Norwegian University of Life Sciences

Master's Thesis 2018 30 ECTS
Faculty of Landscape and Society
Ola Westengen

Understanding the impact of El Niño and La Niña on Bangladesh's crop production and disaster management plan

Afroza Mahzabeen Anannya
International Environmental Studies
Faculty of Landscape and Society

The Department of International Environment and Development Studies, Noragric, is the international gateway for the Norwegian University of Life Sciences (NMBU). Established in 1986, Noragric's contribution to international development lies in the interface between research, education (Bachelor, Master and PhD programmes) and assignments.

The Noragric Master's thesis are the final theses submitted by students in order to fulfil the requirements under the Noragric Master's programmes 'International Environmental Studies', 'International Development Studies' and 'International Relations'.

e-mail: Mahzabeen.anannya@gmail.com

Noragric
Department of International Environment and Development Studies
The Faculty of Landscape and Society
P.O. Box 5003
N-1432 Ås
Norway
Tel.: +47 67 23 00 00
Internet: https://www.nmbu.no/fakultet/landsam/institutt/noragric

Declaration

I, Afroza Mahzabeen Anannya, declare that this thesis is a result of my research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been added. This work has not been previously submitted to any other university for the award of any type of academic degree.

Signature………………………………..

Date………………………………………..

Acknowledgment

I would like to express my special appreciation and thanks to my supervisor **Dr. Ola Westengen**, Department of International Environmental and Development Studies (NORAGRIC), Norwegian University of Life Sciences; you have been a tremendous mentor for me. I would like to thank you for encouraging my ideas, supporting my research and regular supervision

I am grateful to all the teachers in the same department for their valuable suggestions and inspiration throughout the research period. I also thankfully acknowledge the support and encouragement I received from all the staffs and members of Norwegian University of Life Sciences. I am especially thankful to NMBU writing center, for their wise direction while writing my thesis.

I am also extremely grateful to my beloved parents, family members and other relatives for their moral support and encouragement. I would also like to thank all of my friends who supported me in writing and incented me to strive towards our goal.

Lastly, I would like to thank my husband, *Mr. Badrul Hyder*, for his unconditional support and loving encouragement throughout the research period and for his help in making me strive towards my goal.

Afroza Mahzabeen Anannya
June 2018

Abstract

ENSO is a natural phenomenon which creates climate anomalies around the world. And this has linked with extreme disaster in some part of the world. This climatic anomalies and extreme disaster events have an impact on agricultural production. Based on it, this study focuses on ENSO impact on crop production and its integration in disaster management of Bangladesh. Following a mixed methods approach, quantitative data on ENSO, rainfall, temperature and agricultural production and key informant interviews (KII) data were analyzed to pursue two objectives, to determine the impact of ENSO on the production of major crops (the three major types of rice, wheat, and potato) and to understand the perception and integration of ENSO in Bangladesh's disaster policies and management plan. The statistical analysis did not identify any impact of ENSO on any of the five crops, but it indicated that all the crops have a significant positive correlation with average maximum temperature whereas rainfall does not show any significance for crop production. KII or expert opinion reflects that ENSO is considered as a cause of natural disasters in Bangladesh, but no policies or early preparedness plan address issues related to ENSO. As Bangladesh prioritizes climate change as the main concern over natural climate variability, ENSO induced climate variability gains less focus. The dearth of research on the impact of ENSO in Bangladesh is likely one of the reasons for its absence in policies and disaster management plans. Though, the statistical analysis does not identify a link, from the experts' opinion it reflects that there might be a connection with disasters such as flood or drought. So, further research on ENSO impact on agricultural production can deliver a solution for early preparedness. Future studies can control the effect of fertilizer, irrigation, and mechanization on crop production and identify the impact of ENSO.

Keywords: ENSO, Crop production, Temperature, disaster, policy, Bangladesh.

List of Abbreviations

BMD	:	Bangladesh Meteorological Department
BBS	:	Bangladesh Bureau of Statistics
DDM	:	Department of Disaster Management
ENSO	:	El Niño Southern Oscillation
FAO	:	Food and Agricultural Organization
GDP	:	Gross Domestic Product
NOAA	:	National Oceanic and Atmospheric Administration
WFP	:	World Food Program

List of Contents

Chapter 1: Introduction

Changing climate and weather conditions are among the most discussed topics and global concern at present. The changes in climate are allegedly resulting in increasing number of disasters, migration and food insecurity. The problem with food security is induced by increasing number of conflicts and climate-related shocks make the problems worse (FAO, IFAD, UNICEF, WFP, and WHO. 2017). Two of the dimensions of Food security is food availability and accessibility. These two are closely related to agricultural production and food price. Agriculture ensures household food availability in rural families and creates employment opportunities. So, increasing agricultural food production can act to increase rural household incomes, which will reduce poverty and ensure food security from household level (Muza, 2017). But, a decrease in a food production leads to an increase in food price. This threatens both food availability and access to food for poor people. From 2007, the food price hike has been noticeable (Muza, 2017). This is a matter of concern to the policy makers (Pinstrup-Andersen, 2009). However, this food production also depends on climate and disasters and as the climate changes, this effect is exacerbated.

Several studies have suggested that, as the climate changes, catastrophic weather events are likely to increase in numbers. Besides this, extreme weather events around the world are also linked with El Niño-Southern Oscillation (ENSO). This can be termed as a medium frequency climate anomaly (Abdolrahimi, 2016). According to Hammer and Colleagues (2001), "*The most dramatic, most energetic, and best-defined pattern of inter-annual variability is the global set of climatic anomalies referred to as (El Niño and the Southern Oscillation) ENSO"* (p. 515). This is a naturally occurring phenomenon impacting the entire world's climatology. These impacts can be both positive and negative, but mostly it has a greater level of negative impacts (Abdolrahimi, 2016). In addition to climate variability, El Niño Southern Oscillation (ENSO) is a recurrent change in climate and it is a sensitive factor for food production. According to World Food Program (2016), "El Niño is now threatening the food security and livelihoods for some 60 million people worldwide" (p. 1). Thus, this study has tried to analyze the impact of ENSO on agricultural production in Bangladesh. To do so, a brief on ENSO and agriculture in Bangladesh have given below to provide a basic understanding before going to the main study.

1.1 El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) is a natural event. This involves fluctuating oceanic temperature in the central and eastern equatorial Pacific along with changes in the atmosphere (WMO, 2014). El Niño is known as a weak warm ocean current (Trenberth, 1997). This is the warming of surface water around the equatorial zone of the Central and Eastern Pacific Ocean. The exact location of the warm ocean current is near the coast of Peru and Ecuador but affects the atmospheric circulation all over the world (Muza, 2017). The warming usually occurs around Christmas (December) time ((Trenberth, 1997). This is a recurring phenomenon occurring every 2 to 7 years and the usual duration is between 12 months to 18 months (Muza, 2017). La Niña is the opposite phase consisting of cold current of water (Trenberth, 1997). El Niño and La Niña are oceanic components and Southern Oscillation is the atmospheric component of ENSO. There is a third phase which is the neutral situation between El Niño and La Niña (WM0, 2014). The neutral phase is when there is no sea surface warming or cooling of the Pacific Ocean. For this study, El Niño and La Niña will be referred to as ENSO when discussed together.

1.2 Agriculture in Bangladesh

Bangladesh is an agricultural country. Having a large population (more than 150 million) and only 8.2 million hectares of agricultural land is difficult for ensuring food security (Islam and Shirazul, 2009). Agriculture contributes around 20% of GDP in Bangladesh and about 50% of people depend on agriculture for livelihoods. There are other activities such as fishing, livestock, and forestry under agricultural sector. However, crop production is the highest among all the agricultural activities providing around 60% of the total agricultural sector GDP. With increasing population and changing the climate, agricultural production in the country is facing challenges (BBS, 2008).

In Bangladesh agriculture is highly affected by different climatic parameters. Climatic Variables such as temperature, rainfall, humidity, sunshine hours determine cropping seasons and crimping types. As a disaster vulnerable country, flooding, droughts, salinity intrusion, tropical cyclones and sudden storms also disrupt agricultural production (Sikder & Xiaoying, 2014). Therefore, Bangladesh is sensitive to climate change as it will cause changes in climatic parameters and increase the number of disasters. These challenges are making agricultural highly vulnerable. As the climate changes, the challenges for agriculture are increasing day by day. Additionally, the annual population is increasing by 0.2 million and the cultivable land is decreasing by 0.08 million hectares. Non-agricultural activities such as increasing number of infrastructures, industrialization, urbanizations etc. are reducing the available agricultural lands (BRRI, 2009).

1.4 ENSO and its relevance in Bangladesh

Agriculture is the most weather-dependent human activity (Oram, 1985). Even with recent advances in the field of agricultural technologies, weather and climate parameters play a significant role in crop production. (Rosenzweig et al. 2001). The ENSO cycle can vary in length and strength, but, its impact depends on the affected systems sensibility and vulnerability (Rosenzweig and Hillel, 2008). Any climate-induced disaster could be a significant restricting factor for staple food production. In case of Bangladesh, the country suffers for several climate-related disasters annually. According to Del Ninno and Colleagues (2003), "*The 1998 flood in Bangladesh led to major crop losses, losses of other assets and lower employment opportunities and thus affected household incomes as well as market prices"* (p. 1224*)*. As food price hikes affect the staple food, poor marginalized people are the worst sufferers as large part of their income is spent on buying food (Wheeler and Von Braun, 2013). The dimensions of food security are disrupted by extreme disaster events (Begum, Hossain and Haese, 2014). Therefore, food security is highly vulnerable to climate change. Bangladesh depends widely on its own crop for food availability and access. ENSO, being responsible for climate variability and subsequent disasters may affect food security system of Bangladesh.

Disasters are often induced by climate anomalies. Substantial anomalies in flood volumes exist during both El Niño and La Niña years comparing to other years. This situation exists across more than one-third of the world's land surface (excluding Greenland and Antarctica). Climate anomalies increased by 34% during El Niño and 38% during La Niña (Ward et. al., 2014). ENSO events can continue for several months and change the expected normal seasonal characteristics totally. On one hand, a wet season can become very dry and the crop growing season can face drought. On the other hand, a dry season can become very wet and experience flooding (Glantz, 2017). The change in rainfall level due to ENSO induces disasters such as drought and flooding.

1.5 Research objectives

This research looks through the following research objectives to fulfill the research goal-

- The first objective of this research is to evaluate the relationship of ENSO cycle and crop production in Bangladesh. In this objective, research has assessed the yearly changes in food production in different ENSO occurrence in different years.
- The second objective is to understand the perception and incorporation of ENSO in Bangladesh's disaster management and policies.

1.6 Research questions

To attain the research goal and objectives, research goes through the following questions,

- Is there any correlation between the ENSO cycle and crop production in Bangladesh?
- What is the importance of ENSO in the context of Bangladesh in policies and disaster management?

Consequently, these two research questions justify my research object. If this paper can establish a direct or indirect relationship between ENSO occurrences and agricultural production of Bangladesh, it can easily conclude that ENSO has an impact on agricultural production of Bangladesh. This paper will also reflect ENSO's importance in Bangladesh in terms of policy-making and disaster management.

1.7 Justification of the study

Bangladesh is a climate vulnerable country. The country is struggling to provide its large population with increasing need for basic rights. Access to food is one of the six basic rights in Bangladesh. As an agricultural country, Bangladesh depends on its agricultural production for basic crops such as rice, potato and wheat. Climate change and global warming are already making agricultural production harder for Bangladesh. ENSO is a naturally occurring event influencing the climatic parameters and therefore affecting the crop production around the world. ENSO cycle changes the rainfall and temperature pattern and causes climate anomalies. This, in turn, affects crop production. Because of these issues, this study is conducted to provide a base for ENSO's impact on crop production in Bangladesh and to reflect the present importance of ENSO in disaster management of Bangladesh. As a disaster vulnerable country, it is necessary to identify the influence of ENSO on crop production in Bangladesh. This can be helpful to better understand the impact of ENSO on Bangladesh under changing climates.

1.8 Significance of the study

Research regarding ENSO around the world is usually region or country based. Therefore, ENSO's impact on agriculture is studied in different countries. Sadly, there has been little researches on ENSO'S impact on Bangladesh. This research could determine the production variability in Bangladesh in terms of ENSO cycle. Understanding the overall impact of ENSO on Bangladesh's crop production is a crucial tool for managing dimensions (Food availability, Food access) of the food security in the country. In addition, increasing the country's effectiveness of food security management can lead to a sustainable food system. So, this research can indicate ENSO's relevance for agriculture in Bangladesh which can be helpful to provide Bangladesh with necessary measures to ensure crop production in the country. These measures can be early warning and preparedness adequately addressed in disaster management plan and introduction of ENSO in existing policies. Therefore, even if the research does not identify any relevant impacts on crop production, it can be a baseline for future studies addressing issues on climate change and crop production.

Chapter 2: Literature review

2.1 Background of El Niño and La Niña

ENSO comprises two phases: El Niño and La Niña. El Niño means "Boychild" and it's originated from Spanish. The counterpart of El Niño is La Niña and it means "little girl". The terms were first used in the 19th Century. The fishermen in Peru and Ecuador used the term El Niño to refer to unusually warm ocean water just before Christmas. The strong and moderate level El Niño influence average global surface temperature around the world (WMO, 2014). La Niña creates the opposite climate variation to El Niño, especially in the tropical region (WMO, 2014). Generally, El Niño or La Niña events begin in the middle of the year and reach its peak during November to January. In the following year, El Niño gradually decays in the first 6 months (WMO, 2014). The El Niño and La Niña occurrence have become a leading source of interannual climate variability worldwide (Trenberth, 1997). So, El Niño and La Niña are part of a cyclic process and it can be referred to as ENSO cycle which creates climate variability worldwide.

ENSO is a leading mode of climate variability. Month-long periods of above-normal (El Niño) and below-normal (La Niña) sea surface temperature in the equatorial Pacific Ocean along with changes in atmospheric circulation is a natural phenomenon (Davey, Brookshaw & Lneson, 2014). El Niño and La Niña are opposite statuses of ocean current and that cannot be defined as normal or abnormal. Climatic factor dominates ENSO-neutral phase (Abdolrahimi, 2016). El Niño, La Niña and neutral phase influence climatic parameters beyond the Pacific Ocean.

2.2 ENSO and Climate Variability

The extent of ENSO's influence beyond the Pacific Ocean means that the ENSO and it's teleconnections have a spatial impact worldwide. The worldwide impact varies with the strength of the event. With stronger occurrence, ENSO can impact several parts of the world but with the weaker occurrence, it can cause regional and local impact around the Pacific Ocean (Glantz and Glantz, 2001). The weather pattern around the world can widely affect by ENSO events. Researchers (Wang and Fiedler, 2006; An, 2009; Cai and Cowan, 2009) pointed out that precipitation and temperature pattern can vary with ENSO teleconnections. So, the ENSO effects climatic patterns in various places.

The atmospheric processes extend beyond the Pacific Ocean and influence the pattern of seasonal winds, rainfall and temperature worldwide. These teleconnections have substantial socio-economic impacts as well (Davey, Brookshaw and Lneson, 2014). Bouma and colleagues (1997) mentioned that "*The El Niño Southern Oscillation (ENSO) is the most prominent global climate system associated with year-to-year weather variability and extreme events*" (p. 1435). The year 1997-1998 was a much-observed event of ENSO. After that, El Niño is considered the main reason for unusual climatic occurrences worldwide (Azmoodehfar & Azarmsa, 2013). However, Rainfall and temperature are the commonly studied climatic parameter to determine the effect of ENSO.

Rainfall is a determining factor for agricultural cultivation, natural disasters (Flooding, drought) etc. The ENSO cycle is known for influencing earth's climate for 130000 years (Abdolrahimi, 2016). Several studies have suggested that ENSO has a profound impact on rainfall pattern and distribution (Ropelewski and Halpert, 1987). The spatial distribution of precipitation reflects ENSO's impact. ENSO causes increased rainfall across the east-central and eastern Pacific. ENSO is also responsible for the drought in the Western Pacific region, East and South Asia, Southern Africa and Australia (Abdolrahimi, 2016). ENSO causes decreased rainfall and initiates the drought condition. So, there is a shift in rainfall pattern during El Niño and La Niña.

During El Niño, there is a shift in tropical rainstorm pattern toward eastern regions. This induces higher air pressure and creates dryer condition over northern Australia and Indonesia. Southwestern Africa and Northwestern India experiences dryer winter. Rainfall amount increases in the central and eastern Pacific region and west coast of South America (Salinger, 2005). El Niño causes drought in the western Pacific region and increased the amount of rainfall over the equatorial coast of South America. El Niño also influences the storms and hurricanes in the central Pacific region (Cashin, Mohaddes and Raissi, 2017). Nearly, opposite pattern is noticed during La Niña events (Salinger, 2005). So, ENSO has been forming climate irregularities and this is visible in rainfall pattern in different regions in different ways.

2. 3 ENSO impact around the world

2.3.1 Asia

Annual precipitation patterns vary in East and South Asian countries. The western tropical Pacific region works as an area where Asian Monsoon and ENSO crisscross. The exact location of the region is in the middle portion of the Walker circulation (Kinter III, Miyakoda, and Yang, 2002). So, ENSO apparently affects Asian countries.

Several countries in Asia suffer from ENSO effects. Indonesia has proven records displaying that in El Niño years, above 90% time the country experiences droughts (Quinn, et al., 1978). Severe El Niño occurrences in the 1980s and 1990s have caused extreme drought situation in the country and that resulted in delayed rice harvesting. This affected the overall food security in Indonesia (McPhaden, 1999; Harger, 1995; Ameien, et. al., 1996). Philippines is another country in Asia suffering impacts of ENSO. The seasonal rainfall in the country is widely affected during extreme ENSO events. El Niño events cause water stress and result in drought. La Niña, on the other hand, causes excessive rainfall in the Philippines (Hilario, et. al., 2009; Lyon et al. 2006). The duration of the rainy season and a number of tropical cyclones in the Philippines is also influenced by ENSO occurrences (Hilario, et. al., 2009). ENSO effects rainfall widely in China but there is no effect on temperature. There is very less effect on China's rice production compare to Indonesia or Philippines. China has a reliable and developed irrigation system so change in rainfall does not affect production (Deng, et. al., 2010). South Asian countries also experience the effect of ENSO.

Sri Lanka experiences increase in Maha (a type of rice) rice production and decrease in Yala (a type of rice) rice production in El Niño years and experience the opposite in La Niña years (Zubair, 2002). In Nepal, rainfall is associated with positive and negative as the country experiences more rainfall and less rainfall respectively (Shrestha, 2000). India has a history of 132 years that indicates severe droughts are occurring during El Niño occurrence though not all El Niño events create drought situation in the country (Kumar et. al., 2006).

2.3.2 Africa

African region also experiences the impact of ENSO. African region has a very significant correlation between rainfall pattern and ENSO events. But the impacts vary from one country to another (Camberlin, Janicot, & Poccard, 2001). During an El Niño event, Southern Africa experiences drought between December to March which is usually rainy season (Thomson, et. al., 2003). In case of vegetation, 16% land area in minimum level vulnerability to El Niño and high vulnerability rate is 1.18%. This differs for diverse kinds of vegetation across the region (Propastin, Fotso, & Kappas, 2010). Propastin and colleagues (2010) also show that ENSO induced drought effects all over Africa based on Land use processes.

