons while 9 (9.2%) small farmers could not remember the season the losses occurred.

The banes of crop failure coupled with high cost of production, low prices, poor grades received at the mills, and late payments by millers force small farmers to deploy various coping strategies to manage income shocks. Coping strategies are usually short term responses to unexpected or abnormal events (van der Geest and Warner 2014). In other words, specific ex post risk management options employed to minimize livelihood impacts of adverse climatic shocks (Cooper et al. 2008). Eighty-six (45.5%) small farmers stated that they relied on money from other sources to cover income shortfall from rice farming and/or to cover the costs of replanting the following season. This is not surprising given that 181 (95.8%) small farmers interviewed reported engaging in some form of off-farm employment and/or receive a government pension. Janvry and Sadoulet (2016) note that the poor usually have multiple sources of income while small farmers typically derives approximately fifty percent of their income from off-farm employment and self-employment.

Thirty-eight (20.2%) small farmers reported that because of the losses sustained, they had to adjust their spending on food and other household expenses or use savings to cover the shortfall in income. Consumption smoothing is commonly practiced among farmers in developing countries (Rosenzweig and Wolpin 1993; Townsend 1994; Morduch 2002; Hoddinott 2006; Pandey et al. 2007). Mehar, Mittal, and Prasad (2016) found that reduce food intake is a general response among farmers coping with climate shocks. Another study showed that farmers reduced the number of meals taken and reduce expensive food items to cope with income loss (Ashraf, Routray, and Saeed 2014). However, adverse risk coping strategies such as reduce food consumption may have long-term irreversible health consequences (Janvry and Sadoulet 2016).

It is interesting to note that small farmers utilize their savings as a coping strategy. Good production years and strong prices coupled with off-farm employment allow them to engage in formal savings. The use of savings to help with agricultural inputs and avoid complete crop failure is a common practice (Ashraf, Routray, and Saeed 2014). Furthermore, 15 (7.9%) small farmers noted that they were able to use the money received from one season to re-plant in the next season while just 11 (5.8%) relied on input credits. While rice millers are mandated under the law to pay 50 percent of the amount due within two weeks of receipt of the grains and the remainder within 42 days (RFA 1998), this is not always the case. Additionally, millers usually offer input credits at high interest rates.

Nine (4.8%) small farmers engaged in self-help practices where they rotated helping each other sow, apply fertilizer, and spray chemicals. This form of solidarity network helps to reduce input costs and minimizes the risk of poor quality work perform by unsupervised paid laborers. Input adjustment, sale of livestock, and borrowing are also important coping strategies (Ashraf, Routray, and Saeed, 2014). Eight (4.2%) small farmers indicated that they adjusted or deferred rice input expenses. For example, instead of buying new seeds, they retained seeds to replant, reduced the recommended amount of fertilizer and/or sprayed less chemicals. While these coping strategies are cost saving in nature, the risk of lower yields at harvest is likely to be higher. Other coping strategies include the sale of livestock and borrowing from family to help pay for inputs. Table 6.21 summarizes the various coping strategies employed by small farmers.

Table 6.21 Coping Strategies Employed by Small Farmers

Coping Strategies	No. of Farmers	%
Use money from other sources	86	45.5
Adjust food/household expenses	19	10.1
Use savings	19	10.1
Rice turnover	15	7.9
Input credit	11	5.8
Self-help to reduce cost	9	4.8
Adjust/ defer input expenses	8	4.2
Sell livestock	4	2.1
Borrowed	3	1.6

6.12 Paying for Changes in Farming Practice

Paying for adaptation practices may cause small farmers to become more vulnerable (Mertz et al. 2009). That is, losses or complete crop failure may still occur leaving farmers out of pocket and/or in debt. For example, a small farmer may purchase a tractor on credit to ensure timely land preparation and hence sowing within the season to avoid early season floods and/or harvesting in the rain. However, erratic rainfall patterns may still occur leading to losses due to flooding and lodging of plants. At this point, the farmer has not only loss the crop but also falls into debt. Kelly and Adger (2000) argue that vulnerability can only be accurately assessed after adaptation has taken place. As such, understanding how small farmers pay for adaptation practices is vital to our understanding of net vulnerability related to climate change.

Small farmers reported using various means to help pay for the changes in farming practice that they have undertaken in response to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. One hundred and eighty-one (95.8%) small farmers used savings and/or money received from the sale of the grains to pay for adaptation measures. The use of savings in many cases is warranted given that farmers do not always receive payment from the millers in a timely manner. The Rice Factories (Amendment) Act of 2009 requires millers to pay farmers 50 percent of the amount due within two weeks of receipt of the grains and the remainder within 42 days (RFA 1998). However, some millers seldom abide by this law and their actions often go unpunished by the Guyana Rice Development Board (GRDB). In some instances, farmers are offered postdated checks which restricts them from cashing it until some future date while in other cases piece meal payments are made. In both cases, farmers do not receive interest on late payments. As one small farmer related, “I am almost ready to harvest the current crop [September 2017] and I have not received payment for the spring crop which was harvested in April [2017].” Such situations are not uncommon and small farmers often feel the brunt of late payments since they are forced to go into their savings or rely on other sources of income until they receive payment from millers.

One hundred and twenty-four (65.6%) small farmers rely on income from off-farm employment to help with rice cultivation while 109 (57.7%) reported taking input credit, primarily in the form of fertilizer credit from the millers. However, some farmers avoid taking credit from the millers because of the high interest rate. Fifty-five (29.1%) small farmers noted that they sold livestock to help with rice farming while 46 (24.3%) borrowed from family members. Although, borrowing from family members is usually interest free, farmers try to avoid doing so because it may lead to strain relations.

Thirty-nine (20.6%) small farmers reported using their pension to help pay for additional inputs. Guyanese citizens become eligible for old age pension at age sixty-five while those that contributed to the National Insurance Scheme (NIS) becomes eligible at age sixty. Given that over a fifth of small farmers interviewed stated they receive a pension, this is an important source of adaptation funding.

Nineteen (10.1%) small farmers reported borrowing from other farmers to help cover the costs of inputs. In some cases, small farmers borrow actual inputs (e.g., fertilizer) from large farmers and replace after they harvest. Fifteen (7.9%) small farmers reported receiving government support in the form of seed paddy and/or fertilizer. While this was in relation to helping farmers recover from crop failure and not directly related to adaptation, it may have allowed farmers to repurpose their own funds towards adaptation. Furthermore, 13 (6.9%) small farmers obtained microcredit while six (3.2%) borrowed from a commercial bank. Other sources of funds used for adaptation include cash crops, remittances, sale of productive assets, credit from tractor/combine operator, small business and shop keeping. It is worth pointing out that it is customary practice for tractor and combine operators (usually large farmers) to do land preparation and harvesting on credit. However, this was not mentioned by the majority of small farmers interviewed. Perhaps, this is such a traditional practice that small farmers felt that it was not something new worth mentioning. Table 6.22 summarizes the various ways small farmers paid for the adaptation practices implemented.

Table 6.22 Paying for Adaptation

Source of Funding	No. of Farmers	%
Use savings/ crop turnover	181	95.8
Off-farm employment	124	65.6
Input credit (fertilizer, herbicide, pesticide, seeds)	109	57.7
Sell livestock	55	29.1
Borrow from family members	46	24.3
Pension	39	20.6
Borrow from other farmers	19	10.1
Government support/ subsidy	15	7.9
Obtain institutional microcredit	13	6.9
Cash crop	10	5.3
Borrow from commercial bank	6	3.2
Remittances	4	2.1
Sell productive assets	2	1.1
Other (credit from tractor/combine operator, small business/shop keeping)	6	3.2

As Table 6.22 suggests, the majority of small farmers used their savings or income from the harvest and income from off-farm employment to pay for adaptation. Borrowing from family members and other farmers is usually interest free with no fixed payback period, although the aim is usually to clear debts after harvest is completed and payment is received from the mill. Interestingly, only 19 (10.1%) small farmers borrowed from microfinance institutions and commercial banks to help pay for adaptation. This may be due to several factors including the lack of actual need to borrow, the lack of collateral or other means to assure payback and/or small farmers aversion to borrowing or being in debt. Given small farmers propensity to engage in limited borrowing from formal lending institutions, their net vulnerability may be lower post adaptation.

6.13 Rice Extension Services and Small Farmers' Adaptation

Farmers ability to successfully adapt to climate change rest on information, technologies, and education on how to cope with adverse changes in weather patterns (Davis 2009). In this regard, agricultural extension plays a crucial role in climate change adaptation. Extension agents transfer knowledge from researchers to farmers, advise farmers in decision-making, educate farmers to make similar decisions in the future, enable farmers to clarify their own goals and possibilities and to realize them, and stimulate desirable agricultural developments (Van den Ban and Hawkins 1996). According to Julie, Amungwa, and Manu (2017), the importance of agricultural extension cannot be overstated in that extension agents often initiate changes in knowledge, attitudes, resilience capacities, and skills of farmers.

To learn what agricultural extension services and support are being provided to build the adaptive capacity of farmers, responses were solicited from key informants employed by the Guyana Rice Development Board (GRDB) (district rice extension officers, chief scientist/plant breeder, plant pathologist, agronomist, entomologist, and the rice extension manager). Advice on better agronomic practices was the main service provided to farmers. Specifically, farmers are trained on the six-point practice. The six-point practice consists of six improved management practices for rice cultivation introduced by the GRDB extension department. This include advice on planting in-season (time of sowing), reducing plant densities (seed rate), treating seeds before sowing, controlling weeds, using balance nutrition fertilizer, and managing water in the field. The six-point is presented primarily through on-farm demonstrations and trials. Here district rice extension officers demonstrate to farmers' best practices for handling chemicals, treating seeds for early season insects and pests, and the correct timing and application of insecticides, pesticides, herbicides, fungicides, and balance nutrition fertilizer.

In addition, the use of the correct dosage of insecticide, pesticide, herbicide, fungicide and fertilizer are demonstrated and emphasized. Referring the proclivity of some farmers to exceed dosage recommendations, one key informant noted that "too much of one thing is good for nothing." Carter, Zhong, and Zhu (2012) note that productivity from increase fertilizer usage declines while Guo et al. (2010) points to reduce soil quality from the use of excess fertilizer. Ramli et al. (2018) notes that the brown planthopper – the most serious rice pest in Asia - developed resistance to insecticides leading to its resurgence. Hence, farmers are encouraged to follow usage directions since exceeding recommended quantities may cause more harm than good. Farmers are also trained to manage paddy bug and red rice infestations in an integrative and holistic manner. Demonstration plots illustrate appropriate plant densities, proper land preparation, and water management techniques.

District rice extension officers also serve as facilitators for farmer field schools. Originally developed by the Food and Agricultural Organization (FAO) to promote integrated pest management among Indonesian rice farmers in the late 1980s (Berg and Jiggins 2007), farmer field school is a bottom-up approach that focuses on an innovative, participatory, interactive, and experiential learning approach that seeks to improve the problem solving capacity of farmers (Anderson and Feder 2007). Farmer field schools allow participants to share their knowledge regarding various adaptation practices. As a result, farmers are provided with a basket of adaptation practices to choose from, adopting the practices that is most suitable to their individual farm characteristics and conditions.

Interagency coordination is also a major support provided by district rice extension officers. Concerns of farmers are often communicated to different government departments calling for action to be taken. For instance, issues regarding access to adequate and timely water supply, maintenance of canals, trenches, and access dams (farm-to-market roads) are relayed to the respective water user association, National Drainage and Irrigation Agency (NDIA), regional authorities, and local government organ responsible. Extension officers also advocate for access to timely, easily understood, and accurate weather information from the Hydrometeorological Service on behalf of farmers. In some areas, districts rice extension officers make reports to the relevant authorities when drainage pumps are not working and co-ordinate with koker (sluice) attendants to ensure timely draft of excess rainfall to mitigate the risk of flooding.

The diffusion of new technology is a primary role played by agricultural extension (Agarwal 1983). According to Davis (2009), extension has traditionally entailed sharing information and promoting new technologies. Information communicated on improved and new technologies to prospective users through communication networks such as extension agents impact the likelihood of the innovation being adopted (Rodgers 2003). As such, district rice extension officers noted that they also promote and market seed paddy. That is, they share information with farmers regarding the yield potential and variety characteristics of new seed technologies introduced by the rice research center through the plant breeding program. Based on specific conditions such as soil type, flood risk, drainage and irrigation system, and the general history of the area with regards to floods, they advise farmers on adoption of the new variety or the variety that is best suited. They also serve as a conduit between farmers and the rice research center to ensure that farmers are able to purchase good quality seeds that are free from weeds and diseases in a timely manner.

Another important avenue of support provided by GRDB is the hosting of periodic outreach meetings across each region to address issues facing farmers and the industry as a whole. Outreach meetings provide farmers with the opportunity to share their concerns regarding issues facing their district and/or region. This may include farm-level matters such as drainage and irrigation and conditions of access roads or marketing concerns such as the price received and on-time payment by millers. In addition, experts such as the plant pathologist, agronomist, and entomologist are usually present to help ease concerns and provide immediate feedback to farmers.

District rice extension officers also coordinate field and farmer exchange visits, distribute brochures on seed varieties and different agronomic practices, conduct onsite water salinity tests, and circulate weather forecasts and calendars. Furthermore, they are providing general advice on soil health management, integrated pest management (IMP), and climate smart agriculture. In the future, district rice extension officers could provide support for further climate change adaptation.

6.14 Barriers to Adaptation

Successful adaptation to environmental changes attributed to climate change begins with perception of the changes and an understanding of the corresponding impacts. However, barriers to adaptation often prevent and/or restrict effective and efficient response to the adverse effects of climate change. Barriers to adaptation are those conditions, factors, or obstacles that impede, divert, or block the process of developing and implementing climate change adaptation strategies (Moser and Ekstrom 2010; Biesbroek et al. 2013; Barnett et al. 2015). These may include technological, financial, cognitive and behavioral, and social and cultural constraints (Adger, Agrawala, and Mirza 2007).

