Addressing Climate Change Through a New Lens: A Case Study of the Sangamner Region of Western India

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Abstract

The Sangamner region of western India is a developing economy that is expected to experience serious societal consequences due to 21st century anthropogenic climate change. Environmental stress is expected to have major impacts on the industry upon which this society is based: agriculture. In order to understand the impacts of climate change on the region, this thesis reviewed the past climate variability by combining the data collected from institutional and natural archives covering the years 1831-1889. The institutional archives, although less accurate than modern instrumental data, mainly focused on the harsh environmental conditions that occur in the region. This data showed a correlation between natural disasters — such as drought, famine and flood — and years with less than average precipitation. The natural archive data was then graphed against available instrumental data of temperature and precipitation during the period 1901-2003. This showed a gradually increasing temperature trend as well as a pattern of high variability in precipitation with no clear trend. In order to mitigate the impacts of climate change in Sangamner, the society should focus on preparedness for natural disasters that may occur in the future, implementing sustainable agricultural practices in the short-term, and moving entirely away from the agricultural industry in the long-term.

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Preface

With my major in Environmental Studies and my minor in South Asian Studies, I intended to pursue an honors thesis that would apply to my field of interest. After visiting India during the summer of 2017, I was drawn to the idea of conducting research on the environment of this developing country. I was fortunate enough to be in a few classes in the Spring of 2017 with Atreyee Bhattacharya, who introduced me to the environmental issues in South Asia and specifically to the Sangamner region of western India in my Climate Affairs course. Now, this subject area is represented in my thesis.

Acknowledgements

I would have not been able to complete this work by Dr. Ranjini Ray, my thesis advisors, and my thesis study group. Dr. Ranjini Ray gathered the institutional data for me from the Delhi National Archives, which I would not have been able to accomplish on my own without international travel and proper access credentials. My thesis advisors helped me form this paper over two semesters, providing me invaluable information in order to produce a high-quality product. Krister Andersson gave me constructive criticism on each of my drafts, preparing me to create a professionally constructed paper. Atreyee Bhattacharya provided me with the inspiration to take up this research and helped me with the data analysis along the way. Dale Miller met with me every week, guiding the overall progress of my thesis. My thesis study group that I met with periodically throughout the final semester of my education at CU Boulder supported my work and assisted me in preparing my thesis defense.

Introduction

This thesis examines the impacts of 21st century anthropogenic climate change in the semi-arid Sangamner region of Maharashtra, India given that this area is susceptible to climate variability. The following research question has guided this thesis: By understanding the stresses of long-term climate variability using historical data, what steps can the society of the Sangamner region of western India take in order to prepare for the current degree of anthropogenic climate change? I addressed this question by first conducting a literature review about climate variability and climate change impacts in South Asia and, more locally, the regions of western India and Sangamner itself. After understanding the literature on the subject, I began my own research into the topic. My research consisted of an analysis of both societal and natural archives from the Indian peninsula during the time period between 1831-1889, as well as an analysis of instrumental data and natural archives during the time period between 1901-2003.

The results of this data found that there is a connection between natural disasters — such as drought, famine and flood — and low precipitation. The biggest complications expected in the future for the Sangamner region of western India are increasing temperatures combined with a high variability in precipitation. Both the variability in precipitation in the future and the risk of natural disasters have the potential to impact agricultural economies such as Sangamner. Thus, society must take steps to ensure that the region is prosperous for future generations. These steps include implementing global climate change policy, focusing on local preparedness for natural disasters, and transitioning away from the agricultural industry that is highly susceptible to climate change.

Background

Environmental Adaptation Framework

In order to understand the Sangamner region's susceptibility to variation in climate, I will use an environmental adaptation framework (Diagram 1) as a guide. This adaptation framework uses three core categories to facilitate the understanding of the effects of the biophysical environment: Contributions, Impacts, and Adaptive Strategies. The Contributors refer to environmental stress that has the potential to harm emerging societies. The framework organizes these contributors in a successive format from the broad scope of climate variability all the way down to the narrow scope of the local climate of the Sangamner region. This comprehensive understanding of the contributions will then be used to assess the Impacts — Direct and Indirect — on the environment and society of the area. The background section of this thesis will focus on these first two categories: Contributors followed by Impacts. The last category, Adaptation Strategies, will be addressed in the Discussion section of this thesis after another assessment of the impacts found in the Results section. Using this framework, my thesis will provide an all-encompassing explanation of the susceptibility of the Sangamner region of western India to climate variability and climate change, to include the factors that drive it and strategies to mitigate or adapt to the resulting impacts.