Nigeria experiences variation in precipitation pattern with ENSO occurrences (Adebayo, 1999). Another research (Okeke, Marengo and Nobre, 2006) also stated that Nigerian rainfall has a link with ENSO. Okonkwo and colleagues (2014) identified ENSO occurrences year can be responsible for 31% for variations in Lake Chad Level in Kindjeria. The precipitation in Northern Lake Chad Basin is 13% clarify-able by different ENSO occurrences (Okonkwo, Demoz & Gebremariam, 2014). Madagascar experiences forest fires and droughts after El Niño event (Ingram and Dawson, 2005). A study focused on Tomato production in Mozambique showed that ENSO does not strongly impact summer and winter period in the country, but ENSO impacts the fall and spring period. During a La Niña event, Mozambique has an appropriate condition for agricultural production from April whereas, during El Niño, these conditions arise in May (Gelcer, et. al., 2018). Zimbabwe receives less rainfall during El Niño events whereas La Niña years cause more rainfall. This is a clear sign that Zimbabwe is affected by ENSO cycle (UNDP, 2017). This part shows that Several African countries are affected by ENSO cycle.

2.3.3 Europe

El Niño has a very noteworthy relationship with crop yield irregularities in Europe compared to the climatic variables (Capa-Morocho, et. al., 2014). For Europe, North Atlantic Oscillation holds a crucial role for causing weather and climate irregularities and ENSO can clarify 40% of Variation in North Atlantic Oscillation (Merkel and Latif, 2002; Raible, Luksch, and Fraedrich, 2004). When El Niño occurs in winter, it usually collaborates with Negative North Atlantic Oscillation. This collaboration causes decreasing temperature and change in rainfall patterns all over Europe (Brönnimann, et. al., 2007).

Between October to December, ESNO affects the European rainfall widely. These positive rainfall patterns are experienced in Iberia, Western and Southern France, Northern Italy, the British Isles and South of Scandinavia. The negative rainfall trend over northern Europe from July to September is linked to El Niño events as well (Shaman, 2014). In Europe, winter temperature differs between La Niña years and normal years whereas in El Niño and neutral years, there is no significant difference (Pozo-Vázquez, et. al., 2001).

2.3.4 Australia

Australia situated among tropical and subtropical oceans. Large-scale coupled ocean and atmospheric interfaces affect Australian Climate (Forootan, 2016). Tropical convergence zones move and initiate ENSO. This causes response around tropical and subtropical regions (Cai, et. al., 2012). Northern Australia, Western Australia, and Eastern Australia showed a higher correlation with ENSO (Forootan, 2016). This indicated that ENSO can affect agriculture in Australia.

Several studies have highlighted ENSO’s influence on Australia. Above 60% of Australia, Experiences drought during El Niño due to less rainfall. Northeastern and Southeastern regions significantly suffer from less rainfall. This occurs during September to November, the Austral Spring Season (Taschetto and England, 2009; Cai, et. al., 2011; Wang and Hendon 2007). Wheat yields change as the precipitation changes during ENSO events, but impact varies with regions (Nicholls, 1985; Potgieter, et. al., 2005). Sugarcane production is linked with ENSO induced rainfall changes in Northern Australia (Kuhnel, 1994).

2.3.5 America

Southern South Africa’s precipitation suffers strong influences of ENSO occurrence. This influence occurs at both seasonal to interannual scale (Penalba and Rivera, 2016). The impact of ENSO in South America is different in different places. Western Coast of Chile and Eastern Coast of Uruguay experiences changes in rainfall pattern, it increases usually. In case of Argentina and Central Brazil, ENSO effect is not distinct. In Amazon, ENSO creates different effects during the same cycle, for example, droughts or increased rainfall. It can also not have any effect in two regions situated in a short distance from each other. Peru and Ecuador, where ENSO was identified first, has only effects in their coastal regions. Northeastern Brazil experienced severe drought during El Niño events (Kane, 2006). Ropelewski and Halpert (1987, 1989) have also identified temperature and rainfall variation in Argentina, Brazil, and Uruguay. North America experiences affect of ENSO as well.

Southern USA, Northern Mexico, and Southern California experience precipitation severe irregularities during strong El Niño occurrences. The western coast of U.S. receives less precipitation in winter during El Niño. Compared to neutral years, Canada has warmer and drier winter and spring season in El Niño and strong El Niño years. In tropical Mexico, spring season receives increased precipitation during El Niño years (Izaurralde, et. al., 1999).

2.4 ENSO, early preparedness, and Disaster management

As mentioned earlier, it is evident that ENSO has a widespread impact all over the world. As it is a cyclic phenomenon causing extreme disaster event, early preparedness can reduce the disaster risks. Countries can develop appropriate cautionary measures and reduce ENSO induced impacts. This can include importing food and providing people with a necessary instance if there is a scarcity of food due to ENSO induced flooding or drought (Tabor, Ginting and Aji, 2015). However, different countries deal with this issue differently.

Not all governments consider ENSO as a threat to people (Glants, et. al., 2018). Different ENSO years might affect differently and predict the event well ahead is not always possible. The El Niño event in 1997-98 developed faster and vanished quicker than expected. The vent could not be predicted well in advance (Barnston, Glants and He, 1999). Researchers suggested that no two ENSO event comprises similar characteristics and the ENSO cycle holds several uncertainties (Glants, et. al., 2018). However, early preparedness is always helpful to face extreme disaster situations.

Preparedness and mitigation are part of disaster management process. Mitigation ensures the increased capacity of vulnerable communities and preparedness is having a plan and early warning measures. Training is also a part of preparedness which prepares disaster responders to act when the disaster hits (de la Poterie, et. al., 2018). ENSO induced flooding and drought can be less disastrous, if early preparedness can be ensured. In 2016, South Asia experienced severe drought and extreme heat waves and the conditions are worsening by El Niño as the countries experienced hotter and drier situation than normal (Cai, et. al., 2017). A study focusing on the flood and drought in China is in 2015-2016 showed that El Niño is linked with precipitation variance for about 9%

to 73% (Ma, et. al., 2018). Institutions can ensure better preparedness measures for disasters such as drought. Australia and United States of America experienced severe drought extremes in the recent period. Therefore, both countries are introducing new drought management policies and strategies (Cai, et. al., 2017). As countries for disaster, a focus on ENSO related disasters can be helpful to prepare communities for this cyclic event. This can be helpful to reduce risks around the world.

2.5 ENSO Impact on Bangladesh

Most South Asian nations receive a significant amount of rainfall or monsoonal period annually. The monsoon in Asia is a principal element of the coupled ocean, land, and atmosphere system (Chowdhury, 2003). In India, considerable work has been done on the variability of climate and particularly rainfall by analysis of the extensive datasets of the Indian Meteorological Department (IMD). But the nature of climate variability over other parts of the Indian monsoon regime, such as Bangladesh, Sri Lanka, Nepal, and Pakistan, is not as well documented (Kriplani et al., 1996). According to Farooqi and Colleagues (2005), "*In a warmer climate, the El Niño-Southern Oscillation (ENSO) events become stronger and more frequent. Therefore, their impact on the Asian monsoon could lead to high inter-annual variation in rainfall characteristics*" (p. 18). As India is a big country, its overall rainfall data will not match other Asian countries. For example, other than the northeast part of India (along with the Meghna basin), there is no significant correlation between the rainfall over Bangladesh and rainfall over India (Kripalani et al., 1996). Therefore, climate characteristics of Bangladesh are different.

Bangladesh is a climate vulnerable country. According to Hossain and Colleagues (2000), "there is a decrease in rainfall in El Niño years in all the seasons: the pre-monsoon, Monsoon and post-monsoon" (p. 2). Annual rainfall from selected meteorological stations from 1950 to 1992 showed a negative relation between El Niño events and rainfall in Bangladesh. The rainfall showed a decreasing tendency in El Niño active years. The observation in four stations in the period of 43 years (1950-1992) observed 70% decrease of rainfall in Jessore, 67% for Dhaka and Barisal, and 72% for Srimangal (Hossain et. al., 2000). According to Chowdhury (2003), "significant rainfall deficits were recorded in strong El Niño years; rainfall remained moderate-to-high during the moderate El Niño and La Niña"(p. 113). There is no explanation for Bangladesh experiencing a wet period during Moderate El Niño (Chowdhury, 2003). But La Niña results in increasing rainfall in the country (Hossain et. al., 2000). The variation in rainfall can influence agricultural production. However, the change in temperature is also noticed.

Unusual warming dominated most of the tropic from December 1997 to February 1998 (WMO, 1998). The temperature in 1998 was the warmest worldwide in 139 years of instrumental recording started. The El Niño contributed to record warming of the year 1998 in first 6 months. Considering the normal temperature from the year 1961 to 1990, the average near-surface temperature in 1998 was 0.57C above the 30-year normal measurement. All continents experienced higher mean annual surface temperature. The higher temperature in 1998 winter for 10 days was observed in Bangladesh. The higher temperature in South-West Monsoon was also noticed in 1998 (Hossain et al., 2000). Changes like this are climatic parameters can affect the agricultural cultivation of Bangladesh.

Bangladesh is an agricultural country. The country has fertile lands and favorable weather for agriculture. This results in an abundance of crop growth and production. 17% of total GDP comes from the agricultural sector. 45% of total labor force is working in this sector (BBS, 2016). Rice (Aus, Aman, and Boro) Wheat, Potato and Jute cultivation are widespread. These crops are cultivated in different seasons for different climatic features. In 1997-1998, Bangladesh received shortage of rainfall. This resulted in short drought during major crop production period. The main crop production was reduced by 12% to 20% in the 1997-1998 economic year compared to a normal year (Hossain et. al., 2000). So, changes in seasonal temperature and rainfall pattern control crop cultivation and production.

Rainfall plays a vital role in the agricultural production of Bangladesh. Both decreased and increased amount of rainfall hampers agricultural production. Studies have found that 1mm increase in rainfall at the vegetative, reproductive and ripening level of Aman rice can decrease its production by 0.036, 0.230 and 0.292 ton respectively (MoEF, 2016). According to Bangladesh Agriculture Development Corporation (BADC), water scarcity limits crop’s production because irrigation can cover only 56% of the area (MoEF, 2016). Due to decreased rainfall, Aman rice production was 0.7 metric tons less than the previous year in 1997-1998 (Hossain et. al., 2000). Temperature also influences crops in different production stages.

The temperature range for crops varies. Temperature range leads the vegetative and reproductive growth. If there are changes in the certain temperature range, crops face difficulties to grow. If we investigate Aman rice production, a higher temperature can decrease production. For example, 1C increase in maximum temperature at vegetative, reproductive and ripening stage will result in decreased production by 2.94, 53.06 and 17.28 tons respectively. If the temperature changes by 2C and 4C, wheat and potato production can be disrupted. It can account for 60% or more production loss of the achievable yields. Soil organic matters are also affected by temperature. Higher temperature means a negative impact on soil organic matter (MoEF, 2016). However, changes in climatic parameters induce natural disasters.

Natural disasters such as drought, floods, cyclones etc. are recurring phenomena in Bangladesh. Increased or decreased amount of Rainfall decides whether there will be flooding or Drought. These disasters can affect all dimensions of food security (MoFDM, 2005). According to Hossain and Colleagues (2000), "El Niño is generally associated with drought, whereas La Niña results in increased rainfall and flooding in Bangladesh". Drought occurs when there is less to no rainfall and flooding can be due to excessive rainfall. Walker's observation in the 1920s has explained the scientific views of El Niño teleconnections to Bangladesh. His observations state that there is low atmospheric pressure in the region between Australia and India, whereas, in the eastern Pacific Ocean, the high atmospheric pressure is observed. In general, wind flows from high-pressure areas to low-pressure areas. This way moisture from Pacific oceans accumulates around Bangladesh and India. Moisture accumulates in La Niña situation and Bangladesh faces heavy rainfall, floods, and cyclones. This is known as Walker circulation. During El Niño, the sea surface temperature increases in the Pacific Ocean and the wind flow reverses or stops. This causes a decrease in rainfall. This leads to Drought in Bangladesh (Hossain, et. al., 2000). Flooding and Drought can affect vulnerable communities in Bangladesh and hamper agricultural production for a period.

River overflow can cause flooding. The influence of ENSO on Jamuna (one of the main rivers) river in Bangladesh is noticeable during monsoon. Considering the Jamuna river flow series from 1956-1963, the chance of exceeding average annual flow is 0.40. But in El Niño year the chances of exceeding drops to 0.22 and in La Niña years increases to 0.58 (Tanner et.al, 2007). This is a clear indication that, there is an increased probability of drought during El Niño years. Drought effects on Bangladesh are mostly on pre-monsoon and post-monsoon period. In Bangladesh, drought occurs every two years. But in the 1990s, drought condition in the north-western part of the country has created shortfall rice production of 3.5 million tons. Other crops are also affected by this situation (MoEF, 2016). This indicates a threat to food security in the country. In case of food production in Bangladesh, floods are far worse than drought.

In studies, it was noticed that in major El Niño year, Bangladesh did not experience any catastrophic flooding. Only two events of severe flooding clashes with El Niño years. In some years, such as 1963, 1965 and 1969, Bangladesh had moderate flooding and those years were moderate El Niño years (Chowdhury, 2003). So, there is a slight influence of ENSO on drought and flooding events of Bangladesh. According to Chowdhury (2003), "Southern Oscillation Index (SOI)– rainfall in the upstream Ganges-Brahmaputra-Meghna (GBM) basins in India is strong, the same SOI – rainfall relationship offers limited applicability in the context of Bangladesh climate". The author mentioned this due to Bangladesh experiencing normal rainfall during few moderate El Niño years. More intensive research on this sector may clarify this in future. But, limited applicability stands for influence as well because during a moderate or weak ENSO years Bangladesh can experience flooding but in La Niña years or SOI positive years, Bangladesh may experience severe flooding (Hossain et. al., 2000). The studies discussed above indicated a link between flooding and La Niña and shows natural disasters are linked with ENSO to an extent. So, there can be a connection with the agricultural production.

Natural disasters influence agricultural production. If we consider 1988 flood of Bangladesh, it reduced crop production by 45% (MoEF, 2016). 1988 was an SOI positive year (Hossain et. al., 2000). Due to several factors, in changing climate the frequency of devastating floods may increase. Long flooding period tends to delay the Aman rice plantation, and this might cause loss of agricultural production. This is evident from 1988 flooding. The country experiences flash flooding and this is the reason of Boro rice production loss in Haor (a wetland ecosystem in the northeastern part of Bangladesh) areas. If we consider this situation, Bangladesh will have more flooding related issues in changing the climate and food security will be hampered (MoEF, 2016).

Cyclones can also cause seasonal flooding in some areas and disrupt food security. Hossain and Colleagues (2000) also mentioned that "*Bangladesh has not been struck by any catastrophic cyclone, during strong El Niño years*" (p. 4). During small SOI, whether positive or negative and the isotherm (28.5c) stays west of 165E longitude, the probability of cyclone hitting Bangladesh is higher than normal period. So, ENSOs atmospheric part influences cyclone occurrences (Hossain et. al., 2000). Cyclones can also induce huge damage to agricultural food production. In 2007, Cyclone Sidr hit the Aman rice harvesting season. The loss in rice equivalent was about 1.23 million tons with 535,707 tons in the four severely affected districts, 555,997 tons in badly affected 9 districts and 203,600 tons in moderately affected 17 districts in Bangladesh (MoEF, 2016). So, natural disasters can hamper agricultural production all over the country.

The background sums up that ENSO cycle can influence climatic parameters. This, in turn, can affect agricultural production either directly or by initiating extreme disaster events such as flooding, drought etc. This study focuses to find out the impact of ENSO on agricultural crop production in Bangladesh. In the next chapter, the methodology of the study is described.

Chapter 3: Research Methodology

3.1 Study Area

The study area for this research is Bangladesh where agriculture is the main way to secure food security. Bangladesh is in South Asia with 149.7 million people and the total area is 147,570 square kilometers (BBS, 2012). The country is located between the Himalayan Mountains on the northern side and Bay of Bengal on the southern side (World Bank, 2010). The geographical location also makes it vulnerable to different climatic events.

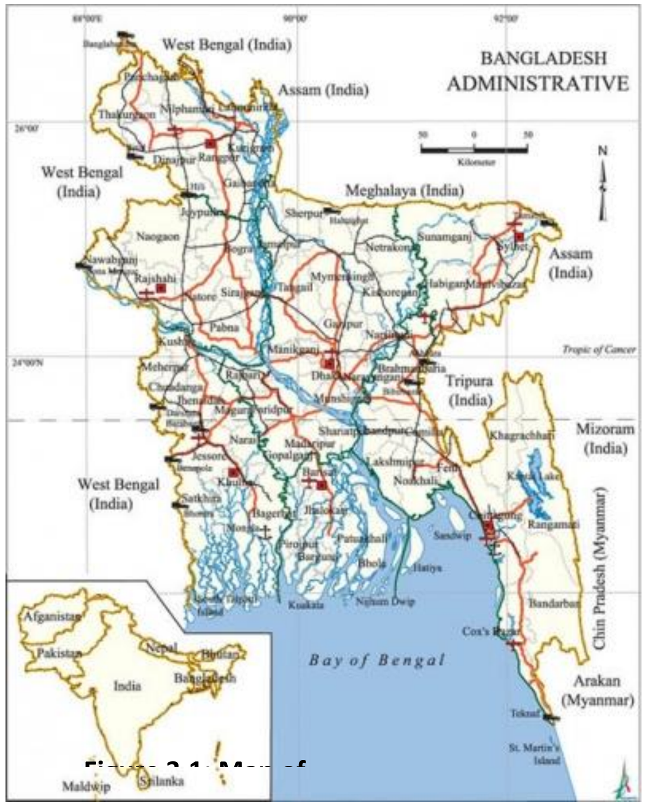


Figure 3.1: Map of Bangladesh. Source-(Banglapedia, 2015)

Bangladesh is a climate vulnerable country. The country faces tornados, flooding, drought, storms on yearly basis (MoEF, 2009). This events highly affect the food production in the country. Annual food production, average rainfall/temperature, and a number of disaster events these are all linked. Changes in climate can lead to warmer and humid climate with changes in rainfall pattern which will interrupt agricultural production.

Several studies have focused on agricultural production in Bangladesh, how the country is climate vulnerability. Disasters frequently disrupt livelihood, agricultural production, and food security. But, few types of research focused on ENSO and its consequences in Bangladesh.

3.2 Research Design

This study uses mixed method research techniques. So, there is both quantitative and qualitative approach in this research. The first objective of this study is to find out the impact of ENSO on agricultural crop production in Bangladesh. The null hypothesis for the objective is that ENSO has no impact on agricultural production of Bangladesh. The alternative hypothesis is ENSO has an impact on agricultural crop production in Bangladesh. This hypothesis is tested under quantitative approach.