The literature highlights many barriers to adaptation, but the list of possible barriers is seemingly infinite (Biesbroek et al. 2013). Specific barriers explored by previous studies include social (Stage 2010; Jones and Boyd 2011; Vulturius and Gerger Swartling 2015), economic (Biesbroek et al. 2011), cultural (Nielsen and Reenberg 2010), informational (Deressa et al. 2009; Amdu, Ayehu, and Deressa 2013), policy and institutional environment (Eakin 2005; Sietz, Boschütz, and Klein 2011; Oberlack 2017), and cognitive, affective and behavioral (Lorenzoni, Nicholson-Cole, and Whitmarsh 2007) among others.

While there are a number of factors that impede farmers' ability to respond to climate change, such factors are highly context specific and difficult to compare (Biesbroek et al. 2011)). Demographic, farm-level, socio-economic, and institutional characteristics may differ from country-to-country. Thus, barriers to adaptation may also differ. In the context of Guyana, small farmers were asked to rank the importance of potential socio-economic, informational, and institutional barriers to adaptation[48].

One hundred and seventy-five (92.6%) small farmers indicated that the availability of information regarding the changes in weather patterns observed was important or very important in making adaptation decisions. Effective response to climate change requires accurate, accessible, and useful climate information (Roncoli, Ingram, and Kirshen 2002). Although daily weather forecasts by the Hydrometeorological Service are available via newspapers, radio, and television, the accuracy of such information is often lacking

[48] A list of potential barriers to adaptation was read to small farmers; they were asked to rank each barrier in terms of importance (very important, important, slightly important, not important).

according to farmers. Farmers further noted that forecast information is usually granular in nature and thus often fails to convey the specific weather conditions expected in a particular area or district. Gbetibouo (2009) found that the lack of information about long term climate change was an important barrier to adaptation in the Limpopo Basin, South Africa while Gadédjisso-Tossou (2015) noted that the exchange of climate information through climate change communication would enable small farmers to change planting dates in three regions of Togo. Furthermore, the existence of microclimates across different regions often render general forecast for a particular region less valuable to some farmers. For instance, a forecast of persistent rainfall in a specific region may be limited to only the northern part of that region. However, farmers throughout the region may take precaution which limits the adaptive behavior of farmers in areas not affected.

One hundred and seventy-one (90.5%) small farmers ranked access to adequate irrigation and drainage infrastructure as important or higher when making adaptation decisions. Since rice in Guyana is irrigated, the importance of a well-maintained irrigation system remains paramount to farmers' response to changes in climatic conditions. Timely and adequate access to water for land preparation helps farmers to sow in-season in an attempt to avoid harvesting in wet out-of-season conditions. Early sowing also helps ensure that plants are well established in the fields and can survive temporary flooding if or when sudden and/or heavy rainfall arrives. Adequate irrigation facilities also assist farmers to engage in better water management in order to control weeds and replenish evaporated water. In areas where gravity flow is customary, access to adequate and timely water help farmers save on input costs related to mechanically pumping water into their fields. Such savings can be subsequently redirected towards other adaptation measures, as needed.

Access to water (Gbetibouo 2009) and water scarcity (Amdu, Ayehu, and Deressa 2013) were found to be major barriers to climate change adaptation. Access to proper drainage is equally important as it relates to excess rainfall that leads to flooding. Poorly maintained drainage infrastructure impedes farmers' ability to successfully adapt. For instance, adding more outlets to the field to facilitate faster drainage during intense rainfall is futile if drainage canals are not properly maintained to allow excess water to recede smoothly.

One hundred and eighty-three (96.8%) small farmers noted that access to knowledge regarding adaptation practices is important or very important as it relates to making changes to their farming practices. Lack of or poor access to extension services (Amdu, Ayehu, and Deressa 2013; Bryan et al. 2013), and lack of information or knowledge concerning appropriate adaptations (Gbetibouo 2009; Deressa et al. 2009) were important barriers to adaptation found in the literature. However, in Guyana extension officers have been communicating and sharing information on improved management practices through farmer field schools, field days, field visits, and seminars. However, attendance at these events have dwindled in recent years. This is due in part to the lack of new information or new farm management practices that would encourage more farmers to participate. For instance, the six improvement management practices (six-point) for higher yields was introduced a decade ago. As such, farmers are wary of re-cycled information being presented. Gadédjisso-Tossou (2015) argued that intensifying extension activities would enhance farmers' adaptive capacity.

Farmers' ability to make changes to their farming practices also depend on their ability to pay for the changes. The socio-economic position of households (Ziervogel et al. 2006) or financial constraints (Deressa et al. 2009) may affect farmers' capacity to adapt.

As such, 51 (27.0%) and 93 (49.2%) small farmers indicated that access to money, savings and/or credit is very important and important, respectively. The majority of farmers have a secondary source of income while some were able to receive input credit, albeit at a steep interest rate. In the absence of a dedicated agricultural lending institution, access to agricultural finance is very difficult since commercial banks are reluctant to lend to small farmers or do so at high interest rates. Rural finance in Guyana is very limited due to the banking sector risk-averse attitude towards the risk faced by the agricultural sector, the lack of agricultural expertise in the banking sector, and difficulties to realize such securities (WB 2010a). Additionally, small farmers often lack legal title to the land which could otherwise be used to secure a loan. It must be noted also that several small farmers were averse to taking credit for the fear of being in debt. Instead, they are forced to appropriate whatever little savings and/or income from other sources, to cover adaptation costs. Access to credit (Bryan et al. 2009; Gbetibouo 2009) and affordable credit schemes (Gadédjisso-Tossou 2015) are important barriers to adaptation found in the literature. Despite difficulty in securing agricultural loans, 39 (20.6%) small farmers noted that access to money, savings and/or credit is not important. These farmers have multiple sources of income and thus can afford to pay for the changes needed to successfully adapt.

Insecure property rights is also a key barrier to adaptation (Gbetibouo 2009; Sarker 2012). As such, 71 (37.6%) small farmers indicated that ownership of land is very important while 108 (57.1%) indicated that it is important in guiding their decision to adapt. Land tenure allows farmers to engage lending institutions to obtain credit which can be used for adaptation purposes. Ownership of land also incentivize farmers to invest in their land and make improvements where necessary. For instance, farmers could invest in leveling the land, build-up levees, and/or add more drainage knowing that the land could not be repossessed. Ownership also means lower production costs since farmers do not have to make rental payments. Such savings can be put towards land improvement and adaptation as a whole. While access to land (Bryan et al. 2009), lack of suitable land (Bryan et al. 2013) and land scarcity (Amdu, Ayehu, and Deressa 2013) were found to be major barriers to adaptation elsewhere in the world, this was not the case in Guyana.

Even if farmers have the knowledge and financial resources to adapt, they still need labor to help with adaptation. Fifty-two (27.5%) small farmers indicated that the availability of labor is very important while 102 (54.0%) stated it is important when it comes to adapting to climate change. Seasonal labor help with sowing, applying fertilizer and spraying for weeds and insects. However, changes in rainfall, temperature, insects and pests, diseases, weeds, and extreme weather events increases the overall demand for labor. For example, additional labor is needed to help make and clear drains, spray more for paddy bugs, load and off load grains from boats, and dry wet grains. The demand for labor to help respond to climate change is also thwarted by the decrease in the labor pool. This is because the number of young people involved in rice farming is declining. With the increase demand and a smaller labor pool, the cost of labor has increased which creates another barrier to adaptation. Regardless, 28 (14.8%) small farmers indicated that labor was not important. These farmers usually engaged in rice farming on a full-time basis and do the work themselves or are a part of a solidarity network that help each other. Studies by Sarker (2012) and Amdu, Ayehu, and Deressa (2013) found labor shortage to be a major barrier to adaptation.

All small farmers interviewed indicated that the price received for paddy grains were important or very important to their decisions to adapt. In Guyana, the price received by farmers is determined by the market. Small farmers contend that the high costs of production coupled with potentially low prices received at the mills result in small profit margins. As such, they are hesitant to invest in costly adaptation practices given the uncertainty surrounding the price they will receive at harvest.

One hundred and eighty-seven (98.9%) small farmers indicated that the absence of subsidized inputs and the access to tax exemption on inputs and equipment play a pivotal role in their decisions to adapt. Similarly, 185 (97.9%) small farmers noted that the lack of government assistance limits their ability to successfully adapt to the changes observed. Subsidized inputs and tax exemptions leave more money in farmers' pockets which can be used towards adaptation. In addition, tax exemption provides small farmers with the opportunity to acquire their own equipment and machinery to help with adaptation. Government assistance such as free seed paddy and other safety nets can help small farmers recover from crop failure and other losses attributed to climate change.

Gbetibouo (2009) found that the lack of access to markets was an important barrier to adaptation. As such, 183 (96.8%) small farmers reasoned that the availability of rice markets is important or very important to their adaptation efforts. They contend that the availability or access to markets would increase the demand for their grains which would increase the price received at the mills. Thus, increase access to markets would incentivize farmers to invest in adaptation practices with the expectation that they will receive a higher return on their investment. In addition, some farmers note that the lack of timely payment from millers constrain their ability to effectively adapt. Poor farm-to-market roads limit farmers' ability to easily monitor their fields and respond in a timely manner. Some farmers also conveyed that the absence of experts at outreach meetings hosted by the Guyana Rice Development Board (GRDB) do not allow for timely responses to their questions and/or concerns. Table 6.23 summarizes the importance of various barriers to adaptation to farmers.

Table 6.23 Barriers to Adaptation

Barriers	No. of Farmers							
	Very Important	**%**	**Important**	**%**	**Slightly Important**	**%**	**Not Important**	**%**
Availability of information about extreme weather events, changes in rainfall and temperature	85	45.0	90	47.6	7	3.7	7	3.7
Access to adequate irrigation and drainage facilities	89	47.1	82	43.4	7	3.7	11	5.8
Access to knowledge regarding adaptation practices	87	46.0	96	50.8	1	0.5	5	2.6
Access to money/savings/credit	51	27.0	93	49.2	6	3.2	39	20.6
Ownership of land	71	37.6	108	57.1	1	0.5	9	4.8
Availability of labor	52	27.5	102	54.0	7	3.7	28	14.8
Price received for rice paddy	155	82.0	34	18.0	0	0.0	0	0.0
Subsidized inputs	130	68.8	57	30.2	0	0.0	2	1.1
Tax exemption on inputs and equipment	114	60.3	73	38.6	1	0.5	1	0.5
Availability of markets for rice	106	56.1	77	40.7	1	0.5	5	2.6
Government assistance	115	60.8	70	37.0	1	0.5	3	1.6
Other (payment on time, access to dam, outreach)	26	100.0	0	0.0	0	0.0	0	0.0

Given the various difficulties faced, 163 (86.2%) small farmers noted that the government should help while 26 (13.8%) specifically mentioned the Guyana Rice Development Board (GRDB). As one small farmer relates, "the government should intervene and see that small farmers get a better deal". Despite this expectation however, farmers are wary of government assistance. Another small farmer noted, "you have to help yourself, [there is] no expectation from government."

6.15 Co-benefits, Maladaptation, and Limits to Adaptation

As the preceding sections highlight, adaptation strategies undertaken by farmers in response to perceived changes and related impacts of rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds are numerous. While efforts to adapt in one area are likely to generate co-benefits in other areas, some adaptation practices may also conflict and/or become maladaptive in other areas. In addition, adaptation practices may be finite in nature. Although not specifically part of the survey data collected, the ensuing discussion examines possible co-benefits, maladaptation, and limits to adaptation.

6.15.1 Co-benefits

Co-benefits or ancillary benefits refer to the multiple positive effects of one policy, strategy or action across different objectives (Mach, Planton, and von Stechow 2014). In adaptation terms, more than one benefit can be derived from a single practice. Weed control reduces competition for water, space, and nutrients. As a result, rice plants are able to thrive freely and make full use of the natural and artificial resources in the field. This will likely result in better quality and quantity of yields. By controlling weeds, farmers are simultaneously removing potential host plants for insects and pests. This co-benefit helps ensure that the quality and quantity of yields are not affected by insects such as the paddy bug.

Leveling the field enables better water management. This allows for improved management of excess water which reduces the number of patches[49] in the field. As a result, uniform growth of plants is maintained across the field which increases the quality and quantity of yields. A co-benefit of better water management is that it can also be used to suppress some weeds. By growing the rice through water, some early season weeds are unable to grow through the shallow flood in the field.

Another adaptation practice that fosters co-benefits is the rotation of rice varieties. Some farmers reported rotating varieties between the two seasons and sometimes from year to year. In the autumn season when there is a greater chance of excess rainfall and flooding in certain areas, some farmers plant a variety that are sturdier and can withstand lodging. In the spring crop where there is greater likelihood of dry spells, farmers plant a short duration variety which requires less water. Rotating varieties also help to prevent diseases.

6.15.2 Maladaptation

According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, "maladaptation refers to actions, or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future" (Noble et al. 2014). Several current practices by farmers may be beneficial in one area and harmful in another area.

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[49] Patches are areas in the field where plants take longer to establish and/or fail to establish.

As part of their adaptation to changes in temperature and diseases, small farmers indicated that they increased the quantity of fertilizer applied to their fields. While the increase in fertilizer benefits the plants up to a certain point, it also benefits weeds in the field. Also, the final release of water from the field leading up to harvesting increases nutrient cycling. That is, more nutrients flow into the drainage canals which fertilizes grasses along the sides leading to increase overgrowth that eventually obstruct the smooth flow of water especially during heavy rainfall. Additionally, as a form of environmental pollution, fertilizer run-off affects soil and water quality and threatens other life forms thus leading to biodiversity loss.

While increased preventative spraying for insects like the paddy bug may help protect the crop in the short run, it is maladaptive in terms enhancing insect resistance and its control of beneficial insects. This short-term solution may turn into a long-term problem where farmers will need to continuously rely on synthetic chemicals to control insects instead of natural enemies. The continuous and/or accelerated use of synthetic chemicals also negatively impacts air quality and biodiversity.

6.15.3 Limits to Adaptation

While the intent of adaptation is to reduce climate related risk now and/or in the future (Adger et al. 2012), interactions among climate change, biophysical, and socioeconomic constraints can lead to the emergence of limits to adaptation (Klein et al. 2014). That is, at some point or outside a certain range, adaptation may no longer be feasible or deemed effective. Dow, Berkhout, and Preston (2013) note that exceeding adaptation limits will result in rising losses or require transformational change. As such, understanding the adaptation range and limits to small farmers' capacity to effectively respond to climate change remains paramount (Yohe and Tol 2002).