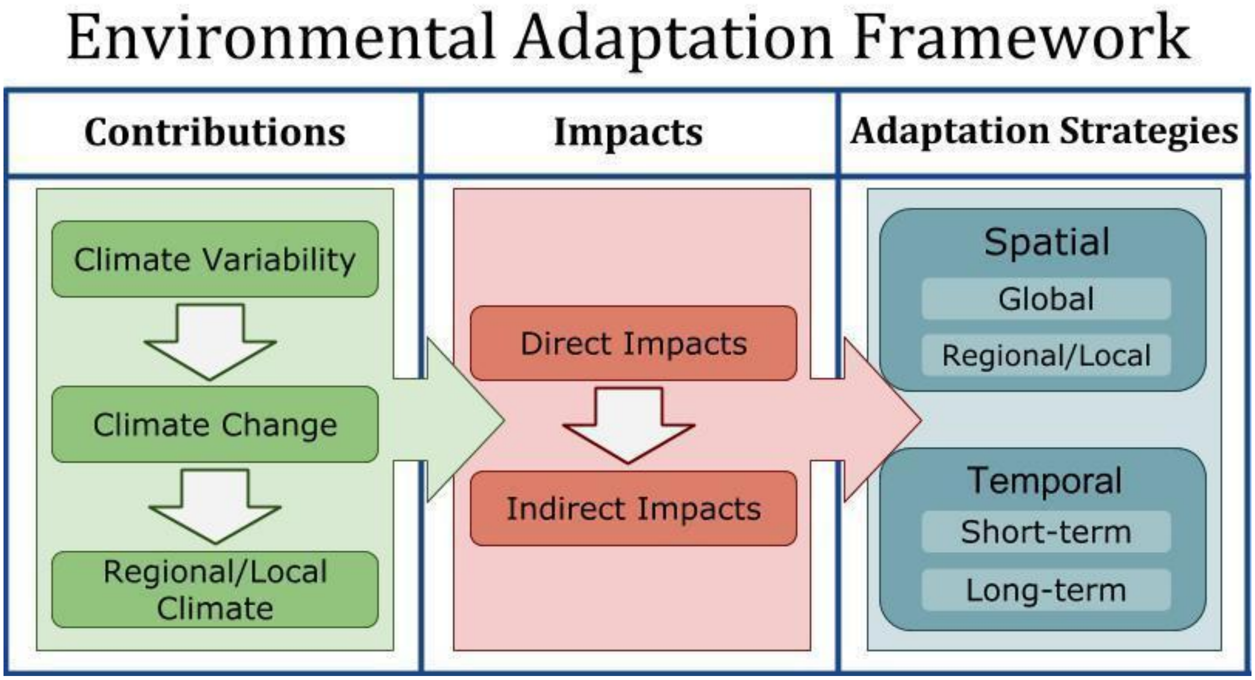

Diagram 1: The Environmental Adaptation Framework used to address the environmental problems facing the Sangamner region of western India. The categories shift from Contributions to Impacts to Adaptation Strategies in order to understand the entire scope of the issue and what this society must do in order to survive.

Climate Variability

Climate variability is defined as any kind of variation in the average climate measured at scales greater than weather events, such as a thunderstorm (IPCC, 2007). Mean climate is the measurement of temperature and precipitation over a 30-year period anywhere around the world (Mehta, 2017). This basic definition only scratches the surface of what climate variability actually means. An understanding of the different types of climate variability on all of the different time scales is necessary to understand how it influences the climate as it is understood today.

The various types of variability in climate are depicted in Figure 1. First, climate variability appears in a periodic or cyclical pattern, such as the daily temperature change experienced as the Earth rotates on its axis (National Research Council, 1995; Mehta, 2017). Second, the climate change may reach a threshold and shift — either as a drastic change or a long-term trend — which can affect the background state of climate variability (National Research Council, 1995). And, lastly, the climate may maintain a relatively steady condition that is considered to be stationary or static (National Research Council, 1995). All of these examples of variation have been recorded as part of Earth's natural variability, which has substantially influenced temperature and precipitation around the world since the formation of the planet.