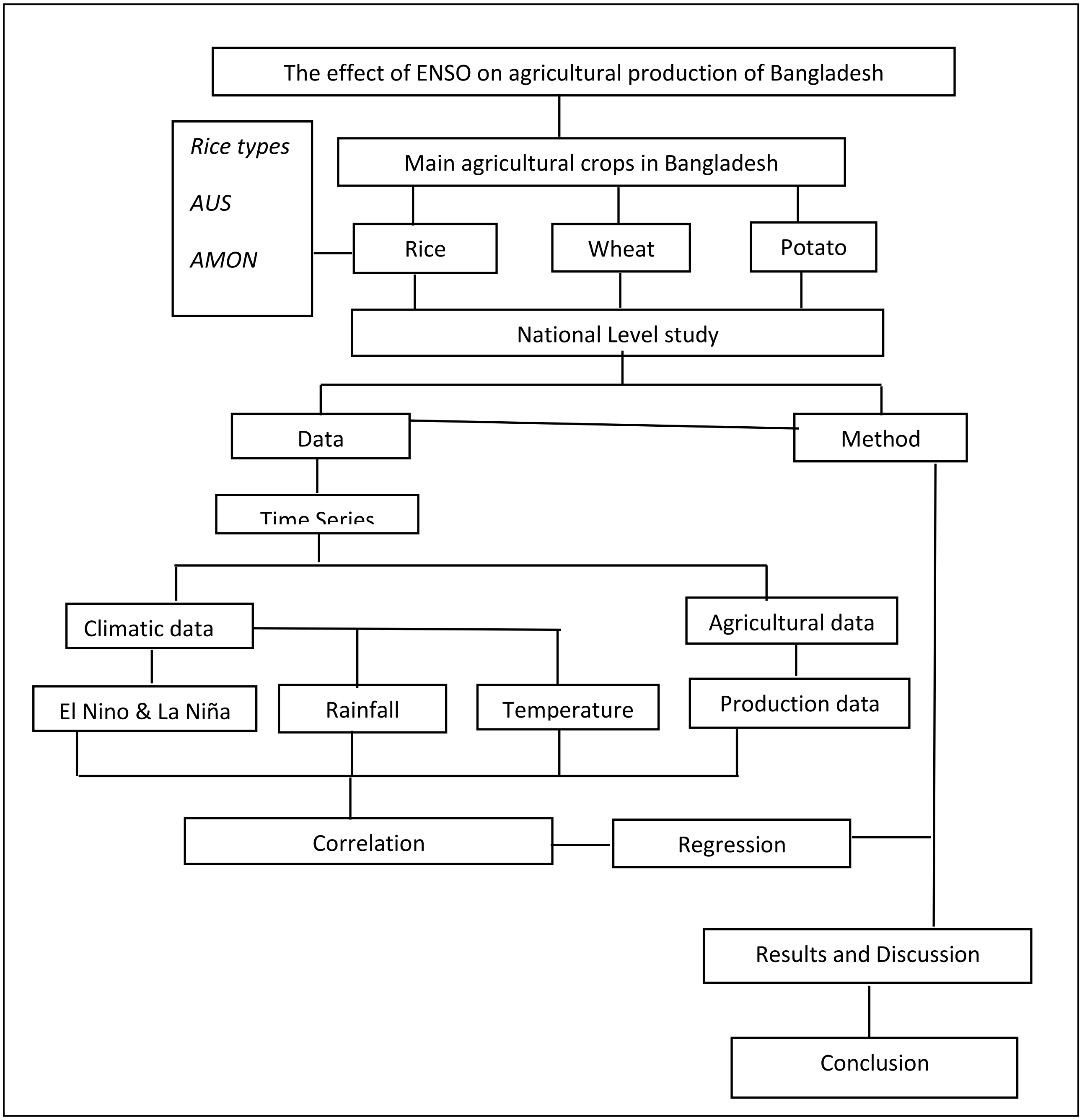


Figure 3.2: Research design flow diagram for quantitative data.

To test the hypothesis, I am following the research design in figure 3.2. This shows how quantitative data is integrated into the study. The second objective of the study is to understand the importance of ENSO in Bangladesh policies and disaster management. To achieve this objective, I choose a qualitative approach. For this, semi-structured interviews were conducted with experts to know their perspectives. For the Qualitative part, I am following the research design in figure 3.3. Therefore, my research includes mixed method approach to pursue the objectives.

The focus of this research is to find out the impact of ENSO on agricultural production. From previous studies discussed in chapter 2, it is visible that climatic parameters and agricultural production are linked. So, to find out the correlation between ENSO event and agricultural production, a quantitative approach was followed through statistical analysis. I chose this approach because quantitative studies can produce reliable results and the result can be generalized to a larger population (Field, 2009). For this part of the research, data mentioned in figure 3.2 were collected from various sources such as Bangladesh Meteorological Department (BMD), Bangladesh Bureau of Statistics, (BBS) National Oceanic and Atmospheric Administration (NOAA). These are the sources of quantitative data for this study.

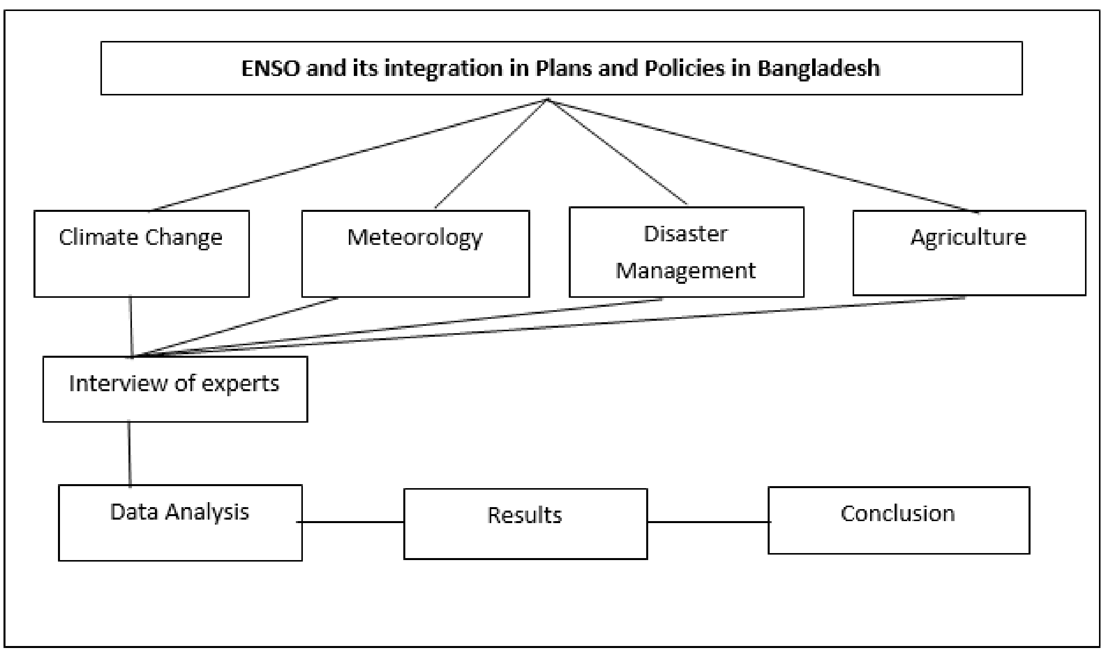


Figure 3.3: Research design flow diagram for qualitative data.

This study uses Qualitative approach to understand the importance of ENSO in policies and disaster management in Bangladesh, which is the second objective of the research. Policies and disaster management plans in the field of climate change cover various areas. So, to have a clear view, four experts from four different fields were interviewed. The respective fields are Climate Change, Meteorology, and Agriculture and disaster management. All the experts are involved in their respective fields for more than 15 years. The qualitative approach followed a semi-structured interview.

3.3 Quantitative Research Methods

3.3.1 Data collection

3.3.1.1 Meteorological Data Collection

Rainfall, high and low temperature are meteorological data for this study. To access the data, I applied officially in the head office of Meteorological Department in Dhaka. The Bangladesh Meteorological Department (BMD) is responsible for keeping records of all meteorological data. This is a government organization. The BMD operates under Ministry of Defense, Government of the People's Republic of Bangladesh. BMD monitors and issue forecasts and warning for all meteorological events such as cyclones, nor'wester (Storms occurring usually in summer season all over Bangladesh with Lightening), tornadoes, thunderstorms, heavy rainfall, drought, cold and heat waves etc (Khatun, et al., 2016). They also have all meteorological data available for research and studies which is available through formal application process.

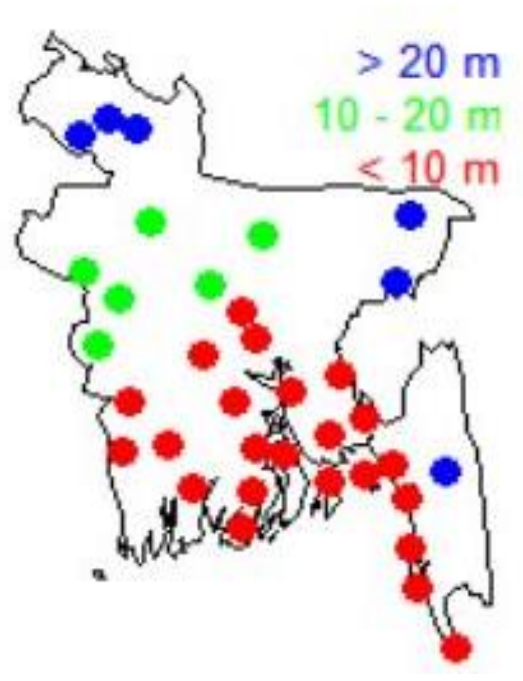


Figure 3.3: Meteorological station of Bangladesh. (Source- Khatun, et. al., 2016)

BMD has a very formal procedure and waiting line to get the data. At, first, I applied with a letter from the university. After getting approval, I submitted a filled-up form for the data and paid a certain amount fixed by the department to get the data. I had to wait for five-week to get the data because there are several applications under process. I submitted the first week of January 2018 and got the data in February 2018. Table 3.1 is a list of the meteorological stations in Bangladesh used in this study.

Table 3.1: List of Meteorological Stations (Source: Khatun, et al., 2016).

Name of the meteorological station	International Station Number	Name of the meteorological station	International Station Number
Dhaka	41923	Chuadanga	41926
Tangail	41909	Jessore	41936
Mymensingh	41886	Khulna	41947
Faridpur	41929	Mongla	41958
Madaripur	41939	Satkhira	41946
Srimangal	41915	Barisal	41950
Sylhet	41891	Bhola	41951
Bogra	41883	Khepupara	41984
Dinajpur	41863	Patuakhali	41906
Ishurdi	41907	Chandpur	41941
Rajshahi	41895	Teknaf	41998
Rangpur	41859	Chittagong	41978
Syedpur	41858	Comilla	41933
Coxs Bazar	41992	Rangamati	41966
Feni	41943	Sandwip	41964
Hatiya	41963	Sitakunda	41965
Kutubdia	41989	M.court	41953

This study collected the data for 35 weather stations in Bangladesh for rainfall and temperature. The temperature data is available in two parts, one is maximum average temperature, and another is minimum temperature value. For this study, I used both temperature value in the analysis as separate variables instead of combining them. The data is from 1980 to 2016. The data for 2017 is available until September. According to the meteorological department, the data for 35 years is authentic for studies related to climate change and relevant issues. BMD is the only source to collect meteorological data in Bangladesh. The study analyzes data from 34 weather stations. One weather station has data from 1999 and is not considered in the study. Using data from 34 stations, I calculated the annual country average.

3.3.1.2 Agricultural data collection

Agricultural production data is the core factor of this study. I am using data for Rice, Potato, and Wheat in my research. Rice is the staple food of Bangladesh. Three types of rice are considered for this study. They are Aus, Amon, and Boro. These three types of rice have three different harvesting seasons. Aus is harvested in July-August. Broadcast Aman is harvested in November-December and Transplanted Aman in November-January. Boro has two types also, one is local Boro, harvested in April-May and yielding Boro, harvested in May-June (BBS, 2018). Potato is also an important crop in Bangladesh, though it is not considered as a staple food here as oppose to other parts of the world. Potatoes are mostly used in curries. Most potatoes in Bangladesh are harvested in February-March. Wheat is a winter crop in Bangladesh. I chose these five kinds of crops as they are considered as major crops in Bangladesh. The data collected includes the total area of the crop cultivation, total production from 1970-1971 to 2014-2015. For this study, I am using data from 1980-1981 to 2014-2015. I collected the data from BBS, a government organization responsible for keeping records. This data was collected from Bangladesh Bureau of Statistics (BBS). They published a report titled as "45 years Agriculture Statistics of Major Crops (Aus, Amon, Boro, Jute, Potato & Wheat)" in January 2018. For this study, I used the data from this report. I collected the report from the BBS office.

3.3.1.3 El Niño and La Niña data collection

The data for El Niño and La Niña is available at National Oceanic and Atmospheric Administration (NOAA) website. This is an American scientific agency within the United States Department of

Commerce. NOAA focuses on ocean and atmosphere condition. The data for ENSO is available under their Climate Prediction Center. For NOAA, Oceanic Niño Index (ONI) is the de-facto standard. NOAA uses this to identify El Niño (warm) and La Niña (cool) events in tropical Pacific. ONI is the running 3 months SST anomaly for Niño 3.4 region, for example, 5^oN-5^oS, 120^o-170^oW (GG Weather, 2018).

Table 3.2: The summery of Quantitative Data.

Data type	**Source of Data**	**Available period of Data**	**Comments**
Meteorological Data (Rainfall, High, and low Temperature)	Bangladesh Meteorological Department	1980 to 2016 (Monthly basis)	Data used from 1980 to 2015
Agricultural data	Bangladesh Bureau of Statistics	1970-1971 to 2014-2015 (Annual)	Data used from 1980-1981 to 2014-2015
El Niño and La Niña Data	National Atmospheric and Oceanic Administration	1950 to 2017 (monthly Basis)	Data used from 1980 to 2015

3.3.2 Data analysis

Different quantitative data have different timelines. The data was organized at first to match the different data with each other in the same time frame. All the meteorological data are available on monthly basis for each year from January to December. ENSO data is also available on monthly basis. But, the agricultural data is available on yearly basis. Data is calculated from July to June. Therefore, I organized rainfall and temperature data from July to June for all the weather station and then calculated a country average before as part of the analysis. The Data for ENSO is categorized marking their strength for each year (July to June). The categories are strong, moderate and weak El Niño and La Niña. Three events are categorized as Very Strong El Niño. After organization, data were analyzed.

Data analysis was done in both Microsoft Excel and R studio. Certain statistical methods were followed (Will be elaborated after analysis). The data was used to produce graphical representation. For this research, the dependent variable is agricultural production and the independent variable is El Niño and La Niña. Rainfall, High and Low temperatures are considered as independent in linear regression models. Correlation, Bivariate, and Multivariate regression analysis are done in R studio. Regression analysis predicts the outcome of the dependent variable based on the values of the independent variables.

3.4 Qualitative Research methods

3.4.1 Data Collection

Qualitative data for this thesis are the four interviews with experts from the following fields – Climate Change, Meteorology, Disaster Management and Agriculture. The interviews focus to know the expert's perspectives on ENSO and its possible incorporation is disaster management in Bangladesh. The interviews are conducted to pursue the second objective. The data is collected through four semi-structured interviews with four experts in four different fields mentioned previously in research design.

The experts are the Key Informant. Several experts I approached were unwilling to participate in this research. The most common reason mentioned by them is lack of working expertise in this area of research few rejected because of their busy schedule. Initially, the plan was to have 8 interviewees, but 4 interviews are conducted. The data collected through these interviews are qualitative in nature. The interview durations are 45 minutes to 60 minutes. The reason behind choosing this four fields is to gain perspective on the topic of this study from the angle of climate change, meteorology, disaster management, and agriculture. All the interviewees are selected under purposive sampling. They are asked open-ended questions and encouraged to reflect their opinion on this research. All the interviewees participated voluntarily, and they have relevant expertise for more than 15 years in their respective fields.

3.4.2 Data analysis

For this study, all the interviews were transcribed and written as texts. The interview data is coded after transcribing. Inductive coding is used to analyze the data. Inductive coding means assessing raw interview data to obtain useful information. Inductive coding examines the data closely and discovers the valuable information from the interviews. The information with similar meanings is identified. After this, same texts are assigned to a new category. After all the texts are categorized, these categories are analyzed to reduce repetition of texts and a model is formulated to answer the research question (Thomas, 2003). Throughout the entire process, the data is handed safely and protected in my personal laptop with password protection. There are no biases towards the data.

Chapter 4: Results

This chapter will describe the findings from the quantitative and qualitative analysis. So, chapter four is divided into two parts. Part 1 discusses the impact of ENSO on crop production and part 2 discusses the incorporation of ENSO in Disaster management in Bangladesh.

Part 1: Impact of ENSO on crop production

I conducted quantitative analysis to pursue the first objective which is to identify the possible impact of El Niño and La Niña on agricultural crop production. The results from the quantitative analysis are displayed with scatterplots, boxplots, and regression model in following sub-point.

4.1 ENSO strength in different years

Each El Niño and La Niña events are different from each other and their strength can be different each time (Davey, Brookshaw and Ineson, 2014). These events arise in combination with other climatic aspects. In this study, the data for ENSO is organized according to event's strength. For this study, the ENSO strength is denoted with a number to analyze. Weak, Moderate, Strong and Very Strong El Niño events are marked as 1, 2, 3 and 4 respectively and weak, moderate and Strong La Niña is marked as -1, -2 and -3.

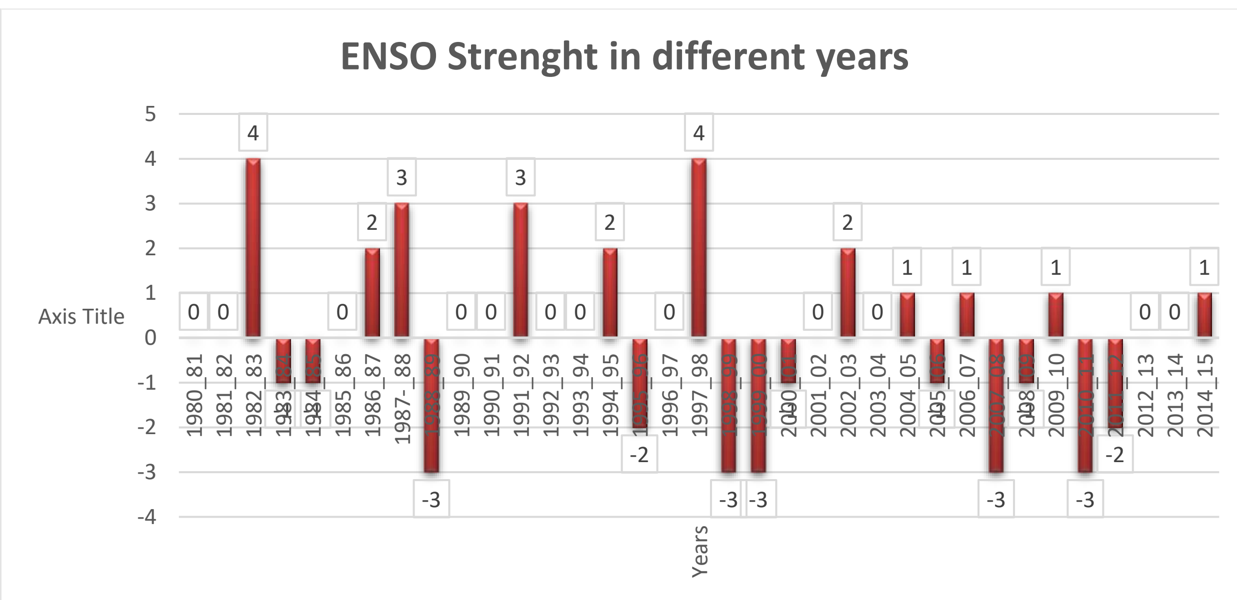


Figure 4.1: ENSO occurrence in different years with Strength.