Limits to adaptation are thresholds or tipping points beyond which adaptive actions cannot safeguard from intolerable risks (Adger et al. 2009; Moser and Ekstrom 2010; Dow et al. 2013; Monirul Islam et al. 2014; Barnett et al. 2015). Limits include the inability of the ecological systems to adapt to the rate and magnitude of climate change (Adger, Agrawala, and Mirza 2007). For instance, the biophysical environment may be limited by changes in temperature, precipitation, salinity, acidity, and intensity and frequency of extreme events including storms, drought, and wind (Klein et al. 2014). Economic limits such as "existing livelihoods, economic structures, and economic mobility" and socio-cultural limits such as "social norms, identity, place attachment, beliefs, worldviews, values, awareness, education, social justice, and social support" may also limit adaptation (Klein et al. 2014). Additionally, limits to adaptation may be further categorized as being hard or soft. Hard adaptation limits mean that no adaptation action is foreseeable while soft adaptation limits mean that options are not currently available but could become available in the future (Klein et al. 2014).

Considering the biophysical environment in Guyana, several limits to adaptation are likely to currently exist now and/or in the future. Increase high temperature limits the amount of time farmers can tend to their fields without suffering from heat exhaustion or other health issues. Even if farmers wear protective clothing (e.g., long sleeve shirts and a hat), the increase in humidity makes working in the fields for extended periods more uncomfortable. With temperature projected to rise further in the foreseeable future, rice cultivation will become more difficult. It will further reduce the amount of time farmers can spend in their fields since protective clothing may no longer be effective. Furthermore, once the heat tolerance of the plant is reached and in the absence of heat tolerant varieties, rice cultivation may no longer be viable. Even if a heat tolerant variety existed, there will still be a heat tolerance threshold to contend with.

Shifts in rainfall patterns, low lands, and current drainage and irrigation systems limit farmers' ability to respond to flooding. In some sections and/or districts across each region, excess rainfall usually overwhelms existing drainage systems resulting in overflows across the land. Thus, pumping out water from inundated fields is physically impossible. As a result, farmers are left with little choice but to wait for the water to recede. Physical environmental thresholds aside, financial limits relating to the cost of pumping water may preclude small farmers from artificially draining their fields. Despite having off-farm income, small farmers are also limited by finite financial resources. Additionally, the cost of maintaining and/or raising levies and dredging silted canals and outfalls on a regular basis are prohibitively high for developing countries like Guyana with endless development priorities. Furthermore, upgrading infrastructure such as levies and canals based on present norms may be not suffice under future conditions. Yohe and Tol (2002) argue that levies can still be overwhelmed, and silt will re-deposit over time.

The intensity and frequency of extreme events such as drought and heavy winds also places limits on adaptation. The lack of water available in the irrigation system during dry spells and drought leaves farmers with no response. In cases where some water is available in the system, small farmers incur additional cost to pump the water into their fields. Kusters and Wangdi (2013) found that water available to poor farmers became increasingly expensive during periods of irregular rainfall. At some point, the costs of pumping water may outweigh the benefits. Drought also lead to saltwater infiltration which limits adaptation in the absence of drought and salt-tolerant rice varieties in Guyana. Farmers in general are also limited in their adaptation to heavy winds. Given the layout of rice fields, the planting of trees to serve as wind breakers is impractical given the number of trees required and the associated costs of planting. While the most recent variety (GRDB 15) released in April 2018 promises better performance against lodging, this may not be the case under future environmental conditions.

The topography, elevation and soil type also limit the type of crops that can be planted. Given that the great majority of the land is clay base, flat, and below sea level, planting other crops that are far less water tolerant presents greater flood related risk. While small farmers could in theory reshape their fields to plant row crops, there are several limits to consider. It is prohibitively expensive to transform the field. The lack of expensive specialized equipment means that harvesting will need to be done manually. However, there is likely to be a labor shortage given Guyana's small population. Still there are likely limits relating to farmers' knowledge of other crops and problems with finding markets.

There are also socio-cultural limits related to social norms, identity, place attachment, age, and education. For most small farmers, rice farming is a social norm of rural life. Having grown up in rice farming, it is part of who they are and what they know; a way of life handed down from their fore parents. It is their legacy and they are intimately attached to the land and rice. Replacing rice with another crop is borderline sacrilegious for many of these farmers regardless of the promised economic benefit. However, at some rainfall and temperature threshold point, they may no longer be able to adapt thus forcing them to give up rice production altogether.

The age and education level of small farmers also induce limits to adaptation. Older farmers are reluctant to change their farming practices. There is also a cultural component that encumbers their way of thinking in that the older generation “knows best”. As one extension officer related, “there are certain farmers that are so bent in their ways, that they would never take advice from a young extension officer.” The lack of education and knowledge may also limit some small farmers from undertaking adaptation practices.

Given that opportunities and resources may be finite for many small farm households, there are also economic limits at the farm-level. Coase (1960) suggested that in a perfectly competitive marketplace where transaction costs are low, efficient outcomes would prevail. High costs of inputs such as fertilizer and chemicals create disincentives for small farmers to adapt. Thus, the lack of economic incentives will do little to encourage farmers to engage in optimal adaptation practices. Similarly, if the price received at the mill is not profitable, then farmers will not incur additional expenses related to adaptation. The lack of government subsidies and tax exemptions would also limit small farmers’ ability to acquire farming equipment to help with adaptation while the absence of safety nets often means farmers have little to fall back on or look forward to in the event of losses due to climate change.

There are also limits to adaptation regarding the application of fertilizer and chemicals such as insecticides and fungicides. At some point, the law of diminishing marginal returns steps in where the returns from applying additional fertilizer, insecticides and/or fungicides results in relatively smaller increase in yields. Additionally, increasing insecticide use may result in insects developing resistance thus rendering the control less effective. Increase use of fungicide also increases the risk of higher traces of chemical residues on grains which could affect quality. In either case, such behavior can be maladaptive.

The lack of ownership of farming equipment also limits small farmers' ability to effectively adapt. For instance, if good weather prevails, small farmers need to wait until large farmers finish preparing their own lands and perhaps other small farmers' lands. Thus, they may likely miss the ideal sowing window. Alternatively, even if small farmers are able to sow early, their harvesting may be delayed if other farmers in the planting section fields are not ready to harvest. This is because, combine operators will not enter a section until multiple fields are ready to harvest.

6.16 Conclusion

This chapter provides an in-depth analysis of small farmers' perceptions, impacts and adaptations to changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds. Small farmers in general had a good understanding of climate change or global warming and were able to reflect on common changes in atmospheric conditions attributed to climate change and how they relate to them. An overwhelming majority of small farmers perceived changes in rainfall, temperature, extreme weather events, insects and pests, and weeds. However, perceived changes in diseases were less noticeable perhaps because most small farmers are planting newer blast resistant varieties. These observations were also supported by key informants.

The specific changes concerning rainfall provide additional insights not captured through the analysis of aggregated precipitation data for Guyana. Small farmers noted that rainfall increased in and out of season while key informants alluded to an increase in rainfall intensity. Although total annual rainfall across the country may not have changed significantly (see Chapter 4), changes in the distribution and intensity of rainfall still pose considerable risks, which was highlighted through the farm-level data.

Among the multiple impacts of the perceived changes in rainfall, both small farmers and key informants indicated that harvesting was most affected due to poor dams, wet fields, and lodging of plants. In response to the various impacts reported, farmers engaged in different adaptation practices. The adjustment of planting dates based on water availability and cultivation of different rice varieties were the main response alluded to by small farmers and key informants, respectively.

Both small farmers and key informants agreed that the observed changes in temperature caused the days to be hotter. This coincides with the findings of aggregated temperature data analyzed which showed that both minimum and maximum temperatures have increased over the last 111 years. Hotter days accelerated the evaporation of water in the field thus requiring farmers to replenish the water to allow the grains to mature.

An increase in paddy bugs was the main observation regarding changes in insects and pests. Paddy bugs damaged the grains leading to lower quality and quantity at harvest. In response, farmers are engaging in more preventative spraying. While this is a more conservative approach, it appears farmers prefer to be safe rather than sorry. However, the increase in preventative spraying may also lead to insects in general and paddy bugs specifically becoming immune and/or the destruction of beneficial insects.

Small farmers and key informants also agreed that brown spot disease has increased. Although newer varieties are blast resistant, they are still susceptible to brown spot. Damage to plants or stunted growth was the major impact of diseases reported by small farmers while key informants felt that changes in disease in general and brown spot in particular, reduced the amount of food the plants manufactured through photosynthesis. In both cases, the yield potential of the plants is negatively affected. Preventative spraying and rotation of fungicides were the primary responses by farmers.

An increase in red rice and duckweed were the major change in weeds observed by both small farmers and key informants. The primary impact reported by small farmers was a reduction in plant population due to displacement. However, key informants provided a more detailed account, noting that the observed changes in weeds increased competition for nutrients, space, fertilizer, and sunlight. The primary response alluded to by both groups involved the spraying of more herbicide and the use of a contact chemical to burn red rice in particular.

Excess rainfall that led to flooding, drought, and heavy winds were the primary extreme weather events observed by small farmers and key informants. In terms of specific impacts, small farmers emphasized the impact of flooding during the early stages of growth. They reported that excess rainfall and associated flooding submerged, uprooted, and/or killed young plants. Key informants however, mentioned that lodging of plants due to heavy winds and flooding was the major impact. Matured fields are more susceptible to lodging since the combination of rainfall and flooding saturates the plant stack making it less sturdy to withstand heavy winds. In response to flooding, farmers pumped out water from their fields while they pumped water into the field during dry spells and drought. There is very little that farmers can do in response to heavy winds.

Some adaptation practices farmers engaged in created synergies while others resulted in conflict. For instance, leveling fields facilitates better water management and also helps farmers suppress weeds by growing the rice through water. Similarly, controlling weeds not only reduces competition for water, space, and nutrients, but also helps to remove potential host plants for insects. On the other hand, increased use of fertilizer helps with plant nutrition but also help weeds to proliferate. Fertilizer leaching and/or run-off also provides nutrients for weeds that grow in drainage canals leading to overgrowth that impedes the flow of excess water.

Given the various changes observed and impacts experienced, all small farmers interviewed acknowledged making changes to their farming practice in the last five years. With a list of adaptation practices read to them, small farmers confirmed engaging in practices that were not previously mentioned. This data meshed well with adaptation practices that were reported and/or ranked higher by key informants.

While both seasons were reportedly affected by the changes observed, small farmers noted that the autumn season has been more affected. Yet, more small farmers reported suffering crop failure in the spring season. This is because the spring season is usually at risk of both drought and flooding. Despite the impacts experienced including crop failure, most small farmers reported higher yields on average. This may be credited to better agronomic practices, ongoing adaptation efforts, and the cultivation of newer high yielding rice varieties. It is worth mentioning that perhaps yields could have been higher had it not been for the negative impacts associated with climate change. Additionally, cost of production would be lower if farmers did not have to pay for various adaptation practices to secure yield quality and quantity.

Most small farmers were able to use money from other sources to cope with low prices, late payments by millers, and the losses suffered due to changes in weather patterns.

This is because most small farmers had at least one secondary source of income to help them cope with any shortfall in income from rice farming. Regardless, there is a loss in welfare since such income could have been saved or used elsewhere.

It is important to note that the rice extension service is also playing a vital role in helping farmers to adapt. Not only are extension officers disseminating new information and technologies, they are also actively involved in farmers' education through farmer field schools, field visits, field demonstrations, and outreaching events. They are also involved in interagency co-ordination as it relates to access to irrigation, and the maintenance of drainage and farm-to-market roads.

Despite the best efforts to adapt, barriers and limits to adaptation do exist. Access to accurate and timely weather information, access to knowledge regarding adaptation practices, access to markets and credit, and government assistance and subsidies prevent farmers from effectively and efficiently adapting. While these barriers may be overcome at some point in the future, biophysical environment limits, and some economic and sociocultural thresholds cannot be overcome now and/or in the future.

Chapter 7 Conclusion and Recommendations

7.1 Introduction

This research primarily adopts a descriptive approach to study climate change perceptions, impacts, and adaptation among small rice farmers in Guyana. The findings provide important insights that serve to enhance our understanding of climate change at the farm-level and can be used to further bolster the incentive farmers have to adapt to shifts in weather patterns while providing empirical evidence for policymakers and other key stakeholders to act upon. Section 7.2 provides a summary of the key findings, while section 7.3 presents the policy implications and recommendations. Section 7.4 suggests research areas for future work.

7.2 Summary of Key Findings

The major findings organized by research questions are presented below.

7.2.1 Research Question 1: How has the climate in Guyana changed?

Evidence from descriptive statistics, linear trend model, and a two-sample t-test show that minimum and maximum temperatures have increased over the last 111 years. The absolute variability measured by the standard deviation and the relative variability measured by the coefficient of variation (CV) suggests greater shifts in minimum and maximum temperatures over the last 45 years. A strong time trend for the mean, standard deviation, and CV of minimum and maximum temperatures is also evident. Hence, these variables are time-dependent. There is also statistically significant evidence that the mean annual minimum and maximum temperatures are different between the periods 1934-1974 and 1975-2015.

Whether or not the amount of rainfall has changed over the last 111 years remains less clear, although longer-term models suggest that precipitation patterns are changing and will further change over the remainder of the century. Evidence from the descriptive statistics indicates a slight upward trend in the mean annual rainfall while there is a steeper trend in the standard deviation and CV. While there is no evidence of a statistically significant time trend in the mean annual rainfall, there is statistically significant evidence of a time trend in the standard deviation and coefficient of variation. This would suggest that, while the overall volume of precipitation may be relatively constant, variability is increasing. There is no statistically significant evidence that the mean annual rainfall is different between the periods 1934-1974 and 1975-2015.