In addition to the types of climate variability, the variations in time scales impact the climate in many different ways. A simple example of periodic climate variability is the year-to-year climate variability that is influenced by the Earth's revolution around the Sun: in a single year differences in temperature and precipitation are seen as the seasons change (Mehta, 2017). Expanding on this idea, the rate of variation can be understood in much greater time scales as well. These scales include year-to-year, sub-decadal, decadal, multidecadal, and even on scales up to hundreds of thousands of years (Mehta, 2017). There are many different variables to be taken into consideration when understanding the reason for the variability on each time scale. The main influence of this variability comes from the external forcing of solar radiation derived from the Sun (Tkachuck, 1983; Reilly, 2009; Mehta, 2017).

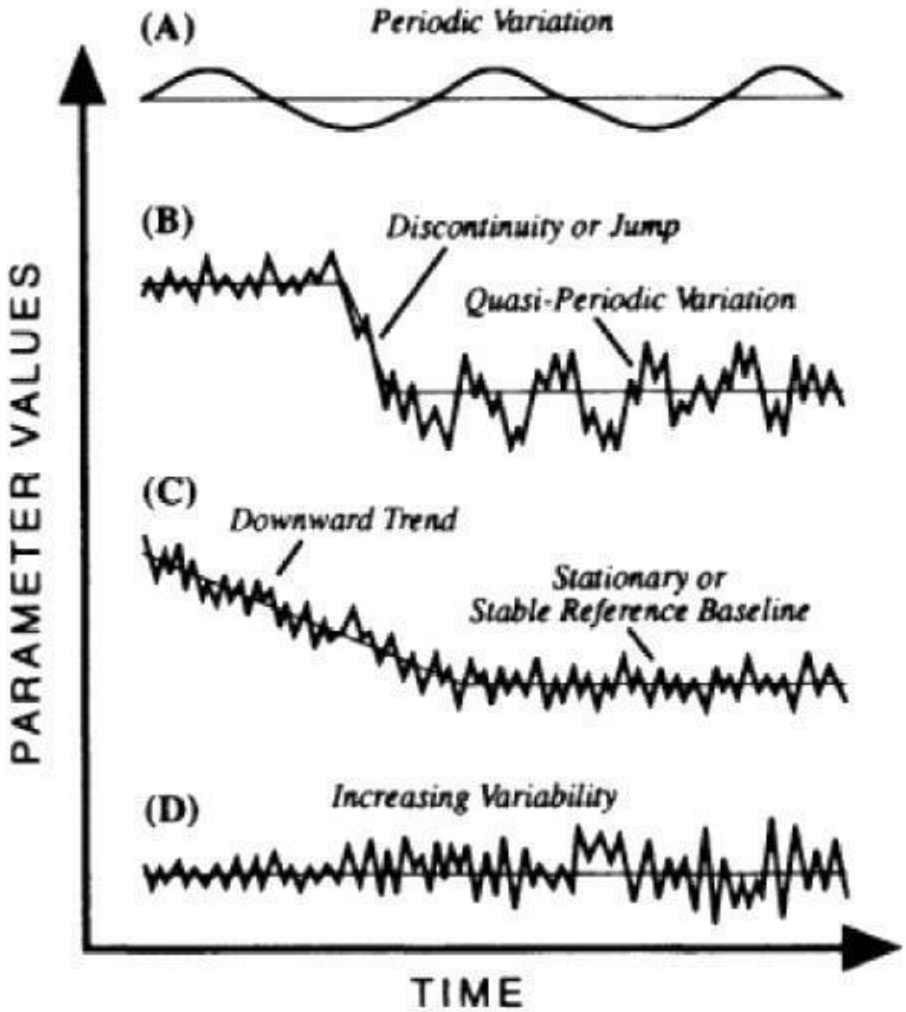

Figure 1: The different types of climate variability are as follows: A. Periodic Variation, B. Discontinuity or Jump and Quasi-Periodic Variation, C. Downward Trend and Stationary or Static Reference Baseline, and D. Increasing Variability (National Research Council, 1995).