Figure 4.1 shows us the positive values as ENSO warm period or El Niño and the negative values as ENSO cold period or La Niña. We can observe that there 11 El Niño and 12 La Niña from 1980-81 to 2014-15. 12 Neutral years are also indicated. So, we can say there is a balance between the occurrences of El Niño, La Niña and neutral years. NOAA uses Oceanic Niño Index (ONI) as a standard to determine El Niño (warm) and La Niña (cool) events in the tropical Pacific. When there is 5 consecutive overlapping of three months periods at or above +0.5 anomalies for warm and -0.5 anomalies for cold, the events are described as El Niño and La Niña Respectively (GG Weather, 2018). And the events are divided into weak (with a 0.5 to 0.9 SST anomaly), moderate with a 1.0 to 1.4 SST anomaly) and strong (with a 1.5 to 1.9 SST anomaly) for El Niño and the similar negative values to divide La Niña as weak, moderate and strong. Very strong events have SST anomaly over +2 or less than -2. The anomalies will be counted if it has equaled or exceeded the threshold for at least 3 continuous overlapping for three months (GG Weather, 2018).

4.2 Correlation between ENSO and Agricultural Production

ENSO is a natural phenomenon and it has links with climate variabilities around the world. Agricultural production is linked to climate change and climate variability. For this study, the Null Hypothesis is that ENSO has no impact on agricultural production and the alternative hypothesis is ENSO has an impact on agricultural production. To test the hypothesis the correlation analysis between ENSO strength and agricultural production is done.

4.2.1 Rice production

Rice is the staple food of Bangladesh and is cultivated all the year round. There are three kinds if rice prominently cultivated in Bangladesh (Aus, Amon, and Boro) and all three are considered in this study. Their correlation with ENSO and changes in different years are discussed in points below.

4.2.1.1 Aus Rice Production

For this study, Aus rice production from 1980-1981 to 2014-2015 is considered. The crop years are considered as July to June in Bangladesh. In figure 4.2, we can see changes in Aus rice production in different years with ENSO Occurrences. Yau is the trendline for Aus rice production and Ye is the trend line for ENSO. Rice production in 1987-88 shows a sharp decrease and that year is A Strong El Niño year. Other than that production shows an increasing trend. From the figure, we can also see there is a significant increase in Aus rice production compared to the previous years.

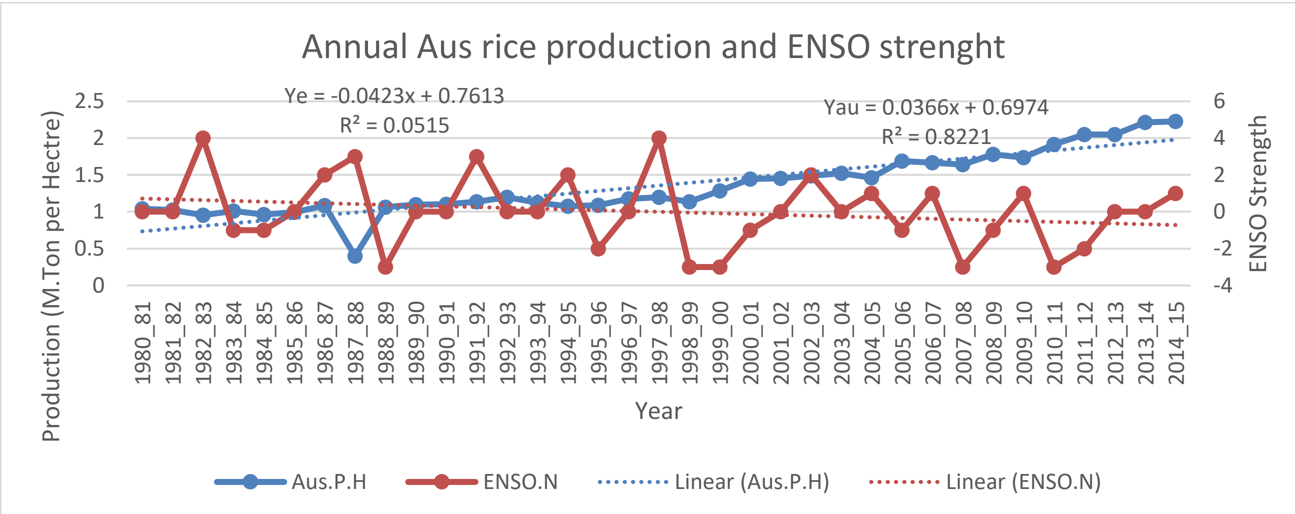


Figure 4.2: Annual Production of Aus rice in response to ENSO Occurrence.

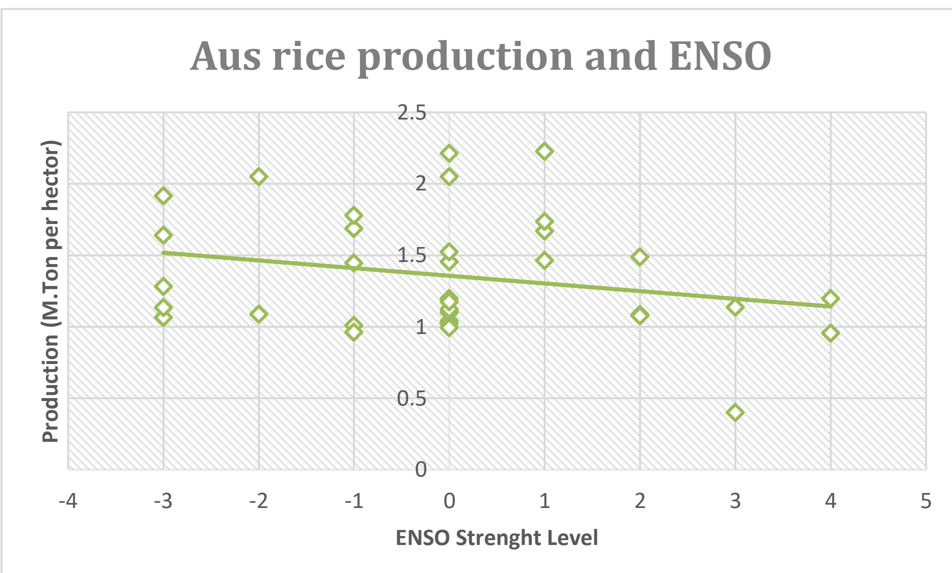


Figure 4.3: Scatterplot between Aus Rice production and ENSO Events.

Figure 4.3 indicates Aus Rice Production and ENSO occurrence according to its strength. There is no visible linear correlation between ENSO and Aus rice production. The Pearson's correlation coefficient value for Aus rice and ENSO strength is **0.09.** The P value for this test is 0.61. The test does not indicate significant correlation among them.

4.2.1.2 Amon rice production

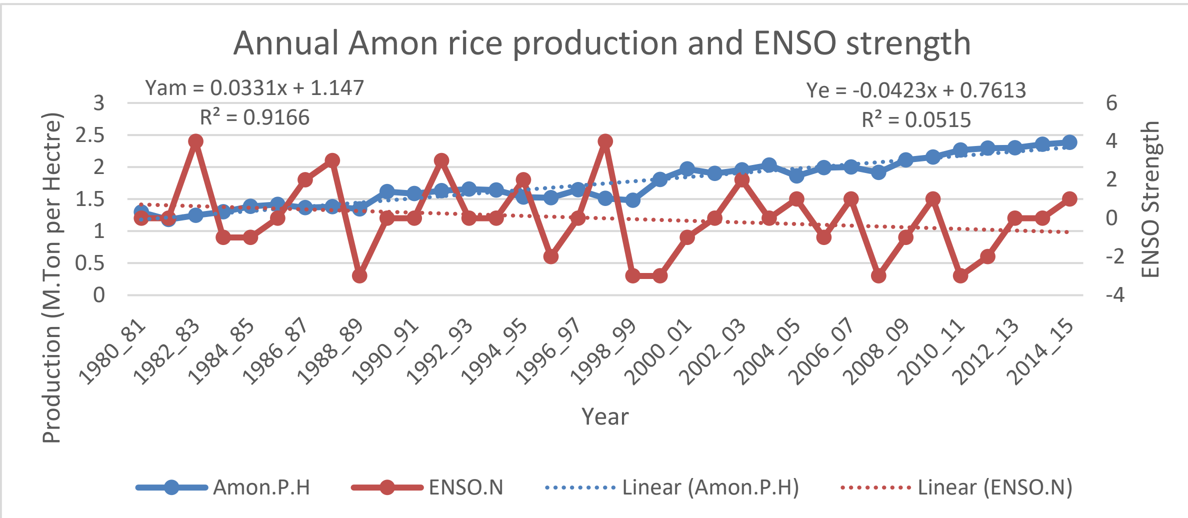


Figure 4.4: Annual Production of Aus rice in response to ENSO Strength.

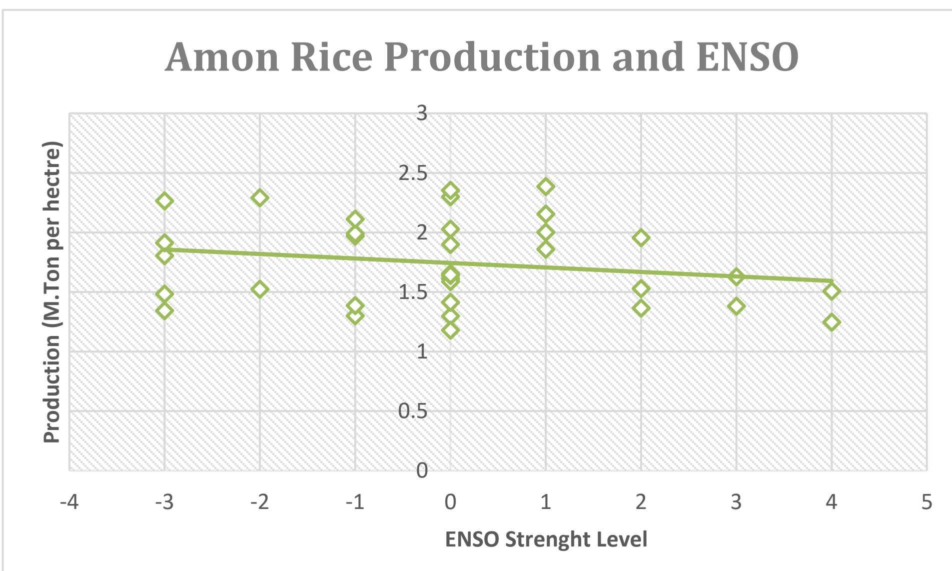


Figure 4.5: Scatterplot between Amon Rice production and ENSO Events.

In figure 4.4, annual production of Amon rice is visible with strength level in different years. There is an increasing pattern of rice production is noticed and the value is significant. Here, Yam shows an increasingly significant trend for Amon rice production and Ye is the trendline for ENSO. No direct visible downfall of production is noticed from the graph.

To analyze the linear correlation between Amon and ENSO, we can investigate figure 4.5. The scatterplot does not show significant linear relation. The Pearson's correlation value for Amon rice production and ENSO strength is **0.076** and the confidence interval for correlation coefficient is 95%. The P value for the correlation test is **0.66**. No significant correlation exists between Amon rice production and ENSO strength in different years.

4.2.1.3 Boro Rice production and ENSO

Boro rice production shows an increasing trend with years similar to Aus and Amon rice. This increasing trend has a significant value. There is no visible fluctuation with ENSO strength in the years considered in this study. Yb is considered as increasing trend for Boro rice production and Ye is trendline for ENSO. Figure 4.7 indicates that there is no linear correlation between Boro rice production and ENSO strength in different years. The Pearson's correlation value for Boro rice production is **0.219** where the confidence interval for correlation coefficient is 95%. The P value for the test is 0.25. the correlation between Boro rice and ENSO is not significant.

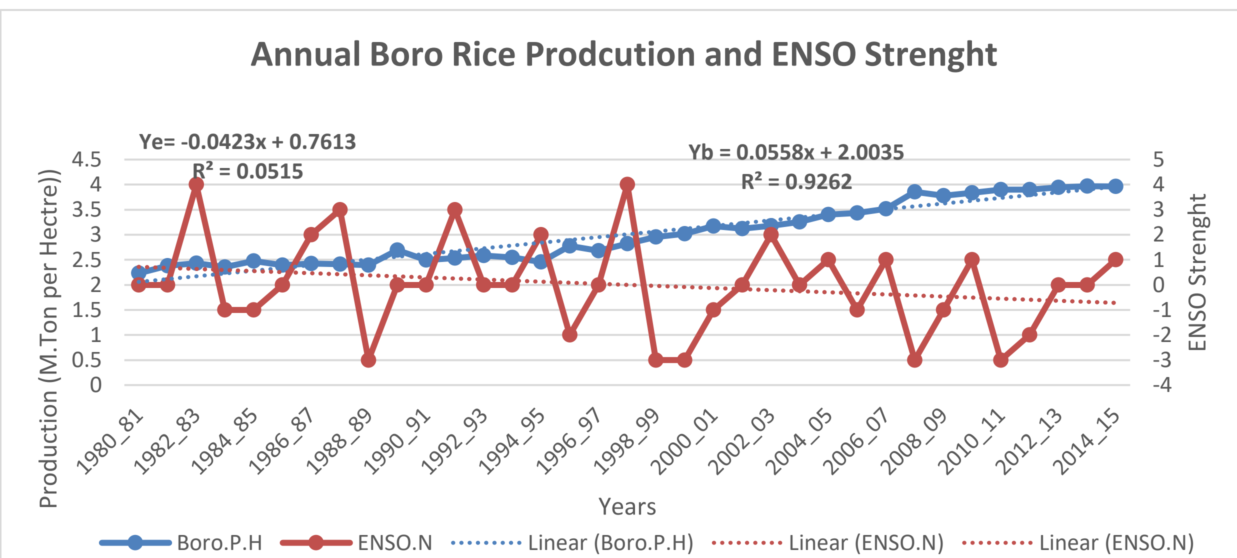


Figure 4.6: Annual Production of Boro rice in response to ENSO Strength.

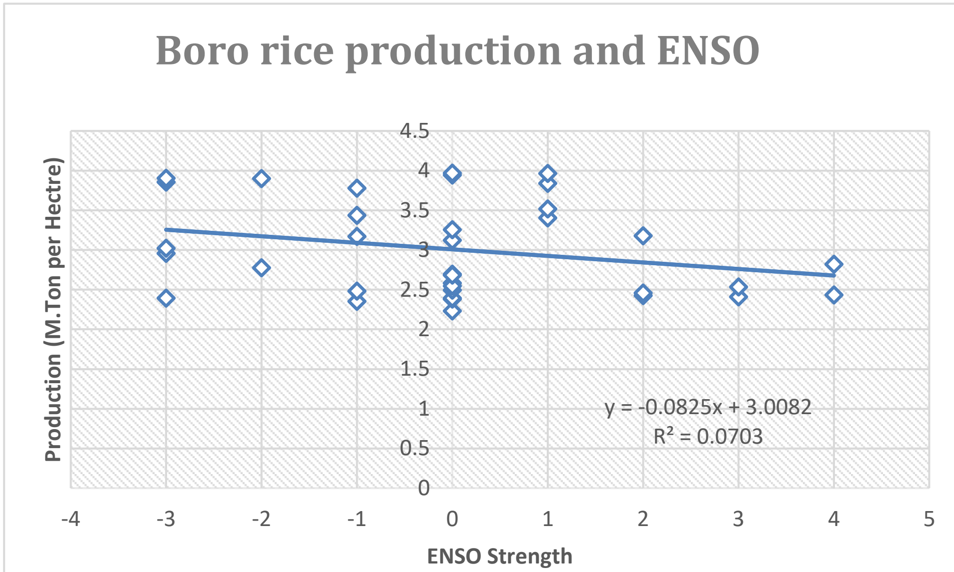


Figure 4.7: Correlation between Boro Rice production and ENSO Strength.

4.2.2 Wheat Production

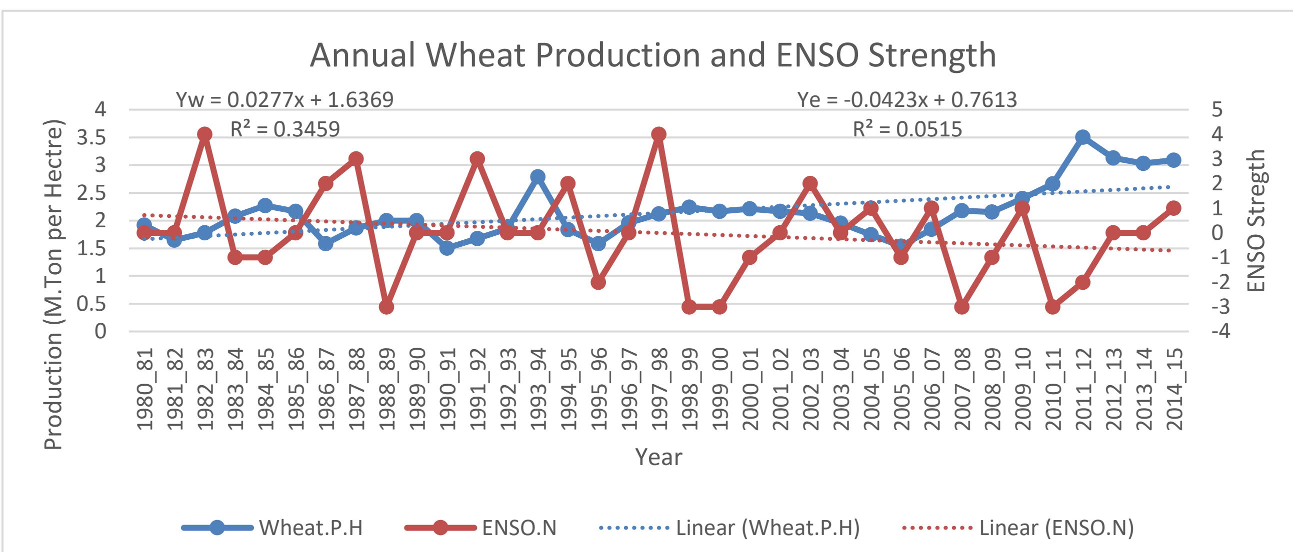


Figure 4.8: Annual Production of Wheat in response to ENSO Strength.

Wheat is the second most prioritized crop in Bangladesh. This is a winter crop and is sensitive to temperature (Hossian and Silva, 2013). If we investigate wheat production over time closely, we can see there is increase and decrease in annual production in figure 4.8. But, Wheat production is increasing with time. The R^2 value is 0.3459 is positive which means the wheat production has increased from 1980-81 to 2014-15 but the increase was not that much. Yw is trend line for wheat production and Ye is trend line for ENSO. In figure 4.9, we can see the scatterplot between wheat production and ENSO strength. It's visible that there is no significant linear relationship. The Pearson's correlation value for Wheat production and ENSO strength is **0.033**. The interval level for correlation coefficient for the test is 95%. The P value for this test is **0.85**. This indicates there is no correlation between wheat production and ENSO in different years.