7.2.2 Research Question 2: What non-climatic factors influence rice yields of small farmers?

Land tenure status, tractor ownership, membership in an agricultural organization(s), secondary non-agricultural income, and farms located in regions two and four were found to have a positive relationship with annual yields. These relationships do not indicate causality, but possible explanations emerged from interviews with farmers and other key interviewees. Small farmers that have property rights are more likely to invest in the development of their land thereby increasing their yields. Owning a tractor enables farmers to take advantage of suitable weather conditions and engage in proper land preparation. This helps ensure that they are able to plant within the season and avoid potential disaster of harvesting out of season under wet conditions thus contributing to higher yields. Membership in an agricultural organization(s) allows farmers to gain access to knowledge and information on new technologies and adaptation practices that can be used to improve their farm management practices. Off-farm income provides farmers with the financial means to afford costly adaptation practices such as additional control measures for insects and pests, pumping of water and the purchase of new seeds. Small farmers in regions two and four appear to be more involved in the day-to-day management of their farms. They also benefit from a close working relationship with extension officers who often go above and beyond. In 2017, the extension officer for region four was recognized as the Extension Officer of Excellence in the Caribbean by Caribbean Agricultural Extension Providers Network (CAEPNET).

Perceived changes in rainfall, farm size, livestock ownership, farmer participate in rice extension training, and household members help with rice farming were found to have a negative relationship with annual yields. Again here, correlation does not imply causality; however, there are noteworthy possible explanations. It is likely that farmers that perceived changes in rainfall were unable to adapt in a timely manner or the adaptive efforts undertaken were ineffective. The adaptation practices applied on larger small farms are usually more difficult and costly to manage. For instance, more labor and larger quantities of chemicals to control insects and weeds may be outside the financial means of small farmers with larger plots. Livestock ownership among small farmers appears to be the main farming activity. Thus, it is likely that these are competing interests where greater emphasis is placed on rearing livestock instead of planting rice.

Farmers that participate in rice extension training may not be able to implement such knowledge because of biophysical and climatic conditions that limit their ability to act. For example, farmers whose land is already low and thus prone to flooding may suffer a decline in yields by reducing seed rates. Alternatively, there may be poor implementation of advice received. Household members that help with rice farming may not possess the skills and experience of seasonal laborers. As such, their involvement with rice farming may be ineffective and/or counterproductive.

In the spring season, land tenure status, tractor ownership, secondary non-agricultural income, and farms located in regions two and four were found to have a positive relationship with rice yields while perceived changes in rainfall, farm size, livestock ownership, farmer participate in rice extension training, and household member(s) help with rice farming were found to have a negative relationship with yields. In the autumn season, male farmers, land tenure status, tractor ownership, membership in an agricultural organization(s), secondary non-agricultural income, soil test, and farms located in regions two and four have a positive relationship with yields. Male farmers are more likely to access new information on adaptation best practices from their male counterparts. A soil test informs farmers of the health and quality of the soil. This information helps them to make better farm management decisions at is relates to fertilizer application and water management which could increase yields. Livestock ownership and adequate irrigation were found to have a negative relationship with yields. Farmers that receive adequate irrigation may not be engaging in proper water management which negatively affects yields.

7.2.3 Research Question 3: How do small rice farmers and key informants perceive changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?

In general, small farmers have a good understanding of climate change or global warming and are able to reflect on common changes in atmospheric conditions attributed to climate change. However, they do not quite understand how or why the climate is changing. The great majority of small farmers and key informants perceived changes in rainfall, temperature, extreme weather events, insects and pests, and weeds. However, perceived changes in diseases were less noticeable perhaps because most farmers are planting newer disease resistant varieties.

Rainfall increasing in and out of season was the key change reported by small farmers while key informants noted an increase in rainfall intensity. This is an important finding since the analysis of aggregate data suggests total rainfall has not changed. Other observations of changes in rainfall include an increase in out of season rainfall, no more seasons, unpredictable rainfall, early or late rainfall, and rainfall fluctuates between seasons. Small farmers and key informants perceived changes in temperature by referring to the increase in hotter days. This coincides with the findings of aggregated temperature data analyzed which showed that both minimum and maximum temperatures have increased over the last 111 years.

An increase in paddy bugs was the main change in insects reported. Small farmers and key informants also contend that paddy bug infestations are correlated with changes in rainfall patterns. An important observation relates to the appearance of the brown planthopper and the leaffolder in the last two seasons. These two insects were previously never recorded in Guyana. Other insects and pests that have increased include water weevil, snail, caterpillar, leaf miner, and slug.

Small farmers and key informants noted that brown spot disease has increased. This may be attributed to the decline in spraying for blast disease since the same fungicide also controls brown spot. While the newer rice varieties are blast resistant, some farmers still reported the presence of blast. These are likely to be farmers that are planting the older varieties.

An increase in red rice and duckweed were the major change in weeds observed. Both weeds compete with the rice for space, sunlight, nutrients, and water. However, a higher percentage of red rice grains in the harvest reduces the quality and by extension the price farmers received. Other weeds that have increased include jhussia, monkey tail, muraina, and sedges. Some farmers and key informants did report a decrease in weeds due to continual control efforts. Excess rainfall that led to flooding, drought, and heavy winds were the primary extreme weather events observed.

7.2.4 Research Question 4: What impacts are farmers and key informants seeing due to the observed changes in rainfall, temperature, extreme weather events, insects and pests, diseases, and weeds?

Changes in rainfall had the greatest impact on harvesting due to poor dams [farm-to-market roads], wet fields, and lodged plants. Impassable dams prevented timely access to the fields and increased the time and costs associated with transporting the harvested grains from the field to the mills. Wet fields delayed harvesting which reduced the quality of grains while lodged plants often go unharvested. The major impact of higher temperatures was the acceleration of water evaporation in the field. This often resulted in farmers needing to replace loss water. However, farmers in general noted that higher temperatures resulted in better yields.

Paddy bugs damage the grains leading to lower quality and quantity at harvest. Infestations detected too late almost certainly results in damages to the entire field. Damage to plants and stunted growth were the major impacts of diseases reported by small farmers while key informants noted that changes in disease in general and brown spot in particular, reduced the amount of food the plants manufactured through photosynthesis. In both cases, the yield potential of the plants is negatively affected.

Small farmers noted that weeds reduced plant population due to displacement. Key informants noted that the observed changes in weeds increased competition for nutrients, space, fertilizer, and sunlight. As such, the amount and quality of grains harvested are negatively impacted. According to small farmers, excess rainfall and associated flooding submerges, uproots, and/or kills young plants. However, key informants mentioned that lodging of plants due to heavy winds and flooding was the main impact.

7.2.5 Research Question 5: What adaptive measures are they adopting in response to these impacts?

The two main responses by farmers in relation to the changes in rainfall involved adjusting planting dates based on water availability and cultivating different rice varieties. Some farmers also planted early and/or ensured drainage in and around their fields were properly maintained. They also added drainage outlets to their fields and/or used mechanical pumps to hasten the removal of excess water from the field. It is interesting to note that some farmers reported not engaging in any adaptation in response to changes in rainfall. In response to changes in temperature that accelerated the evaporation of water from the field, over 50 percent of farmers replenish the water loss from their field. However, about a quarter of farmers did nothing in response. This is perhaps due to low water levels in the irrigation canals or the lack of water as a whole.

Farmers responded to the threat of paddy bug infestation by engaging in more preventative spraying. They are also engaged in seed treatment in an effort to control early seasons insects and pests. Preventative spraying and the rotation of fungicides were the primary responses by farmers in relation to changes in diseases. As it relates to changes in weeds, the primary response by farmers involved spraying of more herbicide and the use of a contact chemical to eliminate red rice. Some farmers, especially seed paddy producers are engaging in dry and/or water rogueing while some are improving water management in an effort to suppress early season weeds.

Farmers are engaging in several responses with regards to extreme weather events. In response to drought, farmers are pumping water into their fields. This is assuming water is available in the irrigation canals. On the other hand, farmers are pumping out water from their fields in response to excess rainfall that leads to flooding. They are also creating new drainage outlets or maintaining existing drainage in anticipation of excess rainfall and associated flooding. Farmers are limited in their response to heavy winds.

7.2.6 Other Findings

Apart from the findings related to the specific research questions, other findings are worth mentioning:

All small farmers interviewed indicated that they have been engaging in multiple adaptation practices over the last five years. The primary practices include increased herbicide and pesticide application (quantity and frequency); planting different rice varieties; buying new seeds each season; treating seeds for insects; changing sowing/ planting dates; increased fertilizer application (quantity and frequency); pump water; reduce plant densities; spray water in field; sow more seeds; leave land idle; rent out land to large farmers; rotate rice variety; exited rice cultivation and seek off-farm employment; block planting; and patching.

While both seasons were reportedly affected by the changes observed, small farmers noted that the autumn season was more affected. However, more small farmers reported suffering crop failure in the spring season. The autumn season coincides with the primary rainy season [May-July] and is historically susceptible to flooding. However, the spring season is at risk of both drought-like conditions and flooding.

Despite the changes observed, most small farmers reported higher yields on average which may be due to better agronomic practices, ongoing adaptation efforts, and the cultivation of newer high yielding rice varieties. Since 2009, six new varieties have been released through the Guyana Rice Development Board plant breeding research program.

The majority of small farmers had at least one secondary source of income and were able to utilize money from such sources to cope with low prices, late payments by millers, and the losses suffered due to changes in weather patterns. Thus, off-farm employment is a key coping strategy. Rice extension service is helping farmers to adapt by disseminating information and technologies and facilitating farmers' education through farmer field schools, field visits, field demonstrations, and outreach events. However, the lack of new information to share with farmers has resulted in low attendance in recent times.

Extension officers are also involved in interagency coordination as it relates to access to irrigation, the maintenance of drainage and farm-to-market roads. Access to accurate and timely weather information, access to knowledge regarding adaptation practices, access to markets and credit, and government assistance and subsidies are major barriers to effective adaptation reported by farmers.

No form of crop insurance currently exists in Guyana. A report by the World Bank found institutional, technical, financial, and operational challenges related to the provision of crop insurance in Guyana. There is currently no drought, flood or submergence-tolerant, or salt-tolerant rice varieties in Guyana. Drainage and farm-to-market roads are neglected and/or poorly maintained. Small farmers and key informants emphasized the poor state of farm-to-market roads and the drainage system despite repeated calls for action to be taken.

7.3 Policy Implications and Recommendations

The findings of this research have far-reaching policy implications for the rice industry. Given the observed changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds, policy recommendations to improve rice production and farmer's resilience under a changing climate are organized into four general areas: crop development and farming practices; irrigation and water resource management; crop and income loss risk management; and disaster risk management (Bockel 2009).

7.3.1 Crop Development and Farming Practices

Policies in this area focus on research and development capacity, including the development of new rice varieties that are tolerant and suitable under the current and projected future climatic conditions. Additionally, support policies such as tax reduction on agricultural inputs and equipment and improving rice extension service capacity in terms of resources, supplies, and equipment can help encourage and/or increase farmers' adaptation and resilience.

7.3.1.1 Research and Development

Changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds are only expected to increase over time, necessitating greater emphasis on research and development. As such, the GRDB should invest heavily in its research facility to bring it up to international standards. This includes purchasing laboratory equipment and supplies to improve research in areas of plant breeding, agronomy, pathology, and entomology. Examples of equipment and supplies needed include a large oven to break dormancy, a screen house and insects to conduct biological control research, and laboratory equipment to conduct grain analysis. A fully equipped research facility will help enhance the efficiency of research and development activities that focus on addressing ongoing and future risks posed by climate change.

While there are ongoing efforts by the GRDB on varietal development, there should be greater emphasis and urgency in developing drought, flood or submergence-tolerant, and salt tolerant rice varieties. Resources from the International Rice Research Institute (IRRI), the International Center for Tropical Agriculture (CIAT), and the Latin American

Fund for Irrigated Rice (FLAR) should be leveraged to help fast track the development of these varieties in order to combat extreme weather events. Alternatively, the GRDB should approve the use of high yielding varieties from other countries that are compatible with the agronomic conditions in Guyana.

7.3.1.2 Taxes Exemption

Changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds have precipitated various adaptation practices among small farmers. However, these practices are costly and sometimes fail to offer relief under extreme conditions. As such, the government (Ministry of Finance (MoF) and the Guyana Revenue Authority (GRA)) should remove value-added tax (VAT) from agricultural inputs (e.g., fertilizer, insecticides, fuel, spare parts, and seeds) and taxes and import duty on machinery and equipment (e.g., motor blower, tractors and implements, combine harvesters) in order to reduce cost of production and enhance farmers' ability to adapt to climate change. By making agricultural inputs zero-rated items under the VAT regime, farmers will have additional disposable income to spend on adaptation practices. It should be noted however, that lower prices for fertilizer and insecticides could be maladaptive. Lower prices can certainly precipitate inefficiencies leading to higher greenhouse gas emissions and other environmental impacts per metric ton of rice produced. Duty-free concessions on farm machinery and equipment will significantly lower the acquisition costs, making it more affordable for farmers in general and small farmers, specifically.

7.3.1.3 Resources and Capacity Development for Extension Officers

The negative correlation between extension training and yields suggests there is room for improvement in their services; this may be particularly true as they are pushed to help farmers deal with uncertain climatic changes. Hence, the GRDB should provide additional professional development and training opportunities for extension officers. This may include both local and overseas training courses and seminars. Areas of training may include climate change impacts and adaptation, weather forecasting, integrated pest management (IPM), rice production and quality control, rice marketing, and training across different agricultural agencies. The knowledge and resources acquired by extension officers will be used to enhance the quality of extension service provided to farmers under a changing climate. Several authors have highlighted the importance of extension service as it relates to climate change adaptation (Charles 2009; Sarker 2012; Nyuor et al. 2016; Huong, Bo, and Fahad 2018).

The GRDB should also ensure that extension officers are properly equipped to effectively perform their duties and responsibilities to support farmers. This includes providing personal protective gear (e.g. raincoats), first aid kits, saltwater meters, projectors, and cameras for field visits and visits with farmers. These resources will help protect extension officers in the field while enabling them to effectively and efficiently discharge their duties and responsibilities. To enhance training activities and the experience of farmers, GRDB should ensure that chemicals and equipment are provided for field demonstrations, and printed brochures and weather calendars are available for distribution. The GRDB should also incentivize farmers for cooperating with the board as it relates to plot demonstration and other activities that require significant farmer involvement.