The implications of the variation within human timescales is of the highest importance when looking into how these changes may have impacted societies in the past, and how it may impact people today. The yearly, decadal, and centennial time scales have been described as integral to understanding these impacts (National Research Council, 1995; Mehta, 2017). By analyzing the variability in a single decade, the impacts of climate on a society's most important resources can be examined; these resources may include water and primary food sources such as plants, animals, and fish (National Research Council, 1995; Mehta, 2017). It also is useful to understand what can influence this form of climate variability. It is not just the external forcing of the Sun that is of concern, it is internal stresses that play a role as well. Internal variability can be influenced by large systems such as the ocean and atmosphere as well as anthropogenic interactions — land use patterns and the release of greenhouse gases through the combustion of fossil fuels (Mehta, 2017).

In order to comprehend the nature of climate variability and assess its impacts on biophysical and human environment, a long-term outlook is essential. Analyzing historical variation in climate, especially pre-dating the Industrial Revolution, provides a baseline understanding of how climate variability has influenced the processes of the Earth (National Research Council, 1995). With this interpretation of variability, a proper analysis of the difference between natural climate variability and anthropogenic climate variability can be conducted. It may be helpful to understand this climate variability with a well-known example from the past. Next, there will be a discussion on the Little Ice Age, and what it can tell us about the climate change that is being experienced today.

Little Ice Age

The Little Ice Age is a period of significant cooling between the 1400s and 1800s, especially in Europe (Tkachuck, 1983; National Research Council, 1995; Reilly, 2009). This cooling was not just a localized event, though; evidence of colder temperatures have been found all over the world, and there were also exceptionally cold temperatures in Asia in the middle of the seventeenth century (Bradley, 1993). Although this period is characterized by an overall cooling of the Earth (see Figure 2), the event was expressed in a myriad of ways in different regions. Some areas of Europe were faced with episodes of poor crop yields and large-scale epidemics, while places, like Newfoundland, were fortunate enough to experience a large amount of productivity in their fishing grounds (Mandia, 1995). The impact these decreasing temperatures had on the plant and animal life may have hurt human societies the most. Differences in growing seasons along with the staggered distribution of plants and animals made it difficult to rely on farming practices used prior to this point in time (Tkachuck, 1983; Mandia, 1995).