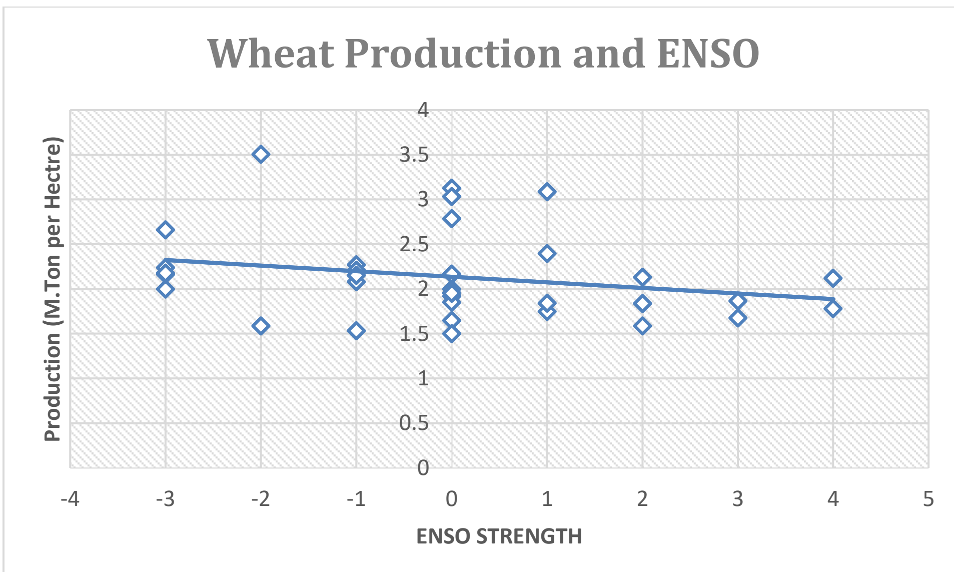


Figure 4.9: Correlation between Wheat production and ENSO Strength.

4.2.3 Potato Production

In Bangladesh Potato is used as vegetables. It plays a vital role in food sector of Bangladesh. The climate conditions in Bangladesh works in favor of potato production (Chowdhury and Chowdhury, 2015). Figure 4.10 shows the annual potato production and its changes with ENSO Strength. We can see there is a gradual increase in potato production with an occasional decrease in some years. The most decreased productions are noticed in La Niña years in 2011-12 and 1988-

89. However, the gradual increase of production shows a relatively significant positive value from years 1980-81 to 2014-15. Yp is the trendline equation for potato and Ye is for ENSO.

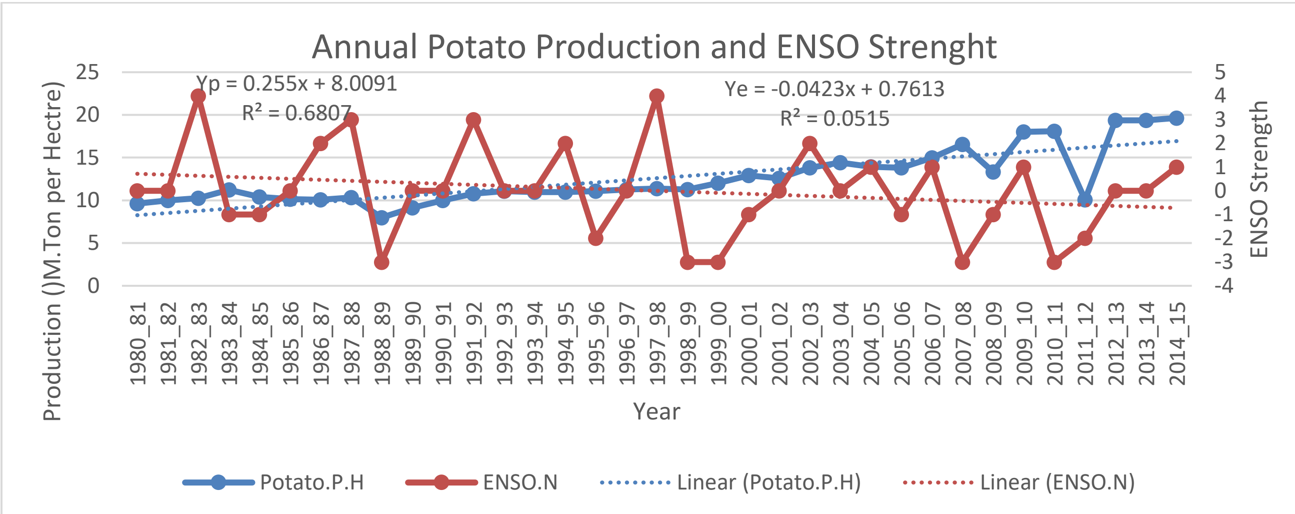


Figure 4.11: Annual Production of Potato in response to ENSO Strength.

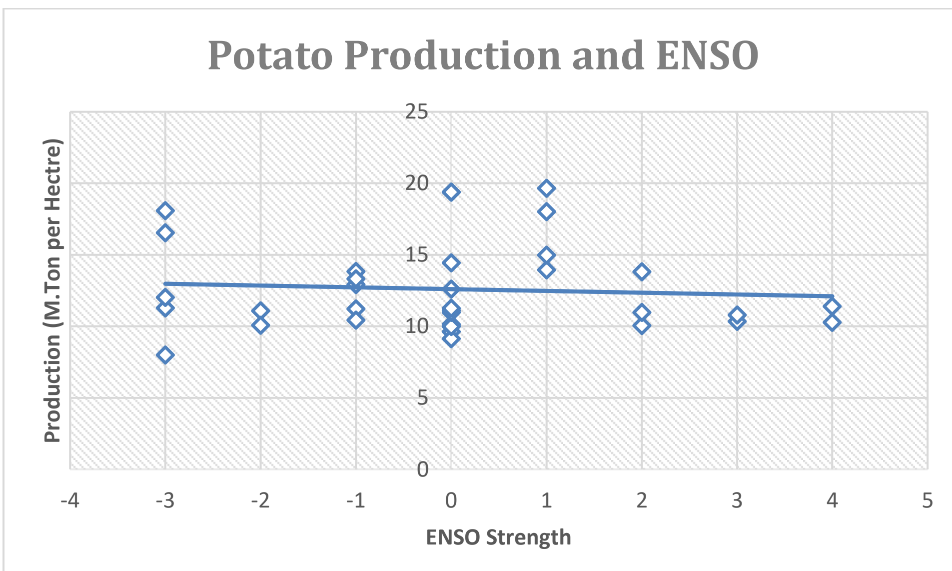


Figure 4.11: Correlation between Potato production and ENSO Strength.

Figure 4.11 shows the correlation between potato production and ENSO Strength. There is no linear relation between ENSO and potato production visible in the scatterplot. **0.008** is the Pearson's correlation coefficient where the confidence interval for the coefficient is 95. The P value for the test is **0.96**. It shows no correlation between potato production and ENSO.

So, from simple correlation analysis, we can see, none of the 5 selected crops show any significant correlation with ENSO strength.

4.3 Average production in different years of ENSO occurrences

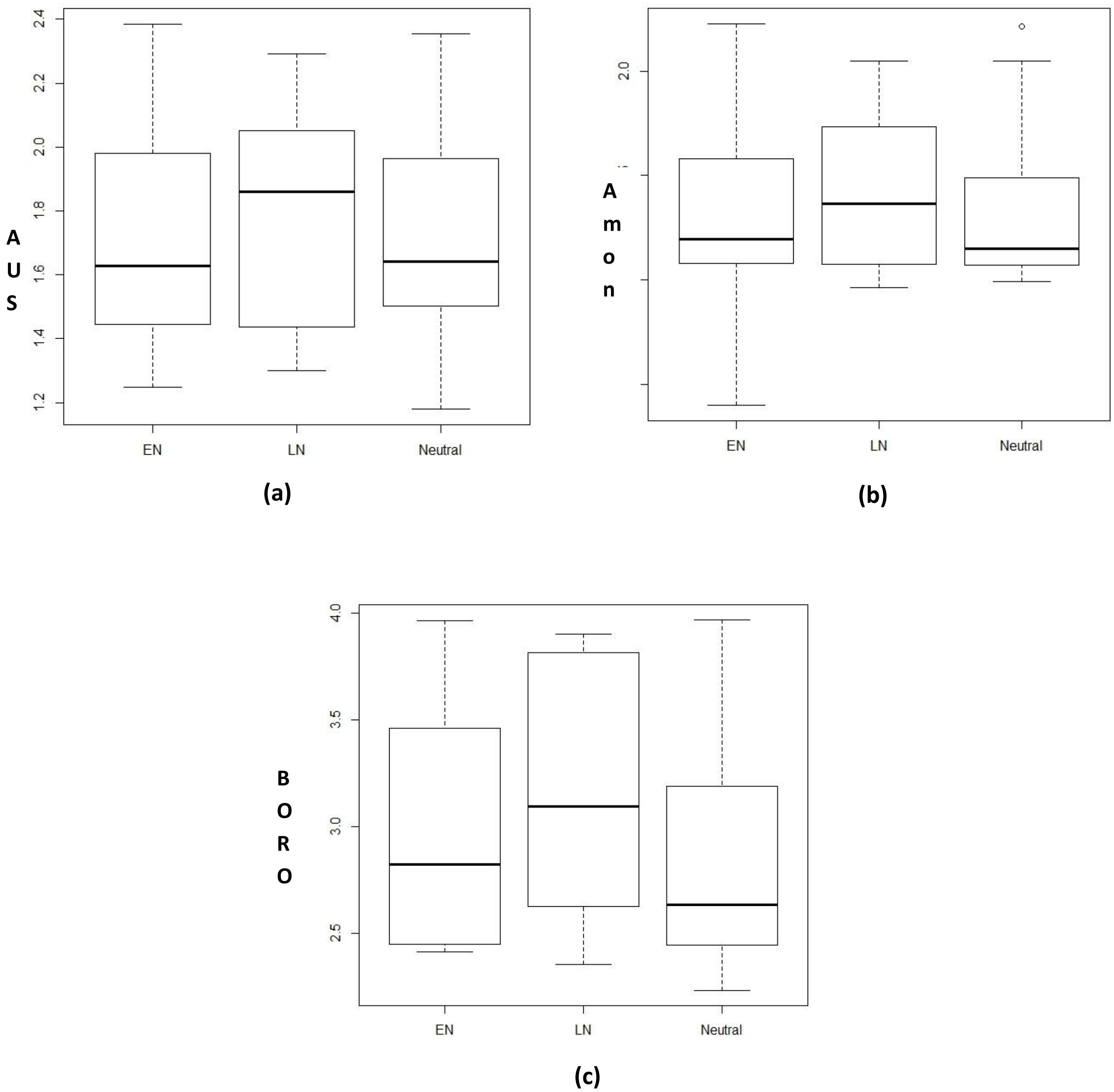
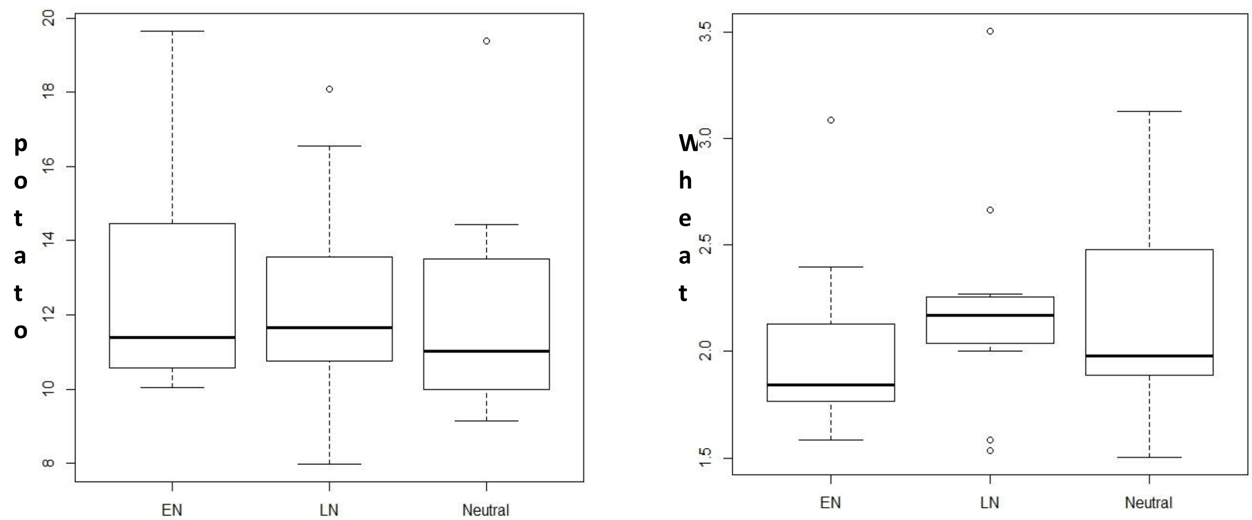


Figure 4.12: Rice production in different years with ENSO Occurrences- (a) amon production (b) Aus Production (c) Boro Production.

Simple boxplot analysis is used to see the difference in average production between different years diving them according to their ENSO occurrence. Figure 4.12 shows three different box plots for. Three types of rice production in different years. All the plots in figure 4.12 show that in La Niña years, all the rice types (Aus, Amon, and Boro) have higher average production compare to El Niño and Neutral years. The range of production varies from the average which is visible and there

Figure 4.13 shows the boxplots for potato and wheat production in different years of ENSO occurrences. Figure 4.13 (a) shows that potato has slightly increased average production in La Niña years than El Niño and Neutral years. For wheat production, we can see in figure 4.13 (b) that Wheat also have increased average production in La Niña years comparing El Niño and Neutral years. There are some outliers which indicate production varied from the mean average in some years.



(a) (b)

Figure 4.13: Wheat and Potato production in different years with ENSO Occurrences- (a) Potato production and (b) Wheat Production

4.4. Regression models showing crop production and its relationship with ENSO and meteorological parameters

The correlation analysis and scatterplots did not show any meaningful relationship between ENSO and crop production. however, the boxplots showed a trend of increased production In La Niña years. So, linear Regression analysis is conducted to find out the effect of ENSO on crop production along with other variables. Climatic parameters, rainfall, maximum and minimum average temperature, are used in the models. Because ENSO usually affects climatic parameter in various places. Four Different models are formulated for each crop by eliminating the less significant variable in the next model. The last model shows the variable having a most meaningful relationship with the crop production. Summary of all the models is present for each crop.

4.4.1 Linear regression models for Aus rice production

Table 4.1 shows four different models for Aus rice production. Except for maximum average temperature, all the other variables show negative coefficient values but none of the values are significant. Maximum average temperature shows a positive coefficient value which indicates that with increasing temperature Aus Rice production increases.

Table 4.1: Linear Regression Models for Aus Rice Production (Summary value of all the models are presented)

Model		Variable	Estimate	SE	P(>|z|)
Aus Production ~ ENSO + Avr.Rainfall + Max.Avr.temp + Min. Avr.temp		**(Intercept)**	-2.226e+01	5.313e+00	0.000238
Adjusted R squared value- 0.4541		**La Niña**	8.651e-02	1.331e-01	0.520944
		Neutral	1.725e-01	1.354e-01	0.212816
		Rainfall	-2.795e-04	2.110e-04	0.195625
R square value 0.5344	***P value 0.0003067***	**Max. Temp**	7.720e-01	1.688e-01	8.3e-05 ***
		Min. Temp.	-1.025e-01	1.927e-01	0.598930
Aus Production ~ Avr.Rainfall + Max.avr.temp + Min.Avr.temp		**(Intercept)**	-2.044e+01	4.690e+00	0.000134 ***
Adjusted R squared value-0.4604		**Rainfall**	-3.278e-04	1.931e-04	0.099643
R square value	***P value***	**Max. Temp.**	7.129e-01	1.554e-01	6.97e-05 ***
0.508	***5.61e-05***	**Min. Temp.**	-8.142e-02	1.899e-01	0.671040
Aus Production ~ Max.avr.temp + Avr.Rainfall		**(Intercept)**	-2.074e+01	4.578e+00	7.74e-05 ***
Adjusted R squared value-0.4741					
R square Value	***P value***	**Rainfall**	-3.420e-04	1.878e-04	0.078
0.5051	***1.297e-05***	**Max.Temp**	6.798e-01	1.331e-01	1.46e-05 ***
Aus.P.H ~ Max.avr.temp		**(Intercept)**	-22.7239	4.5994	2.2e-05 ***
Adjusted R squared value-0.4372					
R square Value 0.4538	***P value 9.198e-06***	**Max.temp**	0.7139	0.1364	9.2e-06 ***

In table 4.1, we are seeing a summary where among three ENSO stages two are showing as El Niño is considered as the base. We can see, ENSO does not have any significant coefficient value with Aus rice production. Maximum average temperature shows very significant Coefficient value in every model but the third model where Aus rice production is analyzed with Average rainfall and Temperature is the best model as it has the highest adjusted R square value of 0.4741. So, it can be stated that in case of Aus rice production, when Maximum Average temperature increases, production increases.

4.4.2 Linear regression models for Amon rice production

Amon rice production, as a dependent variable, was tested in different linear regression models. The models are shown in table 4.2. ENSO strength shows no significant correlation with Amon rice production.

Table 4.2: Linear Regression models for Amon Rice Production (Summary value of all the models are presented)

Model		Variable	Estimate	SE	P(>|z|)
Amon Production ~ ENSO + Avr.Rainfall + Max.Avr.temp + Min. Avr.temp ***Adjusted R squared value- 0.3455***		**(Intercept)**	-1.936e+01	4.986e+00	0.000549 ***
		ENSO			
		Rainfall	-2.795e-04	2.110e-04	0.195625
R square value ***0.4417***	***P value*** ***0.003317***	**Max. Temp**	5.745e-01	1.584e-01	0.001091 **
		Min. Temp.	1.087e-01	1.808e-01	0.552405
Amon Production ~ Avr.Rainfall + Max.avr.temp + Min.Avr.temp		**(Intercept)**	-1.711e+01	4.363e+00	0.000454 ***
Adjusted R squared value- 0.3641		**Rainfall**	-1.740e-04	1.797e-04	0.340451
R square value ***0.4202***	***P value*** ***0.0006577***	**Max. Temp.**	5.124e-01	1.446e-01	0.001272 **
		Min. Temp.	1.120e-01	1.767e-01	0.530697
Amon Production ~ Max.avr.temp + Avr.Rainfall ***Adjusted R squared value-0.3759***		**(Intercept)**	-1.670e+01	4.274e+00	0.000455 ***
R square Value ***0.4126***	***P value*** **0.0002006**	**Rainfall**	-1.545e-04	1.754e-04	0.385020
		Max.Temp	5.579e-01	1.243e-01	8.73e-05 ***
Amon Production ~ Max.avr.temp ***Adjusted R squared value- 0.3802***		**(Intercept)**	-17.5948	4.1369	0.000163 ***
R square Value ***0.3984***	***P value*** ***4.793e-05***	**Max.temp**	0.5733	0.1226	4.79e-05 ***

Maximum average temperature, Minimum Average Temperature, and average rainfall are the other variables showing coefficient values. Both the Maximum and the Minimum temperature is showing positive coefficient value in the models, but the coefficient value of minimum temperature is not significant. Rainfall is showing negative coefficient value for Amon rice production. The coefficient value for rainfall is not significant. From the adjusted R squared value, we can see the last model has the highest value. So, the best linear regression model is the last one. The value for maximum average temperature is most significant in last two models.