7.3.1.4 Integrated Pest Management (IMP) and Improved Management Practices

Increases in paddy bug infestations and other insects and pests suggest the need for swifter uptake of IPM. Although IMP currently exists in Guyana, uptake is still relatively nascent. Therefore, the MoA and the GRDB should emphasize the importance of IPM and encourage its adoption through various farmers' education programs and activities. Given that the six 'improved management practices' were introduced over a decade ago, the GRDB should improve upon these practices. They should also develop video programs on various agronomic practices that farmers can easily access.

7.3.2 Irrigation and Water Resource Management

Policies in this area focus on irrigation system management to allow for better water management and adaptation practices in order to address the increasing frequency of droughts experienced in Guyana.

7.3.2.1 Improve Maintenance and Management of Irrigation System

Poor irrigation system management is exacerbated by the changes in precipitation patterns identified by small farmers. The MoA through the National Drainage and Irrigation Authority (NDIA) and the respective water user associations should ensure that irrigation systems are consistently and properly maintained and/or improved. Proper maintenance of irrigation systems helps ensure that water flow is unimpeded thereby ensuring easy access to water, especially during sowing. Additionally, improve demand management and water allocation is crucial during drought. Thus, rationing of available water is necessary to enhance the efficiency of water use and ensure that farmers further away from the source also benefits.

7.3.2.2 Improve Water Management Innovation

During droughts, the irrigation systems are often affected by saltwater intrusion. With the expected future increase in droughts, improvement in water management innovations such as small-scale water capture, storage, and use can help to mitigate the risk posed by saltwater. This is even more important in areas where there are no water conservancy (e.g., Leguan) and/or irrigation infrastructure in place.

7.3.3 Crop and Income Loss Risk Management

Policies in this area are both *ex ante* and *ex post* in nature. Access to stable rice markets and price floors incentivize farmers to grow rice while access to credit helps farmers pay for expensive adaptation practices. The introduction of crop insurance programs helps to spread risk while the provision of subsidies and assistance help farmers recover from crop failure.

7.3.3.1 Rice Markets and Price Support

The high costs of various adaptation practices farmers are currently engaging in are unsustainable under climate change. The increased costs of production coupled with the risk of lower yields and prices pose a major challenge for small farmers. It is only under profitable market conditions that farmers are incentivized to engage in costly adaptation practices with the expectation that their returns on investment will be worthwhile. In addition, price stabilization policies such as a minimum price can help farmers decide in advance their farm management strategies under a changing climate. Thus, the MoA and the GRDB should intensify the promotion and marketing of Guyana's rice in an effort to further diversify rice exports and secure stable and more lucrative markets. Diversification of rice markets would help to reduce risk associated with price fluctuations resulting from changes in regional and global demand. As a means of supporting farmers, the government should consider providing price support to help mitigate low prices and/or high cost of production that is evident in the rice industry. Stable markets and a minimum guaranteed price will help farmers to make better farm management decisions given the current and expected future changes in climate.

7.3.3.2 Access to Credit

The impacts of changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds coupled with ongoing adaptation efforts reinforce the importance of credit markets under a changing climate. Apart from providing funds for farm investment (e.g., land improvement and machinery and equipment purchases), improving post-harvest practices, smoothing household cash flow, enabling better access to markets, and promoting better risk management, access to credit also plays a crucial role in climate adaptation and resilience of agriculture to climate change (IFC 2014). For instance, access to credit enables farmers to purchase better quality inputs (e.g., seeds, fertilizer, and pesticides), implement irrigation systems, and engage in crop rotation and agroforestry in response to climate change. Thus, the MoA and the GRDB should engage commercial lending institutions to increase the availability of credit at reasonable interest rates to farmers in general and small farmers specifically. Additionally, the government should explore the possibility of re-establishing an agricultural development bank to help support farmers as a whole.

7.3.3.3 Access to Crop Insurance

One of the most significant problems associated with climate change is that it can magnify uncertainty. As such, agricultural insurance can help farmers to transfer or mitigate some risk under a changing climate. The MoA and GRDB should incentivize insurance agencies to develop and provide crop insurance products to help farmers mitigate the risk posed by adverse weather, insects and pests, and disease. For instance, the introduction of Area-yield Index insurance products can prove instrumental in helping farmers to cope with the losses in yields attributed to weather (WB 2010a). In addition, the MoA and GRDB should educate farmers on the importance of crop insurance under a changing climate in order to encourage uptake.

7.3.3.4 Provision of Subsidies and Assistance

The increase in extreme weather events (e.g., flooding, drought, heavy winds) suggests the need to insulate farmers from crop failure. The MoA and GRDB should develop and institute safety net programs that provide subsidies and assistance to farmers, especially those that suffer catastrophic losses due to extreme weather events. Subsidies on inputs can help mitigate the high cost of production. Assistance to farmers who have suffered crop failure and income loss due to extreme weather events can include seed paddy and/or fertilizer so that they can re-plant their fields in the subsequent season.

7.3.4 Disaster Risk Management

Policies in this area emphasize the importance of developing early warning systems to protect against loss from flood damage. In addition, support policies such as developing a framework for better interagency coordination can help rehabilitate and/or maintain drainage and other infrastructure (e.g., farm-to-market roads) systems in a timely manner, helping to mitigate the impacts of excess rainfall and associated flooding currently experienced in Guyana.

7.3.4.1 Improve Weather Forecasts and Climate Monitoring

Shifts in rainfall patterns such as out of season rain and increases in rainfall intensity precipitate the need for more robust weather forecasting and reporting. As such, the capacity of the Hydrometeorological Service (Hydromet) should be strengthened in order to improve the monitoring and collection of climate data. This should include collecting more detailed data (e.g., rainfall intensity) and improving the weather forecast information available to farmers. Specifically, weather reports should be tailored to each region and areas within each region in an effort to develop community-based early warning systems. In addition, the weather forecasts should be presented in a manner that is easy to understand for farmers, many of whom lack formal education. Sarker (2012) stressed the importance of farmers accessing advance weather information to help with climate adaptation. Accurate and timely weather forecast information would also enable extension agents to give appropriate agronomic advice to farmers so that they can make better farm management decisions under the current and expected future climatic conditions.

7.3.4.2 Improved Management of Drainage System

More intense rainfall events, including extreme rainfall that leads to flooding, can easily overwhelm the current drainage infrastructure. The MoA through the National Drainage and Irrigation Authority (NDIA) should ensure that drainage systems are consistently and properly maintained and/or improved in order to help mitigate the risk posed by extreme weather events such as excess rainfall and related flooding. This may include larger appropriations for the dredging of the drainage canals and outfalls, the installment of additional pumps at key locations, and the timely provision of resources (e.g., fuel) to maintain and operate existing pumps. Such a policy can help stabilize the farming environment thus making it less shock prone during extreme weather events such as excess rainfall.

7.3.4.3 Better Interagency Coordination

Severe impacts from both extreme rainfall and drought conditions can be abated with improved communication and collaboration between the various agencies under the MoA. For instance, the prediction of extreme weather events by the Hydromet office could be relayed in a timelier manner to NDIA and the GRDB. The NDIA can ensure that major drainage and irrigation canals are properly functioning to accommodate excess water in the case of flood risks or the storage of water in the case of drought. The GRDB through the extension officers can ensure that farmers are aware of the impending extreme weather events so that they can make better farm management decisions. Thus, the MoA and GRDB should ensure that there is better interagency coordination and collaboration among the various national, regional, and local government agencies and organs that play a role in the rice industry. Improved coordination and collaboration will help ensure better information sharing and that timely action as it relates to getting farm-to-market roads and district-specific drainage canals properly maintained and operationally functional. This may entail increased allocation and/or the timely release of financial resources, dredging of new drainage canals, and/or the construction of all-weather roads in key locations.

7.3.5 Other Policy Recommendations

The findings of this research also highlight the need for policy improvement in several other areas. Improvements in these areas can individually and/or collectively enhance farmers' ability to effectively respond to the observed changes and corresponding impacts of climate change now and in the future.

7.3.5.1 Timely Payment of Farmers

In some areas, timely payment of farmers is a chronic problem, which is further exacerbated by climate change. Farmers whose payments are significantly delayed lack the resources needed to effectively and efficiently respond to climate change. As a result, they may be forced to abandon a specific adaptation strategy or cut corners. Thus, the Ministry of Agriculture (MoA) through the Guyana Rice Development Board (GRDB) should strictly enforce the payment requirements stipulated in the Rice Factories Act of 1998. The law requires rice millers to pay 50 percent of the amount due to farmers within two weeks of receipt of the grains and the remainder within 42 days. As an example, the GRDB can tie the renewal of milling licenses to full compliance with this law. Timely payment will allow farmers in general and small farmers specifically to have the necessary operating capital to effectively and efficiently engage in costly adaptation practices in response to climate change.

7.3.5.2 Independent Graders

Farmers engaging in costly adaptation practices are usually discouraged if the price they received for their grains is not competitive. A major concern is distrust between farmers and millers as it relates to the grading of grains and by extension the price farmers receive. Currently, the grading of grains is done by graders employed by the rice millers. Such an arrangement raises concerns over the integrity of the grading process since millers are in a position to influence graders under their employment. As such, the MoA through the GRDB should introduce independent graders to ensure that farmers are treated fairly by millers. In addition, the GRDB should mandate that all rice mills follow the established grading system. Independent graders and fair grading practices will help ensure that farmers receive optimal prices for their grains thus incentivizing adaptation practices.

7.3.5.3 Centrally Located Drying Facilities

Shifts in rainfall patterns affect harvesting. Grains harvested under wet conditions need to be dried in order to preserve milling characteristics and quality. As such, the MoA through the GRDB should construct additional drying facilities at strategic locations in each rice-producing region to facilitate the drying of paddy that is harvested under wet conditions. This will help farmers to prevent spoilage and/or maintain grain quality and hence price received at the mill. Additional, drying facilities will also reduce the dangers associated with the common practice of drying paddy on the roadways.

7.3.5.4 Consumer Protection

Although the majority of small farmers have increased the use of fertilizer and insecticides as part of their adaptation strategies, issues of quality remain a major concern. Thus, the Guyana National Bureau of Standards (GNBS) should ramp-up its efforts to ensure that fertilizer and chemicals available on the local markets are consistently of high quality. This will protect farmers from unscrupulous distributors and suppliers thus ensuring that they receive value for money spent on farm inputs. Similarly, the Pesticides and Toxic Chemicals Control Board (PTCCB) should ensure that imported chemicals are legal and registered for use in Guyana. This will help promote the safety of farmers and the environment under a changing climate.

7.3.5.5 Agricultural Association Membership

The positive relationship between rice yields and membership in an agricultural association emphasizes the importance of farmers joining agricultural groups. Although the Rice Producer Association (RPA) is expected to play an important role in protecting, promoting, and advancing the interest of rice producers, it is often viewed as politically driven and large farmer-focused. As a result, small farmers do not see the potential benefits of membership. As such, farmers in general and small farmers, in particular, should create or join other agricultural organizations or farmers self-help groups in order to strengthen their voices and gain access to information on new technology, adaptation practices, and climate change. Agricultural organizations can also actively engage farmers in developing positions on issues and connecting legislators whose viewpoints are in sync with that of farmers.

7.3.5.6 Soil Testing

The positive correlation between rice yields and a soil test emphasizes the importance of farmers conducting soil tests. However, the limited access to a soil testing facility in Guyana has been a historical barrier. With the recent construction of a soil testing facility at the University of Guyana's Berbice Campus, the MoA and the GRDB should ensure that small farmers have equal access to the services of the facility and at reasonable costs. These tests provide farmers with important information on soil quality and nutrient needs. Given the observed changes in rainfall, temperature, and extreme weather events, this information can prove crucial in helping farmers better adapt as it relates to water management and quantity and type of fertilizer to apply.

7.3.5.7 Internal Communication and Collaboration

The need for efficient and effective information dissemination is critical under a changing climate. The timely release of new information helps farmers to respond faster and make better farm management decisions. As such, greater attention should be given to communication and collaboration between the research and extension departments at the GRDB. Improved communication will help ensure that farmers are receiving timely advice on agronomic practices and new technologies to help combat the impacts of changes in rainfall, temperature, extreme weather events, diseases, insects and pests, and weeds. In addition, experts in specific research areas should be more involved in extension and outreach activities so that farmers can receive firsthand advice and answers to their questions directly from the respective experts.

7.4 Future Work

Given the strong descriptive nature of this research, future studies can explore the causal effect between rice yields and climate variables. For example, panel data studies based on secondary production and climate data can be used to explore the fixed or random effects of changes in rainfall and temperature on rice yields.

Although this research concentrates on small farmers across the five primary rice-producing regions of Guyana, future research could extend the analysis by including medium and large-scale farmers. This would allow for comparison across groups at the national and regional levels regarding climate change perceptions, impacts, and adaptation. Additionally, research could focus exclusively on specific areas that have historically suffered from floods, droughts, and saltwater infiltration. Such research findings could help policymakers to devise specific policies that target differences at the district and/or regional levels. Future research could also focus on differences across farmers that plant specific varieties. The literature suggests that climate change has heterogeneous effects on different varieties. Yields on older and newer high yielding varieties can be compared to ascertain which varieties are more vulnerable under a changing climate. Future research could also apply similar methodologies in other countries.

The multifaceted nature of this topic also encourages further research in related areas. As such, future studies could examine the impacts of climate change on other agricultural areas. While rice and sugarcane have historically been the bedrock of Guyana's agricultural economy, research can focus on cash crops such as vegetables which forms an integral part of the local agricultural output.

Another appealing research avenue would be to examine the effects of climate change on livestock production. The literature indicates that livestock is affected by floods, drought, and heatwaves. Research in this area can offer interesting insights from a non-crop agriculture perspective which would further strengthen thin empirical evidence that currently exist in Guyana.

Given ongoing concerns regarding the current state of the drainage and irrigation infrastructure, research can focus on ways to improve the current drainage and irrigation systems to better accommodate and/or withstand the additional stress created by a changing climate. Thus, research can explore ways to channel or divert water to prevent flooding during heavy rainfall events or ways to store water in the event of drought.