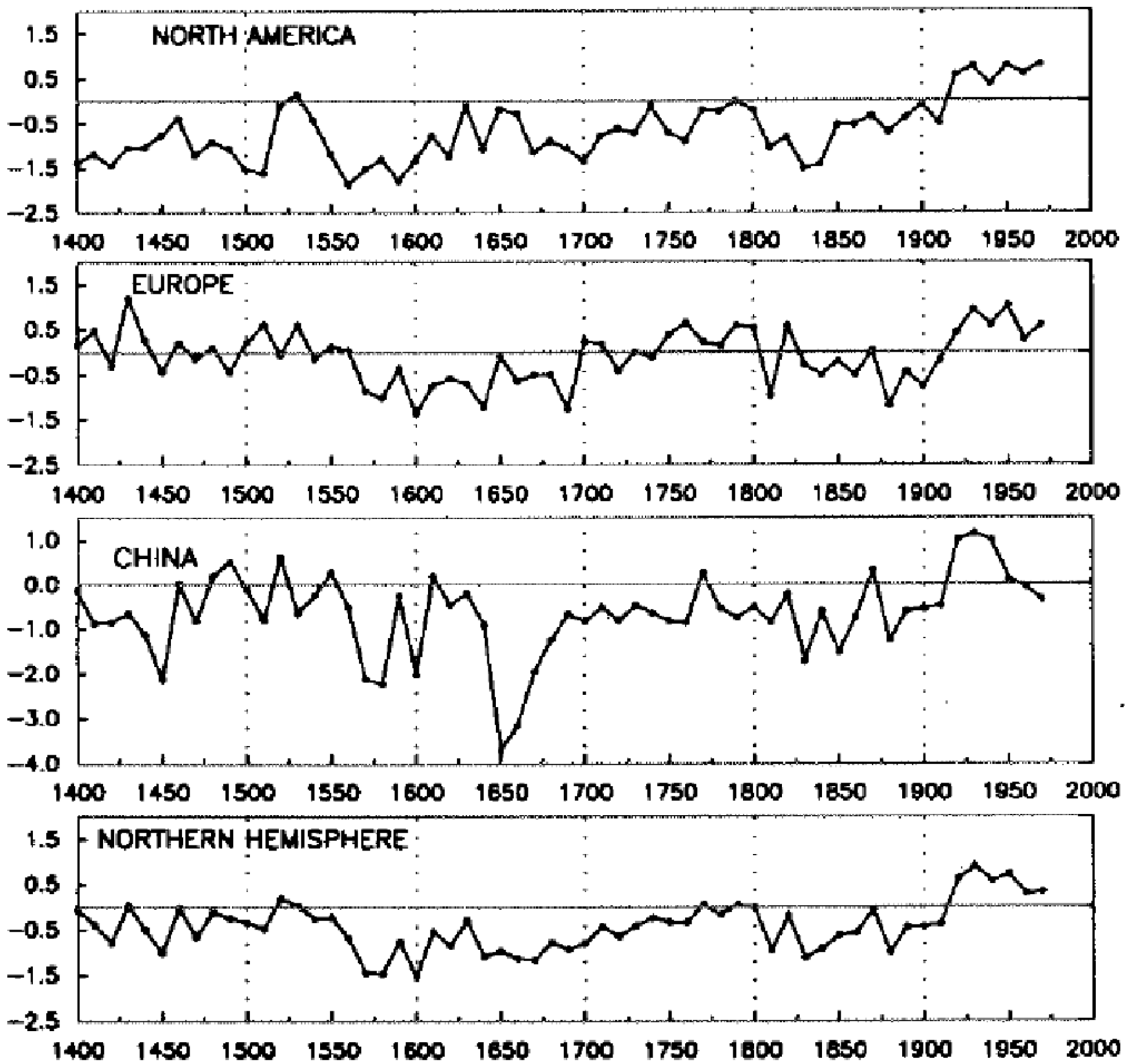

Figure 2: A series of graphs depicting temperature anomalies for North America, Europe, China, and the Northern Hemisphere. The Northern Hemisphere graph shows a trend below the mean temperature from the early 1500s to the late 1700s. The other graphs show similar trends, falling below mean temperature near that time frame—LIA (Bradley, 1993).

This period of the Little Ice Age presented many obstacles for human societies to overcome, and it may have been the driving factor that led to the Industrial Revolution (Tkachuck, 1983). Although the evidence of the Little Ice Age is not disputed, the mechanisms behind it are (Tkachuck, 1983; Reilly, 2009). Explanations ranges from external forcing from low sunspot activity during this time (Tkachuck, 1983; Mehta, 2017) to internal variability derived from an increase in volcanic activity (Bradley, 1993). There is probably not a single answer to this questions — the Little Ice Age was most likely the result of many different factors occurring at the same time (Tkachuck, 1983). This realization makes understanding the role of climate variability more complex as it shows that all factors must be accounted for in order to understand the big picture. Using this information about the Little Ice Age, the climate change being experienced today can be better understood.

Climate Change

Today, the climate is changing at an unprecedented rate, and as such will impact climate variability and its manifestations, such as regional to local climate stress.. Climate change is characterized by smaller time scale intervals than climate variability, and sometimes this change can be inadvertently masked by the larger intervals of natural variability (National Research Council, 1995). In terms of today's climate, the shift is typically attributed to anthropogenic climate change — any change to the climate as a result of human intervention (IPCC, 2007). Currently, the changes in temperature and climate seen across the globe have been observed to be the result of the great release of greenhouse gases into the atmosphere (IPCC, 2007). Greenhouse gases are specific molecules in the atmosphere — including carbon dioxide, nitrous oxide, and methane — that trap radiation emitted from the Earth and warm the overall environment, just like a greenhouse (UNFCCC, 2017). Although there are many factors that contributed to the warming seen today, as explained in the example of the Little Ice Age, there is evidence that most of this temperature change is the result of greenhouse gas emissions emitted from the combustion of fossil fuels (Bradley, 1993; IPCC, 2007).