4.4.3 Linear Regression models for Boro Rice Production

Table 4.3: Linear Regression models for Boro Rice Production (Summary value of all the models are presented)

Model		Variable	Estimate	SE	P(>|z|)
Boro Production ~ ENSO + Avr.Rainfall + Max.Avr.temp + Min. Avr.temp		**(Intercept)**	-3.372e+01	7.916e+00	0.000197***
Adjusted R squared value- 0.4123		**La Niña**	6.534e-02	1.984e-01	0.744233
		Neutral	1.012e-01	2.018e-01	0.619726
		Rainfall	-8.616e-05	3.144e-04	0.786010
R square value 0.4987	***P value 0.000816***	**Max. Temp**	1.035e+00	2.515e-01	0.000293 ***
		Min. Temp.	1.109e-01	2.871e-01	0.702072
Boro Production ~ Avr.Rainfall + Max.avr.temp + ENSO		**(Intercept)**	-3.327e+01	7.718e+00	0.000161 ***
Adjusted R squared value-0.4289		**La Niña**	7.546E-02	1.938E-01	0.699786
		Neutral	1.069E-01	1.984E-01	0.593838
R square value 0.4961	***P value 0.0002892***	**Rainfall**	-6.969E-05	3.071E-04	0.821998
		Max. Temp.	1.079E+00	2.212E-01	3.39E-05***
Boror Production ~ Max.avr.temp + Avr.Rainfall		**(Intercept)**	-3.240e+01	6.669e+00	2.99e-05 ***
Adjusted R squared value-0.4588					
R square Value 0.4907	***P value 2.052e-05***	**Rainfall**	-8.430e-05	2.736e-04	0.76
		Max.Temp	1.056e+00	1.939e-01	5.44e-06 ***
Boro Production ~ Max.avr.temp		**(Intercept)**	-32.8933	6.3873	1.19e-05***
Adjusted R squared value-0.4737					
R square Value 0.4891	***P value 2.948e-06***	**Max.temp**	1.0644	0.1894	2.95e-06***

In table 4.3, a summary of linear regression models is shown. This shows there is no correlation between Boro rice production and ENSO. All the models show that maximum average temperature has significant positive coefficient value for Boro rice production. Rainfall has negative coefficient value for Boro rice production, but the value is not significant in any models. From the adjusted R squared value, it's visible that the last model is the best-fitted model.

4.4.4 Linear Regression models for Potato Production

In table 4.4, a summary of four linear regression models for potato production is shown. The models for Potato production showed similarities with Boro rice production model. This shows there is no correlation between potato production and ENSO in the first two models.

Table 4.4: Linear Regression models for Potato Production (Summary value of all the models are presented)

Model	Variable	Estimate	SE	P(>|z|)
Potato Production ~ ENSO + Avr.Rainfall + Max.Avr.temp + Min. Avr.temp	**(Intercept)**	-1.563e+02	4.799e+01	0.00276**
Adjusted R squared value- 0.2456	**La Niña**	-1.151e+00	1.198e+00	0.34462
	Neutral	3.768e-01	2.218e+00	0.75929
	Rainfall	-3.403e-04	1.898e-03	0.85896
R square value 0.3566 ***P value 0.01981***	**Max. Temp**	5.022e+00	1.518e+00	0.00252 **
	Min. Temp.	3.689e-02	1.733e+00	0.98316
Potato Production ~ Avr.Rainfall + Max.avr.temp + ENSO	**(Intercept)**	-1.562e+02	4.647e+01	0.002131 ***
Adjusted R squared value-0.2708	**La Niña**	-1.147e+00	1.167e+00	0.333506
	Neutral	3.787e-01	1.194e+00	0.753405
R square value 0.3566 ***P value 0.008516***	**Rainfall**	-3.348e-04	1.849e-03	0.857513
	Max. Temp.	5.036e+00	1.332e+00	0.000693***
Potato Production ~ Max.avr.temp + Avr.Rainfall	**(Intercept)**	-1.329e+02	4.097e+01	0.002758 **
Adjusted R squared value-0.2805				
R square Value 0.3228 ***P value 0.001955***	**Rainfall**	-1.230e-03	1.681e-03	0.469622
	Max.Temp	4.403e+00	1.192e+00	0.000817 ***
Potato Production ~ Max.avr.temp	**(Intercept)**	-140.065	39.512	0.001199 **
Adjusted R squared value-0.2906				
R square Value 0.3115 ***P value 0.0004942***	**Max.temp**	4.526	1.171	0.000494***

All the models show that maximum average temperature has significant positive coefficient value for Potato production. Rainfall has negative coefficient value for Potato production and Minimum average temperature has positive coefficient values, but both values are not significant in any models. From the adjusted R squared value, it's visible that the last model is the best-fitted model.

4.4.5 Linear Regression models for Wheat Production

Wheat production is resulted to have a positive correlation with maximum average temperature in all the models. ENSO does not show any significant correlation with Wheat production. Rainfall has a positive coefficient and minimum average temperature has negative coefficient values in the models. But, the values are not significant. From the adjusted R squire value, it's visible, the third model fits the best.

Table 4.5: Linear Regression models for Wheat Production (Summary value of all the models are presented)

Model	Variable	Estimate	SE	P(>|z|)
Wheat Production ~ ENSO + Avr.Rainfall + Max.Avr.temp + Min. Avr.temp	**(Intercept)**	-1.754e+01	7.534e+00	0.02708*
	La Niña	-1.889e-01	1.888e-01	0.32541
Adjusted R squared value- 0.1952	**Neutral**	3.350e-01	1.920e-01	0.09167
	Rainfall	2.801e-01	2.993e-04	0.92608
R square value 0.3135 ***P value 0.04323***	**Max. Temp**	7.862e-01	2.394e-01	0.00267 **
	Min. Temp.	-3.979e-01	2.733e-01	0.15617
Wheat Production ~ Avr.Rainfall + Max.avr.temp + ENSO	**(Intercept)**	-1.431e+01	6.812e+00	0.04390 *
Adjusted R squared value-0.1655	**Rainfall**	-5.389e-05	2.805e-04	0.84890
	Min.Temp	3-3.533e-01	2.758e-01	0.20971
R square value 0.2391 ***P value 0.03506***	**Max.Temp**	6.780e-01	2.257e-01	0.00523**
Wheat ~ Max.avr.temp + Avr.Rainfall ***Adjusted R squared value-0.1906***	**(Intercept)**	-14.5793	6.5635	0.03353 *
R square Value 0.2382 ***P value 0.01286***	**Min.Temp.**	-0.3623	0.2676	0.18519
	Max.Temp	0.6869	3.158	0.00345**
Wheat ~ Max.avr.temp ***Adjusted R squared value-0.1702***	**(Intercept)**	-16.2798	6.5231	0.01775 **
R square Value 0.1946 ***P value 0.007994***	**Max.temp**	0.5460	0.1934	0.00799**

4.3 Maximum temperature and ENSO

4.3.1 Correlation between Maximum Average temperature and ENSO

Maximum Temperature shows a significant correlation with Crop production. Figure 4.14 shows maximum average temperature and ENSO in different years. From the figure, we can see the temperature is gradually increasing and the R^2 value also indicates an increase in maximum temperature. Figure 4.15 shows the correlation between maximum average temperature and ENSO Strength. There is no linear relation between ENSO and potato production visible in the scatterplot. **-0.21** is the Pearson's correlation coefficient where the confidence interval for the coefficient is 95. It shows a week negative correlation between maximum temperature and ENSO.

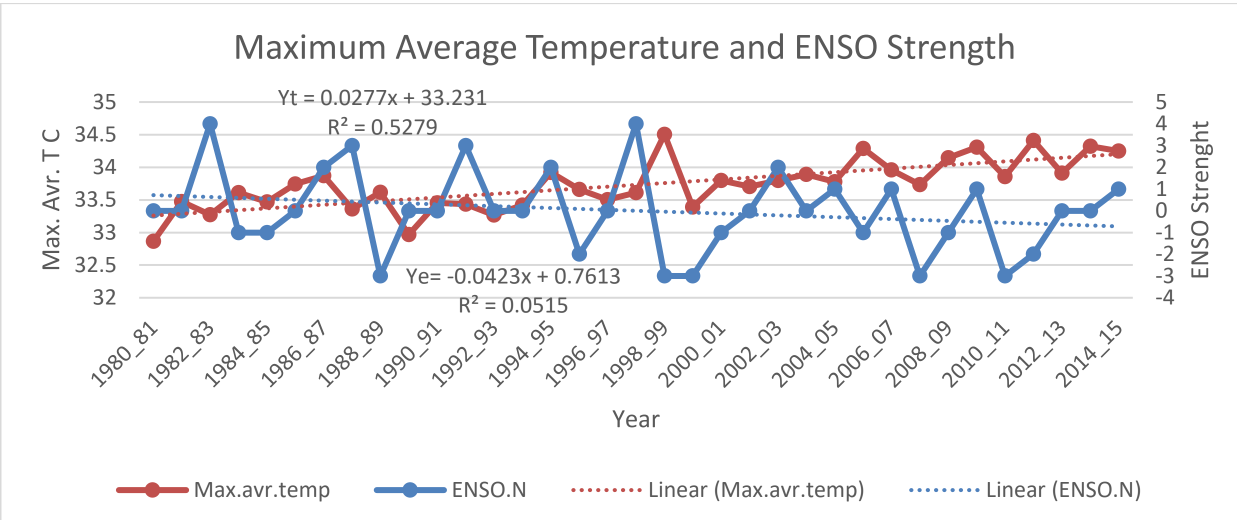


Figure 4.14: Annual Maximum Average Temperature in response to ENSO Strength.

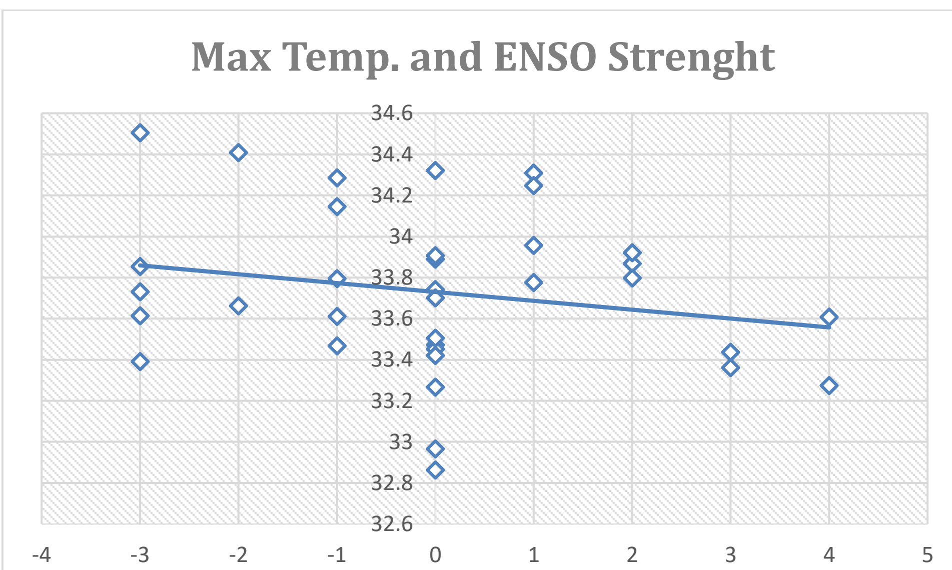


Figure 4.15: Correlation between maximum temperature and ENSO Strength.

4.3.2 Maximum temperature in different ENSO years

Boxplot is used to see the maximum temperature in different ENSO years to compare. Figure 4.16 shows the box plot for maximum temperature in different ENSO occurrences years. Maximum temperature has almost similar mean value for El Niño and La Niña years. There is a very slight increase in average temperature in El Niño years.

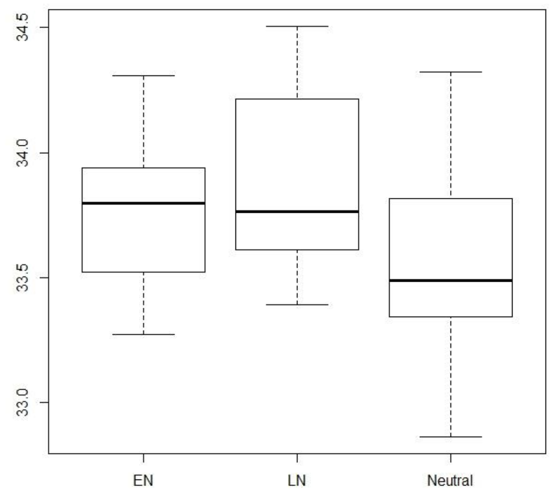


Figure 4.16: Maximum average temperature in different ENSO years.

4.3.3 Regression model for maximum average temperature

For determining the relationship between Maximum temperature and ENSO, bivariate regression analysis was done. Table 4.6 shows the regression model for Maximum temperature and ENSO. ENSO strength is a factor and it has a p-value of 0.1013 which is higher than 0.05. So, there is a significant correlation between ENSO and maximum average temperature.

Table 4.6: Linear Regression model for maximum average temperature and ENSO.

	Sum	Square mean	Square F	P value
ENSO strength	0.6914	0.24570	2.4614	0.1013
Residuals	4.4943	0.14045		

So, overall the statistical analysis cannot identify any significant impact of ENSO on crop production of Bangladesh. However, temperature plays a vital role in crop production in Bangladesh. But, the analysis could not identify possible impact of ENSO on temperature.

Part 2: incorporation of ENSO in disaster management and policies in Bangladesh

I applied a qualitative approach for pursuing the second objective of this study where four key informants were interviewed. Interviews are open-ended. Therefore, it helped the process to know more about their views. This section comprises results from those interviews.

Perception on ENSO

Interviews started asking their general perception about ENSO and its impact on Bangladesh. All four experts expressed that there is more focus on ENSO in other countries like Australia, Indonesia, and African nations, whereas Bangladesh is lagging far behind in this. In Bangladesh, research focus is commonly on climate impacts, climate change adaptations, agroecology, food security which is because of funding availability and a hot topic in the present development activities. Also, studies in Bangladesh generally focus on issues that are frequently brought up in the country like climate vulnerable agriculture, salinity intrusion and agriculture etc. But specific focus on ENSO is limited because ENSO is a natural phenomenon and occurs in other part of the world. Apart from voluntary studies on the topic, there is not much documentation available for this in the context of Bangladesh. There are some government leaded studies right after 1997-1998 ENSO. As Bangladesh suffered prolonged flooding and extreme drought conditions in two consecutive years. But after that, the focus is kind of lost. Like a climate change, expert (a key informant) said ENSO as a post-mortem event in the context of Bangladesh. He explained that ENSO is a term, the experts and researcher bring when there is a context unexplainable like the 1998 flooding. It was longer than usual flooding periods. So, when researching about that, it emerged that 1997-1998 was a strong ENSO period. Thus, the climate change experts termed La Niña was the reason behind the flood. And that is the case of ENSO in Bangladesh. When extreme disaster events occur and there is no possible explanation, the link between ENSO and those events are researched. On the other hand, disaster management expert (a key informant) also mentioned that due to lack of focus on ENSO, this is treated as a foreign event and gain less focus. However, disaster management sector has some studies on ENSO to establish links with disasters. And he stated that "*ENSO is considered a disaster in Bangladesh*". A meteorological expert (a key informant) has given focus on the importance of a study on ENSO for Bangladesh. As he mentioned that "*Study on the impact of ENSO in Bangladesh is necessary because I have not found so many studies on this issue*". However, an agricultural expert (key informant) has accused ENSO can disrupt agricultural production. As he said, Bangladesh agricultural sector is challenged by changing the climate, increasing temperature, rainfall etc. Also, disaster events such as flood, storms, and drought disrupt agricultural production. As ENSO is responsible for these events around the world, it can also disrupt production in Bangladesh. But he pointed out that in Bangladesh, changing climate, Salinity intrusion, flash flooding, and climate adaptive agriculture is focusing issue.

ENSO and climate Variability in Bangladesh

All the experts discussed ENSO and climate variability. The interview data suggest that all four experts from their respective background (Climate change, disaster management, meteorology, and agriculture) think there is an interrelationship between ENSO and climatic parameters in Bangladesh, though there is no sufficient research addressing this. However, they have given extra emphasis on the relationship between rainfall and ENSO. The meteorological expert mentioned that ENSO can affect rainfall pattern in South Asian Region. But BMD cannot be certain on this issue. As BMD monitors the ENSO database from foreign sources. Also, there is less evidence on Bangladesh rainfall pattern and its relationship with ENSO. However, experts indicated that some researchers found that El Niño is associated with less rainfall and La Niña is associated with increased rainfall around the country. But, all the studies are conducted by individual researchers on a voluntary basis. Therefore, the mentioned a country level study is necessary to have evidence about ENSO and its impacts on Bangladesh.

Interviewees also said that the government and the NGOs consider climate change as the main issue. But seasonal climate variability is also a major challenge. As interviewees mentioned that ENSO is a natural phenomenon. This phenomenon might have some impact on climate variability. Because the temperature and rainfall pattern changes from time to time. But studies in Bangladesh treat changing in climatic parameters as climate change effect mostly.

ENSO and Disaster in Bangladesh

Disaster in Bangladesh is a common phenomenon and the interview data suggested that ENSO and disasters are linked. Experts stated that around the world, ENSO is considered as a disaster-inducing phenomenon. As climate change-induced disasters are hitting Bangladesh on regular basis, ENSO can be a cause behind the disasters. There are increasing occurrences of flood, drought, Monga (Extreme agricultural drought in Northern region of Bangladesh) and ENSO events might add more to the existing climate change events. As one of the interviewees mentioned "*seasonal flooding and drought can be altered due to ENSO……We see various country in Asia struggling with this*". So, experts in Bangladesh are aware about ENSOs widespread impact. And this awareness grew after 1998 prolonged flood event. As all interviewees stated that ENSO got attention after the 1998 flooding in Bangladesh. Because after 1998 flood, several studies were carried out focusing on ENSO and flooding, ENSO and rainfall pattern and ENSO and health-related issues. Experts also mentioned that flooding and drought timings are known. But, according to them the problem is the untimely occurrence of a disaster event or prolonged disaster events. Flash flooding is a sudden disaster that disrupts lives and livelihood in Bangladesh. As climate change expert mentioned, "*untimely flooding can disrupt agricultural plantation or harvest*". This untimely flooding can be linked with ENSO. But, the main concern here still lies with climate change, as changing climate can cause flash flooding as well. However, the disaster management expert mentioned that Bangladesh experienced intensive flooding on 1988, 1998, 2004, and 2007. These four-flooding periods inundated more areas then other flooding periods. Two of these years were strong La Niña years and two of them are weak El Niño years. He mentioned, "*Bangladesh do not experience intensive flooding on moderate to strong El Niño years*". He also stated that few extreme drought years such as 1972, 1973, 1979, and 1982 all are El Niño years. The conclusion in this regard is that more research is needed on disasters and ENSO in Bangladesh. As disasters can disrupt agricultural production and livelihood. Along with floods, Bangladesh also have seasonal cyclones which disrupt agriculture in coastal regions. And cyclones are also unpredictable. ENSO and the links between these sudden disasters are not yet established. But, if there is a link, it can be used to save resources and lives by preparing early for these disasters.

ENSO and Agricultural production in Bangladesh

The interviewees highlighted the fact majority of people in rural Bangladesh depends on agricultural livelihoods and this agricultural production meets the food security of Bangladesh. So, if there is any disruption in agricultural production, rural people suffer most. Agricultural expert highlighted that ENSO can influence weather around the world, so any impact on the weather in Bangladesh can cause an impact on agriculture. Though Bangladesh has increased irrigation projects for agriculture, rainfall is still an important factor. Excessive rainfall can cause flooding that can destroy agricultural production. Climate change expert highlighted that agricultural in Bangladesh depends on climate. But he also mentioned, "*In recent time farmers are widely using irrigation pumps to use groundwater for farming………there is increasing use of recent agricultural technology as well*". He also mentioned that flooding can decrease the cultivable land and that can be a reason for less crop production. The disaster management expert mentioned, "*climate change induced disaster effect crop production………this is an indirect effect".*

All the experts stated that ENSO and its influence in agricultural production is a wider issue, but in Bangladesh, there is no proven influence yet. ENSO and its link with climate change can be a reason for extreme weather events in the country and disrupt crop production agricultural production. But in Bangladesh, crop production is increasing despite changing the climate. This is because of irrigation and modern agricultural technologies.