Future research can also focus on co-benefits, maladaptation, and limits to adaptation in the rice sector and beyond. Adaptation practices that result in multiple benefits being realized can be further explored to ascertain how best to replicate such practices across farmers, districts, and/or regions. In addition, research on the spillover effects of various adaptation practices can be pursued. As noted, some practices are maladaptive. Therefore, research can focus on the effects on maladaptation as it relates to rice production and environmental degradation as a whole. Research can also examine the limits to adaptation by studying the threshold at which the marginal costs of adaptation practices exceed the marginal benefits. In short, Guyana's agricultural sector provides ample research opportunities that would generate greater information and awareness of current and future impacts of climate change.

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APPENDIX A – SURVEY INSTRUMENT: SMALL FARMERS

Consent Statement

Dear Participant,

I invite you to participate in this research study that focuses on how small rice farmers in Guyana respond to weather patterns and variation in climate.

I am a graduate student at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia, and I am in the process of writing my Ph.D. dissertation.

The purpose of this research is to determine the impacts of climate change on rice production and how small rice farmers respond and adapt to variations in rainfall, temperature, and extreme weather events such as drought and excess rainfall.

Your participation in this research project is completely voluntary. You may decline altogether or skip any questions you do not wish to answer. Your identity and responses will remain confidential and anonymous. No one other than the researchers will know your individual answers to this questionnaire.

Please give your verbal consent if you agree to participate in this project. It should take approximately 1 hour to complete.

Thank you for your assistance in this important endeavor.

Sincerely,

Omchand Mahdu
Co-Investigator

Respondent ID: _________

Name of Respondent	
Village	
Telephone No.	
GPS Coordinates of Farmer's Home	
Administrative Region No.	

Part A – Socio-economic Data

1. Are you the farmer, the person who makes farming decisions on this farm?
____(0=No, 1=Yes)

If no, who is the head of the farm household and how can I get into contact?

____

2. Age of Respondent (in years): _____

3. Gender of Respondent: ____ (0=Female, 1=Male)

4. What is the highest level of education you completed? ____
(1=Primary, 2=Community High, 3=High School, 4=University, 5=Other

5. Is rice cultivation your primary occupation? ____ (0=No, 1=Yes)

Now I will ask some questions just about last year, 2016.

Notes:

6. Primary or secondary occupations/income sources of farmer (if any) in 2016: [check all that applies]

Agricultural	Check (✓)		Non-Agricultural	Check (✓)	
	Primary	Secondary		Primary	Secondary
Rice farming			Carpentry		
Cash crops/vegetables			Small business (shop keeping)		
Fruits			Wholesale/retail (buy and sell)		
Livestock			Service (painting, weeding, taxi, etc.)		
Fishery			Pension		
Ground provision (plantains, eddo, cassava, yams etc.)			Remittances		
Other agricultural (if any)			Other non-agricultural (if any)		

7. In 2016, did other members of the household participate in rice farming activities? (0=No, 1=Yes)

8. In 2016, did you employ any part-time labor to work on the farm? (0=No, 1=Yes

If yes, what activities were part-time laborers engaged? ________

Part B. Farm Structure and Characteristics

9. In 2016, how many acres of rice did you plant? _____

10. In 2016, who owned the land(s) you planted? What were your rice yields in bags per acre?

Type of land ownership	Size of plot (acres)	Yields (bags per acre)		Total Yields
		Spring Crop	Autumn Crop	
Own land – Self/Family				
Other Owner – Private (Individual)				
Other Owner - Other				

Notes:

11. On the land(s) you own in 2016, do you have legal title? ____ (0=No, 1=Yes)

12. How long have you been a rice farmer in this region (in years)? ____

13. Did you own any farming equipment in 2016? ___(0=No, 1=Yes)

If yes, what equipment did you own? _______

14. Did you shared or co-owned any farming equipment with other farmers in 2016? (0=No, 1=Yes)

If yes, what equipment did you shared/co-owned? _______

15. Did you rent any equipment in 2016? ___(0=No, 1=Yes)

If yes, what equipment did you rent and from whom? _______

16. Did you own any livestock in 2016 (cow, sheep, chicken, duck etc.)? ___(0=No, 1=Yes)

If yes, how many of each do you own? ______

17. What is the soil type/quality of land(s) you planted: ____ (1=Clay, 2=Clay-Loam, 3=Loam, 4=Sandy, 5=Other, 6=Do Not Know)

18. Have you ever tested your soil? (0=No, 1=Yes)

If yes, what was the result? ______

Notes:

Until now, I have been asking questions related to 2016. I will now ask questions related to the last 5 years.

C. Farmers Perceptions, Impacts, and Adaptation

19. Have you observed any major changes in rainfall patterns in your area in recent years (for example, the last 5 years)? _____(0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, how have rainfall patterns changed? ________

How have the observed changes in rainfall affected the quality and quantity of rice yields? ________

How have you responded to the observed changes in rainfall? _______

20. Have you observed any major changes in temperature in your area in recent years (for example, the last 5 years)? _____ (0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, how has temperature changed? ________

How have the observed changes in temperature affected the quality and quantity of rice yields? ________

How have you responded to the observed changes in temperature? _________

Notes:

21. Have you observed any changes in insects in your area in recent years (for example, last 5 years)? _____ (0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, how have insects' population changed? ________

How have the observed changes in insects affected the quality and quantity of rice yields?
____

How have you responded to the observed changes in insects? _________

22. Have you observed any changes in diseases in your area in recent years (for example, last 5 years)? _____ (0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, how have diseases changed? ________

How have the observed changes in diseases affected the quality and quantity of rice yields? ________

How have you responded to the observed changes in diseases? _________

Notes:

23. Have you observed any changes in weeds in your area in recent years (for example, last 5 years)? _____ (0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, how have weeds changed? ________

How have the observed changes in weeds affected the quality and quantity of rice yields? ________

How have you responded to the observed changes in weeds? _________

24. Have you observed any extreme weather event(s) (severe drought, excess rainfall, wind storms, flooding etc.) in your area in recent years (for example, the last 5 years)? _____(0=No, 1=Yes). If the answer is yes, answer question 29.
If yes, describe the extreme weather event(s). _______

How were the quality and quantity of rice yields affected? ________

How did you respond to the extreme weather event(s) noted above? _________

Notes:

25. If you have seen changes in any of the above areas in recent years (for example, the last 5 years), which crop has seen the greater impact? ____ (0=Spring crop, 1=Autumn crop, 2=Both crops equally)

26. How has your overall rice yield changed in recent years (for example, the last 5 years)? _______ (1=Significantly Lower, 2=Lower, 3=Higher, 4=Significantly Higher, 5=No Change)

27. Have you experienced any crop failure in recent years (for example, the last 5 years)? (0=No, 1=Yes).

If yes, which season did the crop failed?____ (0=Spring, 1=Autumn)

28. If you have seen declines and/or experienced crop failure, how have you coped with reduced yields, grain quality, etc. in recent years (for example, the last 5 years)? ________

29. In recent years (for example, the last 5 years), have you made any changes to your farming practice in relation to the observed changes in rainfall and temperature patterns, insects, diseases, and/or extreme weather events? ______(0=No, 1=Yes)

If yes, which if any of the following practices have you adopted to reduce losses?

Adaptive Measures	Check all that apply
Changing sowing/planting dates	
Use different rice varieties	
Buy new seeds each season	
Pump water	
Treat seeds for insects	
Reduce plant densities	
Agroforestry (example rice and coconut)	
Increase fertilizer application (quantity and frequency)	
Increase herbicide and pesticide application (quantity and frequency)	
Crop rotation	
Cultivation of other crops	
Rent out land to large farmers	
Exited rice cultivation and seek off farm employment	
Leave land idle	
Other (please specify)	
No adaptation	

Notes:

30. How did you pay for these changes in farming practice?

Adapt to adaptation	Check all that applies
Borrow from family members	
Sell livestock	
Use savings	
Input credit (fertilizer, herbicide, pesticide, seeds)	
Sell productive assets	
Borrow from other farmers	
Obtain institutional microcredit	
Borrow from commercial bank	
Off farm employment	
Government support/subsidy	
Remittances	
Pension	
Other (please specify)	

31. How difficult was it to pay for these activities? Explain___________

32. How important was each of the following barriers in preventing you from engaging in the activities listed in question 29?

Barriers	1=Very Important	2=Important	3=Slightly Important	4=Not Important
Availability of information about extreme weather events, changes in rainfall and temperature				
Access to adequate irrigation facilities				
Access to knowledge regarding adaptation practices				
Access to money/savings/credit				
Ownership of land				
Availability of labor				
Price received for rice paddy				
Subsidized inputs				
Tax exemption on inputs and equipment				
Availability of markets for rice				
Government assistance/subsidies				
Other (please specify)				

Who did you expect to help? Explain_________

Notes:

33. Have you ever heard of the term climate change/global warming? _____(0=No, 1=Yes)

If yes, what does it mean to you? _______

34. Are you familiar with the Guyana Rice Development Board (GRDB) 6-point practices? ____(0=No, 1=Yes)

35. If yes, what have you heard about these practices? ________

36. Which of these practices have you employed in recent years (for example, the last 5 years)? [Check all that applies]

Practice	Check (✓)
1=Time of sowing (adjusting planting dates)	
2=Seed rate (optimal plant density)	
3=Treatment of seeds (with insecticides)	
4=Weed control (pre and post emergence)	
5=Balance nutrition (fertilizer application)	
6=Water management (timing and adequacy of water application).	

Part D. Institutional Accessibility

37. In recent years (for example, the last 5 years), did you participate in any extension training/activities (farmer field schools, field visits, field demonstrations), or received any advice and/or guidance about rice production? ____ (0=No, 1=Yes). If yes, answer questions 38 and 39.

38. What type of extension training, advice and/or guidance did you receive and how did you use the new knowledge? ________

39. From what source(s) did you receive extension training, advice and/or guidance? ____ (1=Government (GRDB), 2=NGO, 3=Other farmers, 4=Farmers' association; 5=Other (please specify)________)

40. In 2016, did you receive advance weather (temperature, rainfall, humidity, wind etc.) information from any source? (0=No, 1=Yes)

If yes, from what source? ____(1=Agricultural Extension Office, 2=Television, 3=Radio, 4=Newspapers, 5=Other (please specify________)

Notes:

41. In 2016, did you receive any financial assistance or agricultural/input credit? ____ (0=No, 1=Yes)

If yes, from what source(s) did you receive financial assistance or access any agricultural credit? ____(1=Government, 2=NGOs, 3=Commercial banks, 4=Microfinance institution, 5-Family, 6-Rice Miller, 6=Other)

42. In 2016, did you have access to any form of agricultural insurance? ___ (0=No, 1=Yes)

If yes, did you buy insurance? (0=No, 1=Yes). If no, why not?

43. In 2016, were you able to access adequate irrigation facilities (trench, canal, conservancy)? ____ (0=No, 1=Yes)

44. In 2016, did you use a pump to flood your field? ____ (0=No, 1=Yes)

45. In 2016, what rice seed variety(ies) did you use? ____ (1=GRDB 9, 2=GRDB 10, 3=GRDB 11, 4= GRDB 12, 5=GRDB 14, 6=Other (please specify______)

46. What was the source of your seed? ____(1=Retained, 2=Targeted farmers, 3=Other farmers, 4=GRDB, 5=RPA, 6=Rice Miller, 7=Other (please specify______)

47. How would you rate the supply of inputs and equipment rental used in rice cultivation?

Inputs	1=Very Good	2=Good	3=Acceptable	4= Poor	5=Very Poor
Seeds					
Fertilizer					
Pesticides and Herbicides					
Labor					
Equipment: combines/tractors					

48. In 2016, were you a member of the Rice Producer Association (RPA)? ____ (0=No, 1=Yes). If no, why not? _____

49. In 2016, were you a member of any other agricultural related institution/group/organization/farmers' cooperative, water management group etc.? _____(0=No, 1=Yes)

If yes, what is the name of the institution/group/organization/farmers' cooperative that you were a member of? ______

Notes:

APEENDIX B – SURVEY INSTRUMENT: KEY INFORMANTS

Consent Statement

Dear Participant,

I invite you to participate in this research study that focuses on how small rice farmers in Guyana respond to weather patterns and variation in climate.

I am a graduate student at Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg, Virginia, and I am in the process of writing my Ph.D. dissertation.

The purpose of this research is to determine the impacts of climate change on rice production and how small rice farmers respond and adapt to variations in rainfall, temperature, and extreme weather events such as drought and excess rainfall.

Your participation in this research project is completely voluntary. You may decline altogether or skip any questions you do not wish to answer. Your identity and responses will remain confidential and anonymous. No one other than the researchers will know your individual answers to this questionnaire.

Please give your verbal consent if you agree to participate in this project. It should take approximately 45 minutes to complete.

Thank you for your assistance in this important endeavor.

Sincerely,

Omchand Mahdu
Co-Investigator

Respondent ID: _________

Name of Respondent	
Position	
District	
Telephone No.	
GPS Coordinates	
Administrative Region No.	

1. Age of Respondent (in years): _____

2. Gender of Respondent: ____ (0=Female, 1=Male)

3. What is the highest level of education you completed? ____
(1=Primary, 2=Community High, 3=High School, 4=University, 5=Other

4. How long have you been a rice extension officer (in years)? ______

5. Have you observed any major changes in rainfall patterns in your district in recent years (for example, the last 5 years)? _____(0=No, 1=Yes).

If yes, how have rainfall patterns changed? ________

How have the observed changes in rainfall affected the quality and quantity of rice yields in your district? ________

How have farmers in your district responded to the observed changes in rainfall?
____

6. Have you observed any major changes in temperature in your district in recent years (for example, the last 5 years)? _____ (0=No, 1=Yes).

If yes, how has temperature changed? ________

How have the observed changes in temperature affected the quality and quantity of rice yields in your district? ________

How have farmers in your district responded to the observed changes in temperature? _________

7. Have you observed any changes in insects in your district in recent years (for example, last 5 years)? _____ (0=No, 1=Yes).