There is a high level of certainty that these greenhouse gases have come from anthropogenic sources as opposed to natural sources (IPCC, 2007). Using climate models, the warming trend of the latter half of the twentieth century was analyzed. In this analysis it was found that solely natural sources could not produce the degree of climate change that is being experienced today — the only thing that could account for this change is an alternate source, an anthropogenic one (IPCC, 2007). There is also speculation on whether or not the spark of the Industrial Revolution and the subsequent introduction of greenhouse gases led to the expedited end of the Little Ice Age (Tkachuck, 1983). Despite these theories, the role of humans in regards to the changing climate cannot be ignored.

The expected temperature and precipitation changes will exceed anything experienced since before the Little Ice Age began 600 years ago (Bradley, 1993; IPCC, 2007). In addition to this, the natural variability of the global climate may be influencing, and possibly masking, the impacts of this anthropogenic climate change (National Research Council, 1995). The natural variability is being manipulated by forces that have never before been an issue. Although human societies may be used to some variability, such as the changing of the seasons (Mehta, 2017), the prospective changes have the potential to alter even that level of normal variability. This is put best by Reilly:

> As a result, current fears about the dangers of irreversible climate change need to be placed in perspective: Climate change is a constant on our planet, and the human species has already survived several episodes of dramatic environmental change in the past.

> Nonetheless, there are some indications that future changes to our climate may have unprecedentedly disastrous consequences for humans (2009).

By understanding the natural variability that has impacted humans the most in the past— such as decadal variability — people can be more prepared for what the future has in store. Although the climate may not change at the same degree, having this kind of knowledge will facilitate adaptation and could potentially save lives. This is the reason why the Little Ice Age provides an adequate baseline from which to see the impact of climate pressure on variability and, thereby, on society.

Resilience and Adaptive Capacity

Resilience is defined by the IPCC as "[t]he capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation" (IPCC, 2014a). In regards to climate change, this means that there will need to be steps taken to maintain the proper function of the Earth in regards to human use, to include access to essential resources, while the climate evolves over time. This, in essence, is an effort to stop any detrimental consequences that are projected to occur due to anthropogenic climate change. Global action has been taken in order to reduce the emission of greenhouse gases into the atmosphere, mitigating the stress enough to ensure that there is no significant impact on the natural climate system (Denton et al., 2014). This is a strategy that involves the cooperation of countries all over the world. Meanwhile, in order to mitigate the environmental stresses faced locally and regionally, there is an effort to bolster adaptive capacity.

In explanation, adaptive capacity is "[t]he ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014a). In other words, adaptive capacity measures an individual or society's ability to react to pressure, in this case from the environment. If one's adaptive capacity is high, that means there is a higher likelihood of survival and even productivity in the face of climatic stress. On the other hand, if adaptive capacity is low, the potential for catastrophe in the same situation significantly increases. In underdeveloped nations where resources are minimal, adaptive capacity is essential to combat the impacts of anthropogenic climate change (Denton et al., 2014). A couple examples of adaptive capacity include the hurricane warning system set up to promote societal preparedness in Vietnam and the implementation of land management alternatives in central Mexico to increase productivity (Smit & Wandel, 2006). Each region is faced with its own environmental threats, and each region must be able to adapt to those threats in some form or another, but how?

A Case Study

The Sangamner region of western India is an important case study for several reasons. First, being located within South Asia implies that it is already expected to be vulnerable to climate change. As a developing country, India is very likely to be impacted disproportionately worse than other parts of the world, and this will include impacts to the economy, the livelihood of rural populations, and the agricultural industry (IPCC, 2014b). Second, the Sangamner region will face particularly harsh impacts due to the fact that this area relies heavily on the agricultural industry. The greatest issues that will be faced include poor productivity in the agricultural sector and an extremely high dependence on water in a semi-arid, rain-fed region (ASSAR, 2016). Lastly, the lack of money in the region implies that there is not a lot that can be done about potential damages to the economy

(IPCC, 2014b). In order to assess the potential damages, understanding the regional and local climate is necessary.

Climate in South Asia

The powerful nature of climate is not unfamiliar to South Asia, and this can be seen in changes in precipitation and temperature around the subcontinent. The major driver of climate variability in the region is the ocean-atmospheric circulation that is propelled by the natural variability on the decadal time scale (Mehta, 2017). Unfortunately, anthropogenic climate change could present more unpredictable conditions that this natural variability does not account for. What is certain is that any variation in climate will have an impact on the agricultural sector, which implies that the livelihoods of many people will be at risk (Kelkar & Bhadwal). Some of the common conditions within South Asia can be used to understand the implications of the varying forces that are driving the climate in the region.