ENSO and Early preparedness measures

All the experts mentioned that ENSO related preparedness is very common in other countries than in Bangladesh. Bangladesh Meteorological Department (BMD) and Bangladesh Space Research and Remote Sensing Organization (SPARRSO) collect update on ENSO. End of every month, BMD prepares a prediction for next month and distribute among organization to update the rainfall patterns, temperature trends etc. ENSO ONI (Oceanic Niño Index) pattern is also discussed to update.

The climate change expert and disaster expert highlighted that different aid agencies in the country do a meeting in every 2 months to prepare for the disasters where ENSO situation is also discussed to determine whether there can be flooding. This meeting is one of the early preparedness for ENSO in the country. One of the interviewees said, "*ENSO is told to be linked with few flooding events in the country………preparing for Food aids and other measures are relevant to prepare for extreme hazards when there the ONI shows positive and negative anomalies*".

ENSO and Policy concern in Bangladesh

All the interviewees discussed a range of policies, action plans and management plans in Bangladesh that could be relevant to ENSO. But, none of the policies or action plans mentioned about ENSO. Bangladesh has well-established disaster management plan, climate action plans, food policy and action plans. However, none of these policies have mentioned ENSO or El Niño or La Niña in their policy document.

One of the interviewees mentioned, "*Climate change is a big concern now…… all the focus is on that, so policies are focused on that*". He mentioned that "Bangladesh Climate Change Strategy and Action Plan 2009" was formulated and approved by Ministry of Forest and Environment, Government of Bangladesh following COP 13, 2007 in Bali. This action plan covered Food security and disaster management in changing the climate. Disaster management sector gave special focus on flood, drought and tropical cyclone. But, even while focusing on Flood and Drought, ENSO wasn't mentioned. One interviewee said, "*The climate action plan focused on immediate actionable issues and ENSO is not something Bangladesh considers as an issue yet"*. Another interviewee mentioned that, "*You have the policies formulated according to international standards and the issues you have funding for……..and Bangladesh is not a country focused under ENSO territory, so this is not mentioned under policies and plans.*"

Though, ENSO is considered under the issue of disaster. The National Disaster Management Act 2012, National Disaster Management plan 2010-2015 and National Disaster Management plan 2016-2020 do not include ENSO and its possible impacts. One of the interviewees mentioned, "*so many disasters of our own to focus on that ENSO, an event in Pacific do not catch attention until it creates a very extreme situation like 1998 flood*." The interviewees also mentioned the climate action plan and disaster management plan highlighted how the disaster can be mitigated or adapted to. So, the focus is on climate change adaptation and disaster risk reduction through different plans and policies. Bangladesh National Food Policy Plan of Action (2008-2015) has a portion on agricultural disaster management. That part discusses disaster preparedness, early warning system and post-disaster management of agricultural production whereas ENSO and any warning system for that were not included there. Because the policies regarding climate change, food, and disaster management are formulated keeping a certain deadline. Like the climate change expert mentioned, *"Policies formed when there are deadly consequences. In a developing country like Bangladesh that is the truth."*.

Chapter 5: Discussion

This chapter discusses the findings of this study, how these findings are related to each other and what can be its significance in future. Finding out ENSO's impact on crop production in Bangladesh and ENSO's presence in policies of Bangladesh was main objectives of the study. This study's mixed method approach proved a useful approach to pursue the objectives.

From the statistical analysis, I could not identify a significant correlation between ENSO and rice, potato and wheat production in Bangladesh. However, the boxplots of the study show that in La Niña years Bangladesh receives higher average production compared to El Niño and neutral years. The interviewees for this research also stated the fact that in terms of Bangladesh, ENSO's direct influence on agriculture is not proven. The data from interviews also highlighted that other countries, for example, Indonesia, Australia, Philippines have ENSO's impact on crop production. Different researchers agreed that these countries have a direct impact of ENSO on crop production (McPhaden, 1999; Harger, 1995; Ameien, et. al., 1996; Taschetto and England, 2009; Hilario, et. al., 2009). Research suggests that neighboring country India (surrounding Bangladesh from three sides) has impacts of ENSO on crop production (Selvaraju, 2003). However, it is well established that Bangladesh's agriculture is affected by climatic extreme events and changes in climate parameters.

From the quantitative part of this research, it is clearly visible that crop production showed a significant relation with Maximum temperature and that is a positive correlation. The interviewees said also that Bangladesh has increased agricultural production. But, this seems abnormal as most researchers say higher temperature reduces crop production (Lobell, et. al., 2013). With climate change, Bangladesh has a temperature rise, but still its optimum for crop production. Besides Bangladesh has a well-developed irrigation system to support crop production in higher temperature (Pagiola, 1995). Farmers depend on irrigation-based agriculture. This also makes cultivation less dependent on rainfall.

For this study, Rainfall does not show any significant correlation with crop production. But interview data suggests that rainfall will cause a problem if there is severe flooding. Flooding can destroy crops or reduce cultivable land. The flash flood in 2017 in Bangladesh was induced by heavy rainfall and the rainwater rushing from India. It destroyed a vast area of croplands in North-

East Bangladesh (Relief Web, 2017). So, until rainfall is not causing an extreme flooding situation, it has less impact on crop production. The statistical results of this study support this statement. However, from the statistical analysis, it is clearly visible that Bangladesh has a growing production level.

All 5 crops showed increasing production level during the study period. According to a World Bank report, Bangladesh has tripled its food production between 1972 and 2014 (World Bank, 2016). The results of the study also reflect this increase. Areas with modern irrigation method have higher production rate since the 1980s (Quddus and Salimullah, 2004). Mechanization of agriculture is one of the main reason for higher agricultural production in the country. Axial flow pumps, reapers, seed fertilizer drills are some of the equipment's widely used in the country for better crop production (Islam, et. al., 2017). This explains the increasing production rate for Bangladesh. The increasing production trend may have affected the results of this study. The various confounding variables, for example, modernization of agriculture, fertilizer uses, may mask the direct effect of ENSO on crop production. So, this can be a reason that the statistical analysis cannot identify a link between crop production and ENSO. However, extreme disasters can still disrupt crop production.

The interview data expressed that agriculture is highly vulnerable to disasters such as flooding, drought etc. and affected by a change in climatic parameters such as rainfall, temperature etc. Several types of research support this statement. Changing weather conditions such as rainfall and temperature variation can cause pressure on agricultural ecosystem all over the world (Amin, Zhnag and Yang, 2015; Rahman, et. al., 2017). Normal annual flooding is considered beneficial for agriculture (Blaikie et al., 1994; Smith, 1996; Handmer, Penning-Rowsell, and Tapsell, 1999) but extreme flooding events can be disastrous (Paul, 1997). Rashid and Islam (2007) also mentioned that extreme disaster events such as drought, flood, cyclones, and salinity intrusion affect crop production badly.

Interview data suggests there might be a correlation between disasters and ENSO in Bangladesh as some extreme droughts and extreme flooding year's matches with ENSO occurrences. Previous researchers stated that Bangladesh monsoon has very weak relation with ENSO strength (Chowdhury, 2003; Wahiduzzaman, 2012; Ahmed, et. al., 2017). Chowdhury (2003) identified that Bangladesh experiences distinctive features than Indian Monsoon regime in different ENSO years. In Weak El Niño year, Bangladesh experience flooding while India experiences dryer situation (Chowdhury, 2003). So, the correlation between disasters and ENSO in Bangladesh needs to be studied deeply to conclude that there can be an indirect impact of ENSO on crop production in Bangladesh. However, the interview data mentioned that Bangladesh considered ENSO data to be prepared for any untimely event, by organizing a meeting every 3-4 months. These meetings are organized by The Department of Disaster Management in Bangladesh.

The Department of Disaster Management (DDM) is operating since 2012 and it is directly under Ministry of Disaster Management. One of the key informant (Disaster management expert) directly works with DDM since 2008. The disaster management policy discusses several climate-induced disasters. Several government organizations, NGOs, research farms working with climate change are involved in implementing the disaster management plan and polity Bangladesh. The stakeholders work closely with disaster preparedness and three of the key informants are involved directly with this. The interviewees suggested that ENSO is considered into early preparedness to assume whether there will be flooding or not. However, this is not part of the official disaster management plan

As Bangladesh is dependent on external sources for ENSO, the process of early preparedness is depended on the exchange of timely climate information. But from interview data it's clear that institutions are very aware of this event. However, it is not included in any policy or management plan in Bangladesh yet. Lack of sufficient research and attention to the event without big extreme events is a reason, Bangladesh lack policies or plan on this. Instead of just explain unexplainable disaster with ENSO, a proper plan to keep the country prepared for ENSO can create disaster resilience. The early preparedness measure can be a way to mitigate crop loss through extreme disasters relating to ENSO as the country will be aware of ENSO's occurrence. However, the interview data suggest that Bangladesh is very much focused on climate change and its impacts as climate change adaptation and mitigation funding is widely available for making climate adaptation plans and policies. Thus, natural climate variability, whether ENSO related or not, is not matter of much concern.

This study has limitations to explore ENSO's impact on agricultural production. Annual data are used for crop production, ENSO occurrences, Rainfall, and temperature. Using monthly data for temperature and rainfall can be done to analyze the relation between climate parameters closely.

The confounding variables are not considered in the study and this limits the results of ENSO's impact on production. If the effects of confounding variables can be eliminated, the study might have identified a correlation between crop production and ENSO. Seasonal analysis for each crop's season can be done with SST and monthly basis to understand the effect of ENSO in different crop production season. Disaster and ENSO occurrence can be studied to identify indirect of ENSO on disasters.

The statistical analysis does not identify the significant link between ENSO and crop production of Bangladesh. But since there is a certain level of impact of ENSO on Bangladesh. This is visible from the interviews and the box plot analysis. Future studies can consider the limitations of this study and overcome it.

Chapter 6: Conclusion

Agricultural production in Bangladesh is a very important factor to ensure food security for the large population. As ENSO is a natural phenomenon, it has a wider impact on climatic features around the world. This is responsible for disrupted crop production worldwide and can hamper food security. The understanding of ENSO and its impact can be a way to prepare for future. Though climate change is uncertain, ENSO is certain to influence weather system around the world. So, a focus on Bangladesh to know ENSO's influence on crop production is a necessary approach.

This study attempted to use statistical tools to identify the impact of ENSO on crop production of Bangladesh. For this study, secondary data from various sources were used for the period of 1980-81 to 2014-15. Five major crops (three types of rice, wheat, and potato) and three climatic parameters (Rainfall, maximum and minimum temperature) were studied along with ENSO. Four experts were interviewed to know about ENSO and its relevance in terms of climatic variability and disaster risk in Bangladesh along with the statistical analysis.

The quantitative data analysis did not find the statistically significant impact of ENSO on any of the five crops production of Bangladesh, but it indicated that all the crops have a significant positive correlation with average maximum temperature. However, it is visible that Bangladesh has growing trend for all crop production. Interviewees mentioned that various factors are responsible for this increase in crop production in the country such as irrigation, mechanization of the cultivation process. This increasing trend of crop production may have hidden the direct of the effect of ENSO on crop production in this study. Therefore, a significant link cannot be identified.

My study reflected that Bangladesh considers ENSO as a disaster, but no policies or early preparedness plan address issues related to ENSO. Also, there are not many studies showing ENSO's impact in Bangladesh. But in near future, this may change, and future policies might require introducing an early preparedness part for ENSO to avoid any extreme disaster events. As ENSO is a cyclic event, it always poses the threat to effect. Bangladesh disaster management plan can introduce an early warning system for ENSO. This will be beneficial for preparing the country for ENSO induced climate variability and resulting disaster events. ENSO is a natural cyclic phenomenon and it's certain, whereas climate change is dependent on several factors. Therefore, it is important that the disaster management plan recognizes ENSO and related climate variability, as natural climate variability is different than climate change. Further research can focus on this issue from different angles and obtain more insights. For example, in future, studies can focus on extreme disasters and ENSO. Studies focusing to identify the correlation between climate variability and agricultural production of Bangladesh can consider eliminating the effect of confounding variables. For a climate vulnerable country like Bangladesh, identifying the impact of climate variability on crop production is important to build a climate and disaster resilient production system.

References

Abdolrahimi, M. (2016). *The effect of El Niño Southern Oscillation (ENSO) on world cereal production* (Master's thesis, University of Sydney).

Adebayo, W. O. (1999). The spatial–temporal dynamics of temperature and rainfall fluctuations in Nigeria. *Unpublished Ph.D. thesis, Department of Geography, University of Ibadan, Nigeria*.

Ahmed, M. K., Alam, M. S., Yousuf, A. H. M., & Islam, M. M. (2017). A long-term trend in precipitation of different spatial regions of Bangladesh and its teleconnections with El Niño/Southern Oscillation and Indian Ocean Dipole. Theoretical and Applied Climatology, 129(1-2), 473-486.

Amien, I., Rejekiningrum, P., Pramudia, A., and Susanti, E.: 1996, 'Effects of Interannual Climate Variability and Climate Change on Rice Yield in Java, Indonesia', Water Air and Soil Pollution 92, 29–39.

Amin, M. R., Zhang, J., & Yang, M. (2015). Effects of climate change on the yield and cropping area of major food crops: A case of Bangladesh. Sustainability, 7(1), 898-915.

An S.-I. (2009). "A review of interdecadal changes in the nonlinearity of the El Niño-Southern Oscillation." Theoretical and applied climatology **97**(1-2): 29-40.

Azmoodehfar, M. H., & Azarmsa, S. A. (2013). Assessment the effect of ENSO on weather temperature changes using fuzzy analysis (case study: Chabahar). APCBEE procedia, 5, 508-513.

Bangladesh Bureau of Statistics (BBS). (2008) Statistical Yearbook of Bangladesh.

Bangladesh Bureau of Statistics. (2008). Statistical Yearbook of Bangladesh.

Bangladesh Bureau of Statistics. (2012). Bangladesh population and housing census 2011.

Bangladesh Bureau of Statistics. (2016). Statistical Yearbook of Bangladesh.

Banglapedia. (2015). Bangladesh. National Encyclopedia of Bangladesh. Accessed at http://en.banglapedia.org/index.php?title=Bangladesh.

Barnston, A. G., Glantz, M. H., & He, Y. (1999). Predictive skill of statistical and dynamical climate models in SST forecasts during the 1997–98 El Niño episode and the 1998 La Niña onset. *Bulletin of the American Meteorological Society*, *80*(2), 217-244.

BBS, (2018). 45 years Agriculture Statistics of Major Crops (Aus, Amon, Boro, Jute, Potato & Wheat). Statistics and Informatics Division (SID). Ministry of Planning

Begum, M. E. A., Hossain, M. I., & Haese, L. D. (2014). Food security in Bangladesh: Present status and trend. *Progressive Agriculture*, *24*(1-2), 263-271.

Blaikie, P., T. Cannon, I. Davis and B. Wisner (1994) At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, London.

Bouma, M. J., Kovats, R. S., Goubet, S. A., Cox, J. S. H., & Haines, A. (1997). Global assessment of El Niño's disaster burden. *The Lancet*, *350*(9089), 1435-1438.

Brönnimann, S., Xoplaki, E., Casty, C., Pauling, A., & Luterbacher, J. (2007). ENSO influence on Europe during the last centuries. *Climate Dynamics*, *28*(2-3), 181-197.

BRRI. 2009. Bangladesh Rice Research Institute. Extension of Agricultural Machinery at Union Level. A Paper presented from Farm Machinery and Processing Engineering Division of BRRI.

Cai, W. and T. Cowan (2009). "La Niña Modoki impacts Australia autumn rainfall variability." Geophysical Research Letters **36**(12).

Cai, W., Van Rensch, P., Cowan, T., & Hendon, H. H. (2011). Teleconnection pathways of ENSO and the IOD and the mechanisms for impacts on Australian rainfall. *Journal of Climate*, *24*(15), 3910-3923.

Cai, W., Van Rensch, P., Cowan, T., & Hendon, H. H. (2012). An asymmetry in the IOD and ENSO teleconnection pathway and its impact on Australian climate. *Journal of Climate*, *25*(18), 6318-6329.

Cai, X., Shafiee-Jood, M., Apurv, T., Ge, Y., & Kokoszka, S. (2017). Key issues in drought preparedness: Reflections on experiences and strategies in the United States and selected countries. *Water Security*.

Camberlin, P., Janicot, S., & Poccard, I. (2001). Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. *International Journal of Climatology*, *21*(8), 973-1005.

Capa-Morocho, M., Rodríguez-Fonseca, B., & Ruiz-Ramos, M. (2014). Crop yield as a bioclimatic index of El Niño impact in Europe: Crop forecast implications. *Agricultural and forest meteorology*, *198*, 42-52.

Cashin, P., Mohaddes, K., & Raissi, M. (2017). Fair weather or foul? The macroeconomic effects of El Niño. *Journal of International Economics*, *106*, 37-54.

Chowdhury, M. D., & Chowdhury, A. H. (2015). Problems and Prospects of Potato Cultivation in Bangladesh. *Asian Business Review*, *5*(1), 28-32.

Chowdhury, M. R. (2003). The el Niño-southern oscillation (ENSO) and seasonal flooding–Bangladesh. Theoretical and applied climatology, 76(1-2), 105-124.

Davey, M. K., Brookshaw, A., & Ineson, S. (2014). The probability of the impact of ENSO on precipitation and near-surface temperature. *Climate Risk Management*, *1*, 5-24.

de la Poterie, A. S. T., Jjemba, W. E., Singh, R., de Perez, E. C., Costella, C. V., & Arrighi, J. (2018). Understanding the use of 2015–2016 El Niño forecasts in shaping early humanitarian action in Eastern and Southern Africa. *International Journal of Disaster Risk Reduction*.

Del Ninno, C., Dorosh, P. A., & Smith, L. C. (2003). Public policy, markets and household coping strategies in Bangladesh: Avoiding a food security crisis following the 1998 floods. World Development, 31(7), 1221-1238.

Deng, X., Huang, J., Qiao, F., Naylor, R. L., Falcon, W. P., Burke, M., ... & Battisti, D. (2010). Impacts of El Niño-Southern Oscillation events on China's rice production. *Journal of Geographical Sciences*, *20*(1), 3-16.

FAO, IFAD, UNICEF, WFP and WHO. (2017). The State of Food Security and Nutrition in

Farooqi, A. B., Khan, A. H., & Mir, H. (2005). Climate change perspective in Pakistan. Pakistan Journal of Meteorology, 2(3).

Forootan, E., Awange, J. L., Schumacher, M., Anyah, R. O., van Dijk, A. I. J. M., & Kusche, J. (2016). Quantifying the impacts of ENSO and IOD on rain gauge and remotely sensed precipitation products over Australia. *Remote sensing of Environment*, *172*, 50-66.