If yes, how have insects' population changed? ________

How have the observed changes in insects affected the quality and quantity of rice yields in your district? ________

How have farmers in your district responded to the observed changes in insects? _________

8. Have you observed any changes in diseases in your district in recent years (for example, last 5 years)? _____ (0=No, 1=Yes).
If yes, how have diseases changed? ________

How have the observed changes in diseases affected the quality and quantity of rice yields in your district? ________

How have farmers in your district responded to the observed changes in diseases?
____

9. Have you observed any changes in weeds in your district in recent years (for example, last 5 years)? _____ (0=No, 1=Yes).
If yes, how have weeds changed? ________

How have the observed changes in weeds affected the quality and quantity of rice yields in your district? ________

How have farmers in your district responded to the observed changes in weeds?
____

10. Have you observed any extreme weather event(s) (severe drought, excess rainfall, wind storms, flooding etc.) in your district in recent years (for example, the last 5 years)? _____(0=No, 1=Yes).
If yes, describe the extreme weather event(s). _______

How were the quality and quantity of rice yields affected in your district? ________

How did farmers in your district respond to the extreme weather event(s) noted above?
____

11. Given the changes you have observed, have you been supporting efforts to adapt to these changes? _____(0=No, 1=Yes).

If yes, what kind of support have you provided? ________

12. Are there any specific resources that are needed to more effectively support adaptation now and/or in the future?________

13. What barrier(s)/challenge(s) do you currently observe in the rice sector?_______

APPENDIX C – CODEBOOK

Variable ID	Variables Name	Variable Description
RESPID	Respondent ID	Numerical number of the administrative region and the numerical order the farmer was interviewed
NARESP	Name of Respondent	The name of the farmer
VILLAGE	Village	The name of the village that the farmer resides
TELE	Telephone	The telephone number of the farmer
LAT	Latitude	The degrees latitude where the interview was conducted based on WGS84 coordinate system
LONG	Longitude	The degrees longitude where the interview was conducted based on WGS84 coordinate system
REGION	Region	The administrative region of Guyana where the interview was conducted
FARMER	Farmer	The person interviewed is the person that makes the farming decisions
AGE	Age	Age of the farmer interviewed
GENDER	Gender	The gender of the farmer interviewed
EDUC	Education	The education level of the farmer interviewed
PRIMOCCU	Primary Occupation	Rice farming is the primary occupation of the farmer
RICEFARM	Rice Farming	Rice farming was the primary source of income for the farmer
SECAGOCCU	Secondary Ag Occupation(s)	The farmer had a secondary source of income from other agriculture related activities
CASHCROP	Cash Crops	Cash crops were a secondary agricultural source of income for the farmer
FRUITS	Fruits	Fruits were a secondary agricultural source of income for the farmer
LIVESTOCK	Livestock	Livestock was a secondary agricultural source of income for the farmer
FISHERY	Fishery	Fishery was a secondary agricultural source of income for the farmer
GRNDPROV	Ground Provisions	Ground provisions were a secondary agricultural source of income for the farmer
OTHERAGRI	Other Agri	Other agricultural sources were a secondary agricultural source of income for the farmer
SECNAGOCC	Secondary Non-Ag Occupation(s)	The farmer had a secondary source of income from non-agriculture related activities
CARPENT	Carpentry	Carpentry was a secondary non-agricultural source of income for the farmer
SMLBUS	Small Business	Small business was a secondary non-agricultural source of income for the farmer
WHORETL	Wholesale/ Retail	Wholesale/retail was a secondary non-agricultural source of income for the farmer
SERVICE	Service	Services were a secondary non-agricultural source of income for the farmer
PENSION	Pension	A government pension was a secondary non-agricultural source of income for the farmer
REMIT	Remittances	Remittances were a secondary non-agricultural source of income for the farmer
OTRNONAG	Other Non-Agric	Other non-agricultural sources were a secondary non-agricultural source of income for the farmer

HOUSEPART	Household Participate	Anyone in the household other than the farmer help with rice farming
PARTLAB	Part-time Labor	The farmer hired part-time labor to help with sowing, applying fertilizer, spraying etc.
PRTLABACT	Part-time Labor Activities	The activities the part-time laborers were hired to perform
ACREPLT	Acreage Planted	The number of acres planted
OWNLAND	Own Land	The farmer/family owned the rice farm
OWNPVT	Own Private	A private individual(s) owned the rice farm that the farmer is planting
OTROWN	Other Owner	Any other person or entity owned the rice farm that the farmer is planting
SPRINGYLD	Spring	Number of bags of paddy harvested in Spring Crop 2016
AUTYLD	Autumn	Number of bags of paddy harvested in Autumn Crop 2016
TLTYLD	Total Yields	Total number of bags of paddy harvested in Crop 2016
SPBGSACRE	Spring (Bags per Acre)	Spring paddy yields in bags per acre in 2016
AUBGSACRE	Autumn (Bags per Acre)	Autumn paddy yields in bags per acre in 2016
AVRBGSACRE	Average (Bags per Acre)	Total paddy yields in bags per acre in 2016
HECTPLANT	Hectare Planted	Number of hectares planted in 2016
SPPADYLDMT	Spring Paddy (MT)	Spring paddy yields in Metric Tons in 2016
AUPADYLDMT	Autumn Paddy (MT)	Autumn paddy yields in Metric Tons in 2016
SPRYLDMT	Spring Rice (MT)	Spring Rice yields in Metric Tons in 2016
AURYLDMT	Autumn Rice (MT)	Autumn Rice yields in Metric Tons in 2016
SPRYLDMTHA	Spring Yield (MT/ Ha)	Spring Rice yields in Metric Tons per hectare in 2016
AURYLDMTHA	Autumn Yield (MT/ Ha)	Autumn Rice yields in Metric Tons per hectare in 2016
TRYLDMTHA	Total Rice Yield (MT/ Ha)	Total Rice yields in Metric Tons per hectare in 2016
AVRYLDMTHA	Average Yield (MT/Ha)	Average Rice yields in Metric Tons per hectare in 2016
LEGTITLE	Legal Title	The farmer has a legal title for the rice farm
FARMEXP	Farming Experience	The number of years the farmer has been a rice farmer
OWNEQUIP	Owned Equipment	The farmer owned any farming equipment
EQUIPOWN	Equipment Owned	The actual equipment owned
SHAREQUIP	Shared Equipment	The farmer shared any farming equipment with others
EQUIPSHAR	Equipment Shared	The actual equipment shared
OWSHEQ	Owned and Shared Equipment	The farmer owned and shared farming equipment
RENTEQUIP	Rent Equipment	The farmer rent any farming equipment
EQUIPRENT	Equipment Rented	The actual equipment rented
OWNLIVE	Owned Livestock	The farmer owned any livestock
NOLIVESTK	No. of Livestock	The number and type of livestock owned
SOILTYPE	Soil Type	The type of soil on the land(s) planted by the farmer
SOILTEST	Soil Tested	The farmer tested the soil
TESTRSLT	Soil Test Results	The result of the soil test, if applicable
RAINCHNG	Rainfall Changed	The farmer observed any major changes in rainfall in the area
DESRAIN	How have rainfall patterns changed?	The farmer description of how rainfall changed

RAINYIELDS	How did the observed changes affect the quality and quantity of rice yields?	The farmer description of how the change in rainfall affected the quantity and quality of yields
RESPRAIN	How have you responded to the observed changes in rainfall?	The farmer description of how he/she responded to the change in rainfall
TEMPCHNG	Temperature Changed	The farmer observed any major changes in temperature in the area
DESTEMP	How has temperature changed?	The farmer description of how temperature changed
TEMPYIELDS	How have the observed changes in temperature affected the quality and quantity of rice yields?	The farmer description of how the change in temperature affected the quantity and quality of yields
RESPTEMP	How have you responded to the observed changes in temperature?	The farmer description of how he/she responded to the change in temperature
INSECCHNG	Insects and Pests Changed	The farmer observed any major changes in insects in the area
DESINSECTS	How have insects and pests' population changed?	The farmer description of how insect(s) changed
INSECYIELDS	How have the observed changes in insects and pests affected the quality and quantity of rice yields?	The farmer description of how the change in insect(s) affected the quantity and quality of yields
RESPOINSEC	How have you responded to the observed changes in insects and pests?	The farmer description of how he/she responded to the change in insect(s)
DISEACHNG	Diseases Changed	The farmer observed any major changes in diseases in the area
DESDISEASE	How have diseases changed?	The farmer description of how disease(s) changed
DISYIELDS	How have the observed changes in diseases affected the quality and quantity of rice yields?	The farmer description of how the change in disease(s) affected the quantity and quality of yields
RESPDISEASE	How have you responded to the observed changes in diseases?	The farmer description of how he/she responded to the change in disease(s)
WEEDSCHNG	Weeds Changed	The farmer observed any major changes in weeds in the area
DESWEEDS	How have weeds changed?	The farmer description of how weed(s) changed
WEEDSYIELDS	How have the observed changes in weeds affected the quality and quantity of rice yields?	The farmer description of how the change in weed(s) affected the quantity and quality of yields
RESPWEEDS	How have you responded to the observed changes in weeds?	The farmer description of how he/she responded to the change in weed(s)
EXTREWEAT	Extreme Weather Events	The farmer observed any major changes in extreme weather events in the area
DESEXWEAT	Describe the extreme weather event(s).	The farmer description of the extreme weather event(s)
EXTREYIELDS	How were the quality and quantity of rice yields affected?	The farmer description of how the extreme weather event(s) affected the quantity and quality of yields
RESTOEXTRE	How did you respond to the extreme weather event(s) noted above?	The farmer description of how he/she responded to the extreme weather event(s)
CROPAFFECT	Crop Affected	The season that has seen the greater impact from the changes observed
YLDCHNG	Yields Changed	How did the overall rice yield change
CROPFAIL	Crop Failure	The farmer experienced a crop failure
FAILSEAS	Crop Failure Season	The season the crop failure occurred
COPSTRG	Coping Strategies	How did the farmer cope with reduced yields, grain quality etc.?
CFARMPRAC	Changed Farming Practices	The farmer made changes to his/her farming practices
PLANTDATE	Changing sowing/planting dates	The farmer changed the sowing/planting dates

DIFFRICE	Use different rice varieties	The farmer used different rice varieties
NEWSEED	Buy new seeds each season	The farmer bought new seeds each season
PUMPWATER	Pump water	The farmer pumped water
TREATSEEDS	Treat seeds for insects	The farmer treated seeds for insects
REPLTDEN	Reduce plant densities	The farmer reduced plant densities
AGROFOR	Agroforestry (example rice and coconut)	The farmer engaged in agroforestry
INCREFERT	Increase fertilizer application (quantity and frequency)	The farmer increased fertilizer application (quantity and frequency)
INCREHERB	Increase herbicide and pesticide application (quantity and frequency)	The farmer increased herbicide and pesticide application (quantity and frequency)
CROPROT	Crop rotation	The farmer engaged in crop rotation
CULTOTHR	Cultivation of other crops	The farmer cultivated other crops
RENTOUT	Rent out land to large farmers	The farmer rented out the land to large farmers
EXITRICE	Exited rice cultivation and seek off farm employment	The farmer exited rice cultivation and seek off-farm employment
LANDIDLE	Leave land idle	The farmer left the land idle
SPRAYWAT	Sprayed water in field	The farmer sprayed the water in the field
OTHER	Other (please specify)	The farmer engaged in any other adaptation practices
NOADPT	No adaptation	The farmer did not engage in adaptation
BORROWFAM	Borrow from family members	The farmer paid for the changes in farming practice by borrowing from family members
SELLLIVE	Sell livestock	The farmer paid for the changes in farming practice by selling livestock
USESAV	Use savings	The farmer paid for the changes in farming practice by using savings
INPUTCRED	Input credit (fertilizer, herbicide, pesticide, seeds)	The farmer paid for the changes in farming practice by obtaining input credit (fertilizer, herbicide, pesticide, seeds)
SELLPROD	Sell productive assets	The farmer paid for the changes in farming practice by selling productive assets
BORROWFARM	Borrow from other farmers	The farmer paid for the changes in farming practice by borrowing from other farmers
MICROCRED	Obtain institutional microcredit	The farmer paid for the changes in farming practice by obtaining institutional microcredit
COMBANK	Borrow from commercial bank	The farmer paid for the changes in farming practice by borrowing from a commercial bank
OFFFARM	Off farm employment	The farmer paid for the changes in farming practice by seeking off-farm employment
GOVTSUPP	Government support/ subsidy	The farmer paid for the changes in farming practice by using government support and subsidy received
REMITTANCE	Remittances	The farmer paid for the changes in farming practice by using remittances received
PENS	Pension	The farmer paid for the changes in farming practice by using pension received
OTHERADPT	Other (please specify)	The farmer paid for the changes in farming practice by other means
DIFCULTPAY	Difficult to Pay	The farmer found paying for the activities was difficult
AVAILINFO	Availability of information about extreme weather events, changes in rainfall and temperature	Availability of information about extreme weather events, changes in rainfall and temperature was a barrier to adaptation faced by the farmer