Gelcer, E., Fraisse, C. W., Zotarelli, L., Stevens, F. R., Perondi, D., Barreto, D. D., ... & Southworth, J. (2018). Influence of El Niño-Southern oscillation (ENSO) on agroclimatic zoning for tomato in Mozambique. *Agricultural and Forest Meteorology*, *248*, 316-328.

GG Weather. (2018). El Niño and La Niña Years and Intensities. Accessed at http://ggweather.com/enso/oni.htm**.**

Glantz, M. H. (2017). El Niño Ready Nations and Disaster Risk Reduction (DRR)–combined ENRN study report. *Consortium for Capacity Building, Boulder, CO.[Google Scholar]*.

Glantz, M. H., & Glantz, M. H. (2001). *Currents of change: impacts of El Niño and La Niña on climate and society*. Cambridge University Press.

Glantz, M. H., Naranjo, L., Baudoin, M. A., & Ramírez, I. J. (2018). What Does It Mean to Be El Niño Ready?. *Atmosphere*, *9*(3), 94.

Hammer, G. L., Hansen, J. W., Phillips, J. G., Mjelde, J. W., Hill, H., Love, A., & Potgieter, A. (2001). Advances in application of climate prediction in agriculture. *Agricultural systems*, *70*(2-3), 515-553.

Handmer, J., E. Penning-Rowsell and S. Tapsell (1999) 'Flooding in a warmer world: The view from Europe'. In T.E. Downing, A.A. Olsthoorn and R.S.J. Tol (eds.) Climate, Change and Risk. Routledge, London. pp. 125–161.

Harger, J. R. E.: 1995, 'Air-Temperature Variations and ENSO Effects in Indonesia, the Phillipines, and El Salvador: ENSO Patterns and Changes from 1866–1993',Atmos. Environ.29, 1919–1942.

Hilario, F., de Guzman, R., Ortega, D., Hayman, P., & Alexander, B. (2009). El Niño southern oscillation in the Philippines: Impacts, forecasts, and risk management. *Philippine Journal of Development*, *36*(1), 9.

Hossain, A., & Teixeira da Silva, J. A. (2013). Wheat production in Bangladesh: its future in the light of global warming. *AoB Plants*, *5*, pls042.

Hossain, E., Alam, S. S., Imam, K. H., & Hoque, M. M. (2000). The Assessment OF El Niño Impacts and Responses: Strategies for the 1997-98 El Niño Event in Bangladesh. Bangladesh Public Administration Training Centre, Savar, Dhaka.

Ingram, J. C., & Dawson, T. P. (2005). Climate change impacts and vegetation response on the island of Madagascar. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *363*(1826), 55-59.

Islam, K. S., Khan, M. S. H., Md. Rahman, S. U. and Faisal. W. (2017). Three technologies that are changing agriculture in Bangladesh. Accessed at https://www.cimmyt.org/three-technologies-that-are-changing-agriculture-in-bangladesh/.

Islam, M. S., & Shirazul, D. (2009, October). Farm mechanization for sustainable agriculture in Bangladesh: Problems and prospects. In *5th APCAEM Technical Committee Meeting and the Expert Group Meeting on Application of Agricultural Machinery for Sustainable*

Agriculture. United Nations Asian and Pacific Centre for Agricultural Engineering and Machinery, Manila, Philippines (pp. 14-16).

Izaurralde, R. C., Rosenberg, N. J., Brown, R. A., Legler, D. M., López, M. T., & Srinivasan, R. (1999). Modeled effects of moderate and strongLos Niños' on crop productivity in North America. *Agricultural and Forest Meteorology*, *94*(3-4), 259-268.

Kane, R. P. (2006). El Niño effects on rainfall in South America: comparison with rainfalls in India and other parts of the world. *Advances in Geosciences*, *6*, 35-41.

Khatun, M. A., Rashid, M. B, & Hygen, H. O. (2016). Climate of Bangladesh. Norwegian Meteorological Institute and Bangladesh Meteorological Department.

Kinter III, J. L., Miyakoda, K., & Yang, S. (2002). Recent change in the connection from the Asian monsoon to ENSO. *Journal of Climate*, *15*(10), 1203-1215.

Kripalani, R. H., Singh, S. V., Vemekar, A. D. and Thapliyal, V. (1996) Empirical study on Nimbus-7 snow mass and Indian summer monsoon ramfall. Int. J. Climatol., 16, pp. 23-34

Kuhnel, I. (1994). Relationship between the Southern Oscillation index and Australian sugarcane yields. *Australian Journal of Agricultural Research*, *45*(7), 1557-1568.

Kumar, K. K., Rajagopalan, B., Hoerling, M., Bates, G., & Cane, M. (2006). Unraveling the mystery of Indian monsoon failure during El Niño. *Science*, *314*(5796), 115-119.

Lobell, D. B., Hammer, G. L., McLean, G., Messina, C., Roberts, M. J., & Schlenker, W. (2013). The critical role of extreme heat for maize production in the United States. *Nature Climate Change*, *3*(5), 497.

Lyon, B., Cristi, H., Verceles, E. R., Hilario, F. D., & Abastillas, R. (2006). Seasonal reversal of the ENSO rainfall signal in the Philippines. *Geophysical research letters*, *33*(24).

Ma, F., Ye, A., You, J., & Duan, Q. (2018). 2015–16 floods and droughts in China, and its response to the strong El Niño. *Science of the Total Environment*, *627*, 1473-1484.

McPhaden, M. J.: 1999, 'Genesis and Evolution of the 1997–98 El Niño', Science 283, 948–949.

Merkel, U. and M. Latif (2002). "A high resolution AGCM study of the El Niño impact on the North Atlantic/European sector." Geophysical Research Letters **29**(9): 5-1-5-4.

MoEF, 2009. Bangladesh Climate Change Strategy and Action Plan 2009. Ministry of Environment and Forests, Government of the people's Republic of Bangladesh, Dhaka, Bangladesh. xviii + 76pp.

MoEF. (2016). Climate Change and Agriculture in Bangladesh. Government of the People's Republic of Bangladesh. Accessed at https://cmsdata.iucn.org/downloads/agriculture.pdf.

MoFDM. (2005). Food Security in Bangladesh. Government of the People's Republic of Bangladesh and World Food Program- Bangladesh. Papers Presented in the National Workshop on 19-20 October, 2005.

Muza, O. (2017). El Niño-Southern Oscillation Influences on Food Security. *Journal of Sustainable Development*, *10*(5), 268.

Nicholls, N. (1985). Impact of the Southern Oscillation on Australian crops. *International Journal of Climatology*, *5*(5), 553-560.

Okeke, F. N., Marengo, J. A., & Nobre, C. (2006). Investigation of El Niño and La Niña effects and the impact of Atlantic sea surface temperatures (SSTs), on precipitation in Nigeria from 1950 to 1992. *Surveys in geophysics*, *27*(5), 545-555.

Okonkwo, C., Demoz, B., & Gebremariam, S. (2014). Characteristics of Lake Chad level variability and links to ENSO, precipitation, and river discharge. *The Scientific World Journal*, *2014*.

Oram, P. A. (1985). "Sensitivity of agricultural production to climatic change." Climatic Change **7**(1): 129-152.

Pagiola, S. (1995). *Environmental and natural resource degradation in intensive agriculture in Bangladesh*. Washington DC: World Bank.

Paul, B.K. (1997) ‘Flood research in Bangladesh in retrospect and prospect: A review’. Geoforum. 28(2). pp. 121–131.

Penalba, O. C., & Rivera, J. A. (2016). Precipitation response to El Niño/La Niña events in Southern South America–emphasis in regional drought occurrences. *Advances in Geosciences*, *42*, 1-14.

Pinstrup-Andersen, P. (2009). Food security: definition and measurement. *Food security*, *1*(1), 5-7.

Potgieter, A. B., Hammer, G. L., Meinke, H., Stone, R. C., & Goddard, L. (2005). Three putative types of El Niño revealed by spatial variability in impact on Australian wheat yield. *Journal of Climate*, *18*(10), 1566-1574.

Pozo-Vázquez, D., Esteban-Parra, M. J., Rodrigo, F. S., & Castro-Diez, Y. (2001). The association between ENSO and winter atmospheric circulation and temperature in the North Atlantic region. *Journal of climate*, *14*(16), 3408-3420.

Propastin, P., Fotso, L., & Kappas, M. (2010). Assessment of vegetation vulnerability to ENSO warm events over Africa. *International Journal of Applied Earth Observation and Geoinformation*, *12*, S83-S89.

Quddus, M. A., Sen, K., & Salimullah, M. (2004). Performance of crop production in Bangladesh: Growth and regional disparities. *Bangladesh Journal of Agricultural Economics*, *27*(2), 57-74.

Quinn, W. H., Zopf, D. O., Short, K. S., and Kuo Yang, R. T. W.: 1978, ‘Historical Trends and Statistics of the Southern Oscillation, El Niño, and Indonesian Droughts’, Fish. Bull.76, 663–678.

Rahman, M. A., Kang, S., Nagabhatla, N., &Macnee, R. (2017). Impacts of temperature and rainfall variation on rice productivity in major ecosystems of Bangladesh. Agriculture & Food Security, 6(1), 10.

Raible, C. C., Luksch, U., & Fraedrich, K. (2004). Precipitation and northern hemisphere regimes. *Atmospheric Science Letters*, *5*(1-4), 43-55.

Rashid, M.H., Islam, M.S., 2007. Adaptation to Climate Change for Sustainable Development of Bangladesh Agriculture. Bangladesh Country Paper, APCAEM, November, 2007.

Relief Web. (2017). Flash Flood Situation Update, May 03,2017. Accessed at https://reliefweb.int/sites/reliefweb.int/files/resources/Update%20Report%20of%20Flash%20Flood_MAY%2003%2C%202017.pdf.

Ropelewski, C. F. and M. Halpert (1989). "Precipitation patterns associated with the high index phase of the Southern Oscillation." Journal of Climate **2**(3): 268-284.

Ropelewski, C. F. and M. S. Halpert (1987). "Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation." Monthly weather review **115**(8): 1606-1626.

Rosenzweig, C. and D. Hillel (2008). Climate variability and the global harvest: impacts of El Niño and other oscillations on agroecosystems, Oxford University Press New York.

Rosenzweig, C., Iglesias, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events; implications for food production, plant diseases, and pests. *Global change and human health*, *2*(2), 90-104.

Salinger, M. J. (2005). Climate variability and change: past, present and future—an overview. In *Increasing Climate Variability and Change* (pp. 9-29). Springer, Dordrecht.

Selvaraju, R. (2003). Impact of El Niño–southern oscillation on Indian foodgrain production. International Journal of Climatology, 23(2), 187-206.

Shaman, J. (2014). "The Seasonal Effects of ENSO on European Precipitation: Observational Analysis." Journal of Climate **27**(17): 6423-6438.

Shrestha, M. L. (2000). Interannual variation of summer monsoon rainfall over Nepal and its relation to Southern Oscillation Index. *Meteorology and Atmospheric Physics*, *75*(1-2), 21-28.

Sikder, R., & Xiaoying, J. (2014). Climate change impact and agriculture of Bangladesh. *Journal of Environment and Earth Science*, *4*(1), 35-40.

Smith, K. (1996) Environmental Hazards: Assessing Risk and Reducing Disaster. Routledge, London.

Tabor, S., Ginting, E., Aji, P. (2015). Preparing for El Niño: Policy Options. Asian Development Bank. 6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines.

Tanner, T. M., Hassan, A., Islam, K. N., Conway, D., Mechler, R., Ahmed, A. U., & Alam, M. (2007). ORCHID: piloting climate risk screening in DFID Bangladesh. *Institute of Development Studies Research Report, Brighton, UK: IDS*.

Taschetto, A. S. and M. H. England (2009). "El Niño Modoki impacts on Australian rainfall." Journal of Climate **22**(11): 3167-3174.

the World 2017. Building resilience for peace and food security. Rome, FAO.

Thomas, D. R. (2003). A general inductive approach for qualitative data analysis. New Zealand: University of Auckland.

Thomson, M. C., Abayomi, K., Barnston, A. G., Levy, M., & Dilley, M. (2003). El Niño and drought in southern Africa. *The Lancet*, *361*(9355), 437-438.

Trenberth, K. E. (1997). The definition of El Niño. *Bulletin of the American Meteorological Society*, *78*(12), 2771-2777.

UNDP. (2017), El Niño-Southern Oscillation (ENSO) cycle events and their impacts in Zimbabwe. UNDP Zimbabwe, Zimbabwe Resilience Building Fund (ZRBF) Management Unit. Harare, Zimbabwe.

Wahiduzzaman, M. (2012). ENSO connection with monsoon rainfall over Bangladesh. Int J of ApplSciEng Res, 1(1), 26-38.

Wang, C. and P. C. Fiedler (2006). "ENSO variability and the eastern tropical Pacific: a review." Progress in Oceanography **69**(2): 239-266.

Wang, G. and H. H. Hendon (2007). "Sensitivity of Australian rainfall to inter-El Niño variations." Journal of Climate **20**(16): 4211-4226.

Ward, P. J., Jongman, B., Kummu, M., Dettinger, M. D., Weiland, F. C. S., & Winsemius, H. C. (2014). Strong influence of El Niño Southern Oscillation on flood risk around the world. *Proceedings of the National Academy of Sciences*, *111*(44), 15659-15664.

Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508-513.

WMO, WMO Statement of Global Climate, 1998, p.7.

WMO. (2014). El Niño/Southern Oscillation. World Meteorological Organization (WMO). Geneva, Switzerland.

World Bank. (2010). Bangladesh – Country Assessment Strategy FY 2011 – 2014. Bangladesh Country Management Unit, South Asia Region, The World Bank Office, Dhaka

World Bank. (2016). Bangladesh: Growing the Economy through Advances in Agriculture. Accessed at http://www.worldbank.org/en/results/2016/10/07/bangladesh-growing-economy-through-advances-in-agriculture.

World food program. (2016). El Niño and Food Security. Accessed at http://documents.wfp.org/stellent/groups/public/documents/communications/wfp282799.pdf .

Zubair, L. (2002). El Niño–southern oscillation influences on rice production in Sri Lanka. *International Journal of Climatology*, *22*(2), 249-260.

Appendix 1: Annual Crop Production data used for this study (M. Ton per Hectare).

Year	Aus	Amon	Boro	Potato	Wheat
1980_81	1.04	1.298	2.231	9.626	1.92
1981_82	1.023	1.18	2.382	10.011	1.65
1982_83	0.955	1.248	2.434	10.275	1.78
1983_84	1.01	1.3	2.352	11.223	2.08
1984_85	0.963	1.388	2.479	10.42	2.27
1985_86	0.994	1.415	2.393	10.147	2.164
1986_87	1.085	1.365	2.426	10.053	1.586
1987-_88	0.4	1.381	2.41	10.338	1.866
1988_89	1.064	1.344	2.391	7.986	2
1989_90	1.099	1.613	2.695	9.141	2
1990_91	1.103	1.587	2.494	9.986	1.503
1991_92	1.137	1.628	2.534	10.793	1.677
1992_93	1.196	1.656	2.582	11.095	1.853
1993_94	1.122	1.639	2.546	10.957	2.788
1994_95	1.075	1.53	2.457	10.957	1.839
1995_96	1.087	1.523	2.774	11.08	1.586
1996_97	1.175	1.646	2.681	11.255	1.956
1997_98	1.197	1.509	2.821	11.397	2.122
1998_99	1.135	1.483	2.957	11.281	2.24
1999_2000	1.283	1.806	3.019	12.028	2.164
2000_01	1.445	1.97	3.169	12.914	2.21
2001_02	1.455	1.899	3.12	12.599	2.166
2002_03	1.488	1.956	3.179	13.802	2.133
2003_04	1.523	2.029	3.255	14.426	1.953
2004_05	1.464	1.86	3.405	13.946	1.748
2005_06	1.687	1.991	3.437	13.821	1.535
2006_07	1.669	2.002	3.515	14.979	1.843
2007_08	1.64	1.914	3.855	16.542	2.177
2008_09	1.778	2.112	3.776	13.317	2.152
2009_10	1.737	2.156	3.839	18.02	2.396
2010_11	1.916	2.266	3.902	18.092	2.663
2011_12	2.049	2.293	3.9	10.07	3.505
2012_13	2.049	2.299	3.945	19.37	3.128
2013_14	2.213	2.355	3.968	19.37	3.033
2014_15	2.227	2.385	3.965	19.647	3.086

Appendix 2: Average Annual data for Rainfall, Maximum and Minimum Temperature.

Year	Rainfall (mm)	Maximum Temperature (c)	Minimum Temperature (c)
1980-81	2309.14	32.86	17.78
1981-82	2299.03	33.47	17.46
1982-83	2490.58	33.27	17.24
1983-84	3039.51	33.61	17.11
1984-85	2473.17	33.46	17.64
1985-86	2095	33.74	17.64
1986-87	2497.96	33.86	17.79
1987-88	3169.32	33.36	18.09
1988-89	2257.83	33.61	17.79
1989-90	2503.43	32.96	17.73
1990-91	2658.65	33.45	17.90
1991-92	2282	33.43	17.68
1992-93	2441.97	33.26	17.21
1993-94	2419.61	33.42	17.87
1994-95	1778.60	33.92	17.89
1995-96	2436.30	33.66	17.78
1996-97	2188.90	33.50	17.45
1997-98	2442.96	33.60	17.41
1998-99	2767.72	34.50	18.53
1999-2000	2936.65	33.39	18.10
2000-01	2597.28	33.79	17.91
2001-02	2419.82	33.70	18.19
2002-03	2617.25	33.79	17.72
2003-04	2163.4	33.89	18.04
2004-05	2485.36	33.77	17.99
2005-06	2663.82	34.28	18.44
2006-07	2163.02	33.95	17.80
2007-08	2591.73	33.73	17.97
2008-09	2266.54	34.14	18.13
2009-10	2548.4	34.30	18.00
2010-11	2099.62	33.85	17.99
2011-12	2483.62	34.40	17.72
2012-13	2408.08	33.90	17.40
2013-14	2155.57	34.32	18.00
2014-15	2195.74	34.24	17.93

Appendix 3: ENSO strength in different years.

El Niño				**La Niña**		
Weak	Moderate	Strong	Very Strong	Weak	Moderate	Strong
1952-53	1951-52*	1957-58	1982-83	1954-55	1955-56	1973-74
1953-54	1963-64	1965-66	1997-98	1964-65	1970-71	1975-76
1958-59	1968-69*	1972-73	2015-16	1971-72	1995-96*	1988-89
1969-70	1986-87	1987-88*		1974-75	2011-12*	1998-99*
1976-77	1994-95*	1991-92*		1983-84		1999-00*
1977-78	2002-03			1984-85		2007-08*
1979-80	2009-10			2000-01		2010-11*
2004-05				2005-06*		
2006-07				2008-09		
2014-15*				2016-1		

Appendix 4: Interview questions for semi-structured interview of Key Informants

1. What is your perception about El Nino and La Nina?
2. Can you elaborate about El Nino and La Nina’s impact?
3. In case of Bangladesh, how does El Nino and La Nina have influence?
4. What do you think about climate variability and El Nino and La Nina in Bangladesh?
5. What is your perception of climate change and Bangladesh?
6. What do you think about El Nino and La Nina under changing the climate?
7. What do you think about ENSO induced impact on agriculture of Bangladesh?
8. Is there any correlation between disasters and ENSO in Bangladesh?
9. How do disaster management plan and policies deal with El Nino and La Nina?
10. Does Bangladesh have early preparedness or warning system for ENSO?