ADQIRRIG	Access to adequate irrigation facilities	Access to adequate irrigation facilities was a barrier to adaptation faced by the farmer
KNOWADPT	Access to knowledge regarding adaptation practices	Access to knowledge regarding adaptation practices was a barrier to adaptation faced by the farmer
SAVCREDIT	Access to money/savings/credit	Access to money/savings/credit was a barrier to adaptation faced by the farmer
OWNERLAND	Ownership of land	Ownership of land was a barrier to adaptation faced by the farmer
AVAILLAB	Availability of labor	Availability of labor was a barrier to adaptation faced by the farmer
PDYPRICE	Price received for rice paddy	Price received for rice paddy was a barrier to adaptation faced by the farmer
SUBINPUT	Subsidized inputs	The lack of subsidized inputs was a barrier to adaptation faced by the farmer
TAXEXEMP	Tax exemption on inputs and equipment	The lack of tax exemption on inputs and equipment was a barrier to adaptation faced by the farmer
AVAILMKT	Availability of markets for rice	Availability of markets for rice was a barrier to adaptation faced by the farmer
GOVTASSIST	Government assistance/subsidies	The lack of government assistance/subsidies was a barrier to adaptation faced by the farmer
OTHERBAR	Other (please specify)	Other barrier(s) to adaptation faced by the farmer
EXPECT	Expectation	The farmer expected any help and from where
CLIMCHG	Climate Change	The farmer had heard of climate change
CCMEAN	What does CC mean to you?	Farmer describe what they understood about climate change
SIXPNTKNOW	GRDB 6-Point Practice	The farmer heard about the 6-point practice
HEARDSIX	What have you heard about 6-point?	Farmer describe what they have heard about the 6-point practice
TIMESOW	Time of sowing (adjusting planting dates)	The farmer adjusted planting dates
SEEDRATE	Seed rate (optimal plant density)	The farmer optimized plant density
TREATSEED	Treatment of seeds (with insecticides)	The farmer treated seeds before sowing
WEEDCRTL	Weed control (pre and post emergence)	The farmer control weeds pre and post emergence
BALNUTRN	Balance nutrition (fertilizer application)	The farmer used a balanced fertilizer
WATERMNGT	Water management (timing and adequacy of water application)	The farmer ensure timing and adequacy of water application
EXTTRAIN	Extension Training	The farmer participated in any training concerning rice
TYPETRAIN	Type of Training	Description of the training
SOURCETRIAN	Source of Training	The source of the training the farmer participated
ADVWEATH	Advance Weather	The farmer received advanced weather information
SOURCEWEATH	Source of Advance Weather	The source of the advance weather information
FINASSIST	Financial Assistance	The farmer received any financial or agricultural assistance in 2016
SOURCEFIN	Source of Financial Assistance	Source of financial assistance
AGINSUR	Agricultural Insurance	The farmer has access to agricultural insurance
ADEQIRRIG	Adequate Irrigation	The farmer has access to adequate irrigation
PUWATER	Pump Water	The farmer pumped water in 2016
SEEDVAR	Seed Variety	The seed variety that the farmer used in 2016
SOURCESEED	Source of Seed	The source of the seed variety used
SEEDS	Seeds	The farmer rating of the supply of seeds
FERTILIZER	Fertilizer	The farmer rating of the supply of fertilizer

PESTHERB	Pesticides and Herbicides	The farmer rating of the supply of pesticides and herbicides
LABOR	Labor	The farmer rating of the supply of labor
COMTRACT	Equipment: Combines and Tractors	The farmer rating of the supply of equipment
RPAMEM	RPA Membership	The farmer was a member of the Rice Producer Association
OTHRAGMEM	Other Agricultural Membership	The farmer was a member of any other agricultural organization
COMMENTS	Comments	General comments made by the farmer
PRICELOW	Paddy Price Low	The farmer noted that the price of paddy is low
LATEPAY	Late Payment	The farmer noted that they received late payment from millers
POORDRAIN	Poor Drainage	The farmer noted that there is poor drainage in the area
COSTPROD	Cost of Production Increased	The farmer noted that the cost of production has increased
SIXPOINT	Fully Practiced 6-point	The farmer fully employed the 6-point practice

APPENDIX D – MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIATION (1905 – 2015)[a]

Year	Average Rainfall			Average Minimum Temperature			Average Maximum Temperature		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1905	2417.04	215.27	8.91	21.52	0.16	0.76	30.26	0.15	0.50
1906	2463.90	191.17	7.76	21.44	0.21	0.97	30.16	0.19	0.65
1907	2500.82	233.22	9.33	21.36	0.21	0.97	30.10	0.19	0.62
1908	2471.44	209.86	8.49	21.26	0.09	0.42	30.02	0.08	0.28
1909	2550.38	225.03	8.82	21.26	0.09	0.42	30.02	0.08	0.28
1910	2681.98	163.58	6.10	21.24	0.09	0.42	30.00	0.07	0.24
1911	2695.36	143.87	5.34	21.26	0.09	0.42	30.02	0.04	0.15
1912	2550.38	315.38	12.37	21.32	0.13	0.61	30.08	0.13	0.43
1913	2475.42	356.31	14.39	21.36	0.11	0.53	30.10	0.12	0.41
1914	2376.88	331.53	13.95	21.38	0.13	0.61	30.14	0.15	0.50
1915	2273.08	187.46	8.25	21.50	0.19	0.87	30.26	0.23	0.76
1916	2262.86	169.77	7.50	21.58	0.16	0.76	30.34	0.18	0.60
1917	2321.24	117.43	5.06	21.58	0.16	0.76	30.34	0.18	0.60
1918	2372.24	92.91	3.92	21.62	0.13	0.60	30.40	0.12	0.40
1919	2382.14	77.93	3.27	21.66	0.11	0.53	30.42	0.11	0.36
1920	2316.84	179.03	7.73	21.62	0.08	0.39	30.38	0.04	0.15
1921	2307.84	169.01	7.32	21.58	0.08	0.39	30.34	0.09	0.29
1922	2339.04	188.55	8.06	21.54	0.15	0.70	30.28	0.18	0.59
1923	2278.48	198.85	8.73	21.46	0.21	0.97	30.20	0.20	0.66
1924	2260.44	200.67	8.88	21.38	0.16	0.77	30.14	0.17	0.56
1925	2230.54	249.36	11.18	21.34	0.11	0.53	30.08	0.08	0.28
1926	2152.80	225.29	10.46	21.34	0.11	0.53	30.10	0.12	0.41
1927	2262.74	451.82	19.97	21.28	0.19	0.90	30.06	0.18	0.60
1928	2320.90	449.33	19.36	21.28	0.19	0.90	30.04	0.19	0.65
1929	2325.46	448.02	19.27	21.24	0.21	0.98	30.00	0.20	0.67
1930	2392.36	384.96	16.09	21.26	0.23	1.08	30.02	0.22	0.72
1931	2453.06	339.99	13.86	21.28	0.26	1.22	30.02	0.22	0.72
1932	2323.62	95.93	4.13	21.38	0.22	1.01	30.12	0.20	0.68
1933	2410.92	262.18	10.87	21.36	0.24	1.13	30.12	0.20	0.68
1934	2339.44	355.55	15.20	21.36	0.24	1.13	30.12	0.20	0.68
1935	2363.94	348.74	14.75	21.32	0.23	1.07	30.10	0.20	0.66
1936	2392.24	354.00	14.80	21.28	0.18	0.84	30.08	0.18	0.59
1937	2448.16	375.67	15.35	21.28	0.18	0.84	30.06	0.15	0.50
1938	2498.38	453.03	18.13	21.30	0.16	0.74	30.08	0.13	0.43
1939	2576.86	336.85	13.07	21.36	0.11	0.53	30.12	0.08	0.28
1940	2463.50	496.36	20.15	21.48	0.26	1.21	30.24	0.27	0.89
1941	2425.32	500.07	20.62	21.60	0.34	1.57	30.34	0.34	1.11
1942	2384.22	482.76	20.25	21.72	0.40	1.82	30.46	0.38	1.24
1943	2381.50	477.67	20.06	21.82	0.28	1.27	30.56	0.28	0.91
1944	2447.62	480.57	19.63	21.92	0.15	0.68	30.66	0.11	0.37
1945	2679.54	325.15	12.13	21.90	0.16	0.72	30.64	0.11	0.37
1946	2704.36	293.07	10.84	21.82	0.19	0.88	30.58	0.15	0.49
1947	2648.24	367.22	13.87	21.78	0.13	0.60	30.56	0.11	0.37
1948	2572.28	280.55	10.91	21.76	0.15	0.70	30.52	0.16	0.54
1949	2695.88	403.29	14.96	21.66	0.19	0.90	30.44	0.21	0.68
1950	2622.12	383.60	14.63	21.60	0.19	0.87	30.36	0.21	0.68

1951	2738.14	399.97	14.61	21.58	0.19	0.89	30.34	0.21	0.68
1952	2776.90	337.76	12.16	21.54	0.11	0.53	30.30	0.12	0.40
1953	2821.68	342.48	12.14	21.52	0.11	0.51	30.30	0.12	0.40
1954	2849.10	384.70	13.50	21.50	0.14	0.66	30.26	0.18	0.60
1955	2917.14	348.89	11.96	21.44	0.19	0.91	30.22	0.22	0.72
1956	2943.14	362.53	12.32	21.36	0.24	1.13	30.14	0.25	0.83
1957	2839.90	574.33	20.22	21.34	0.21	0.97	30.10	0.19	0.62
1958	2644.02	687.56	26.00	21.42	0.33	1.53	30.16	0.29	0.96
1959	2417.46	573.15	23.71	21.42	0.33	1.53	30.18	0.28	0.92
1960	2302.38	506.19	21.99	21.46	0.30	1.42	30.20	0.26	0.88
1961	2021.44	243.87	12.06	21.54	0.23	1.07	30.28	0.20	0.68
1962	2054.60	227.97	11.10	21.52	0.23	1.06	30.26	0.21	0.69
1963	2162.06	290.57	13.44	21.48	0.15	0.69	30.24	0.17	0.55
1964	2115.24	297.87	14.08	21.62	0.24	1.10	30.38	0.28	0.91
1965	2017.38	292.71	14.51	21.66	0.21	0.96	30.44	0.23	0.76
1966	2143.48	278.66	13.00	21.74	0.21	0.95	30.52	0.24	0.78
1967	2290.00	378.90	16.55	21.74	0.21	0.95	30.52	0.24	0.78
1968	2346.64	434.78	18.53	21.70	0.23	1.08	30.48	0.26	0.85
1969	2374.20	409.76	17.26	21.74	0.30	1.40	30.50	0.29	0.96
1970	2562.12	301.23	11.76	21.76	0.30	1.36	30.52	0.29	0.94
1971	2633.20	286.17	10.87	21.56	0.47	2.17	30.32	0.44	1.45
1972	2587.38	278.43	10.76	21.52	0.48	2.24	30.30	0.45	1.48
1973	2514.08	262.50	10.44	21.48	0.49	2.29	30.26	0.46	1.51
1974	2585.84	156.34	6.05	21.24	0.31	1.47	30.04	0.31	1.04
1975	2566.48	131.24	5.11	21.12	0.18	0.85	29.92	0.18	0.60
1976	2610.88	211.52	8.10	21.16	0.13	0.63	29.94	0.15	0.51
1977	2521.72	318.82	12.64	21.20	0.20	0.94	29.96	0.18	0.61
1978	2473.86	354.87	14.34	21.24	0.24	1.13	29.98	0.20	0.68
1979	2493.54	358.11	14.36	21.40	0.30	1.40	30.12	0.28	0.92
1980	2412.56	352.01	14.59	21.54	0.29	1.34	30.24	0.29	0.95
1981	2350.36	245.06	10.43	21.66	0.15	0.70	30.36	0.15	0.50
1982	2371.60	219.97	9.28	21.70	0.12	0.56	30.40	0.12	0.40
1983	2293.74	341.94	14.91	21.76	0.05	0.25	30.48	0.08	0.27
1984	2317.78	370.15	15.97	21.64	0.25	1.16	30.38	0.23	0.75
1985	2303.04	373.88	16.23	21.58	0.24	1.11	30.34	0.22	0.72
1986	2196.28	328.25	14.95	21.68	0.37	1.71	30.46	0.37	1.22
1987	2187.04	328.97	15.04	21.86	0.55	2.54	30.66	0.55	1.81
1988	2311.56	246.72	10.67	21.90	0.56	2.54	30.70	0.56	1.81
1989	2300.60	225.45	9.80	22.00	0.43	1.96	30.80	0.43	1.40
1990	2526.48	498.16	19.72	22.14	0.33	1.48	30.94	0.33	1.06
1991	2560.78	466.60	18.22	22.08	0.34	1.55	30.88	0.34	1.11
1992	2477.42	581.78	23.48	21.80	0.38	1.75	30.60	0.38	1.24
1993	2530.40	585.98	23.16	21.68	0.40	1.83	30.48	0.40	1.30
1994	2475.24	585.44	23.65	21.62	0.41	1.92	30.42	0.41	1.36
1995	2275.50	341.39	15.00	21.64	0.45	2.08	30.44	0.45	1.48
1996	2344.20	374.08	15.96	21.64	0.45	2.08	30.44	0.45	1.48
1997	2434.86	205.23	8.43	21.86	0.45	2.06	30.64	0.43	1.40
1998	2389.60	159.28	6.67	22.12	0.49	2.22	30.90	0.48	1.57
1999	2433.00	180.58	7.42	22.26	0.30	1.33	31.02	0.31	1.00
2000	2590.92	340.94	13.16	22.20	0.32	1.42	30.96	0.32	1.04
2001	2408.70	519.63	21.57	22.26	0.27	1.21	31.00	0.29	0.94
2002	2413.70	517.05	21.42	22.12	0.40	1.79	30.88	0.40	1.28
2003	2324.80	547.21	23.54	22.08	0.33	1.48	30.82	0.29	0.93

2004	2285.78	530.58	23.21	22.04	0.34	1.53	30.80	0.29	0.95
2005	2237.70	439.29	19.63	22.04	0.34	1.53	30.80	0.29	0.95
2006	2455.16	375.15	15.28	22.02	0.33	1.49	30.78	0.29	0.93
2007	2605.06	401.33	15.41	22.08	0.25	1.13	30.84	0.21	0.67
2008	2837.02	284.12	10.01	21.96	0.09	0.41	30.72	0.08	0.27
2009	2792.38	374.73	13.42	22.00	0.10	0.45	30.76	0.11	0.37
2010	2753.08	373.78	13.58	22.08	0.20	0.93	30.84	0.23	0.75
2011	2760.10	375.07	13.59	21.98	0.29	1.34	30.76	0.30	0.99
2012	2647.94	384.41	14.52	21.90	0.37	1.68	30.68	0.37	1.21
2013	2527.88	255.80	10.12	21.88	0.37	1.69	30.66	0.38	1.23
2014	2442.00	423.71	17.35	21.86	0.36	1.64	30.62	0.36	1.16
2015	2340.94	412.36	17.61	21.88	0.40	1.81	30.62	0.36	1.16

[a] Computations are based on data obtained from the Climate Research Unit (CRU) country dataset (CRU CY v.3.24.01) at East Anglia University for the period 1901-2015. A five-year moving average was used to compute mean and standard deviation (SD). As a result, the time period is reduced to 1905-2015. Coefficient of Variation (CV) = (SD/Mean) *100.