South Asia is considered to be a subtropical region, and this categorization allows for some generalizations to be made about the climatic systems. One of these elements that is relatively constant in all tropical regions is temperature — the latitudinal position of the tropics does not allow for the temperature to vary much (Sobel, 2012). On the other hand, there is a contrasting reality with the variability of precipitation, which is known to vary much more than temperature in different regions within the tropics (Sobel, 2012). Areas in Asia, specifically, also have climatic systems of their own that impact precipitation. For example, the Indian Summer Monsoon that occurs seasonally is the main source of rainfall for the subcontinent, and it has been observed to be weakening in recent decades (ASSAR, 2016). The variability associated with this system has the potential to seriously disrupt the subcontinent's economy (Adamson & Nash, 2014). These kinds of generalizations are not the sole way to understand climatic systems within the tropics, especially since they only take into account the seasonal variability of temperature and precipitation.

In addition to these generalized ideas, there is also uniformity in large climatic events. The El Nino Southern Oscillation is an example of these aforementioned events, and it is known to impact the climate at the country level (Hsiang & Meng, 2015). The natural fluctuation of climate is no new phenomenon, though; an example such as the Little Ice Age shows how a certain amount of variability in climate is common around the world (Hunt, 2006). With that being said, there is data that suggests an increase in the amount of warmer days and nights along with a decrease in the amount of colder days and nights within the South Asian subcontinent throughout the twentieth century (Klein Tank et al., 2006). Although this data may simply show a natural fluctuation in climate over a single century, the impacts of anthropogenic global warming on these processes must be considered.

South Asia is being impacted by climate change in many ways to include the increased occurrences of climatic events that commonly occur in this region — droughts, floods, and storms (IPCC, 2014; UNDP BCPR, 2013). Even without considering the implications of climate change on the conditions of this region, South Asia is still believed to be prone to disaster more than any other place in the world (Kelkar & Bhadwal, 2008). Although this is already a problem that these societies have faced for generations, the foreseen degree of variability will certainly bring about new challenges. The implications of climate change on these disasters are as follows: droughts and floods are likely to increase in both frequency and intensity, while storms are likely to increase in severity (Kelkar & Bhadwal, 2008).

Taking a closer look, much of this society has the potential to be impacted by these disasters. With an agricultural industry that is vulnerable to these issues, the rural economy that the nation is based upon may be drastically impacted. The employment of the majority of the Indian population exists within the agricultural sector, which means that the livelihoods of these people will be at stake (Kelkar & Bhadwal, 2008). There is also a concern about food security in a changing climate. The consequences of the changing climate are merely projections of the future, but the areas that are already affected by these events should be prepared for worsening conditions. The uncertainties within the projection, such as the lack of knowledge about the distribution of future rainfall patterns, should be taken into consideration as well (Kelkar & Bhadwal). A more in-depth understanding of the implications on the Sangamner region is important to analyze the potential risks.

Microclimate of Sangamner

Starting with the geography of the Sangamner region can shed some light on its potential vulnerability to climate change. Sangamner is a semi-arid region **(**Figure 3**)** located within the black soils of the Deccan Plateau in the Ahmednagar district of Maharashtra, India where surface water irrigation facilities have begun to shape the agricultural landscape (ASSAR, 2016). The Western Ghats, a mountain range along the western edge of Maharashtra, create a divide between the coastal areas of Mumbai and the interior of the Deccan region, significantly impacting the climate on each side (see Figure 4; Ratna, 2012). On the windward, or upwind, side of the mountain located next to the coast receives much more rainfall than the leeward, or downwind, side of the mountain located on the western side of the mountain range, creating a rainshadow effect (Ratna, 2012). A rainshadow effect can be defined as the warming of air that is descending associated with a lack of precipitation on the leeward side of a mountain range, such as the Western Ghats (Pidwirny, 2017). This climatic process is responsible for the semi-arid climate of the region. Due to this consistent depression of air, the societies within this region understand the harsh reality of the lack of precipitation and have found ways to adapt in the past.

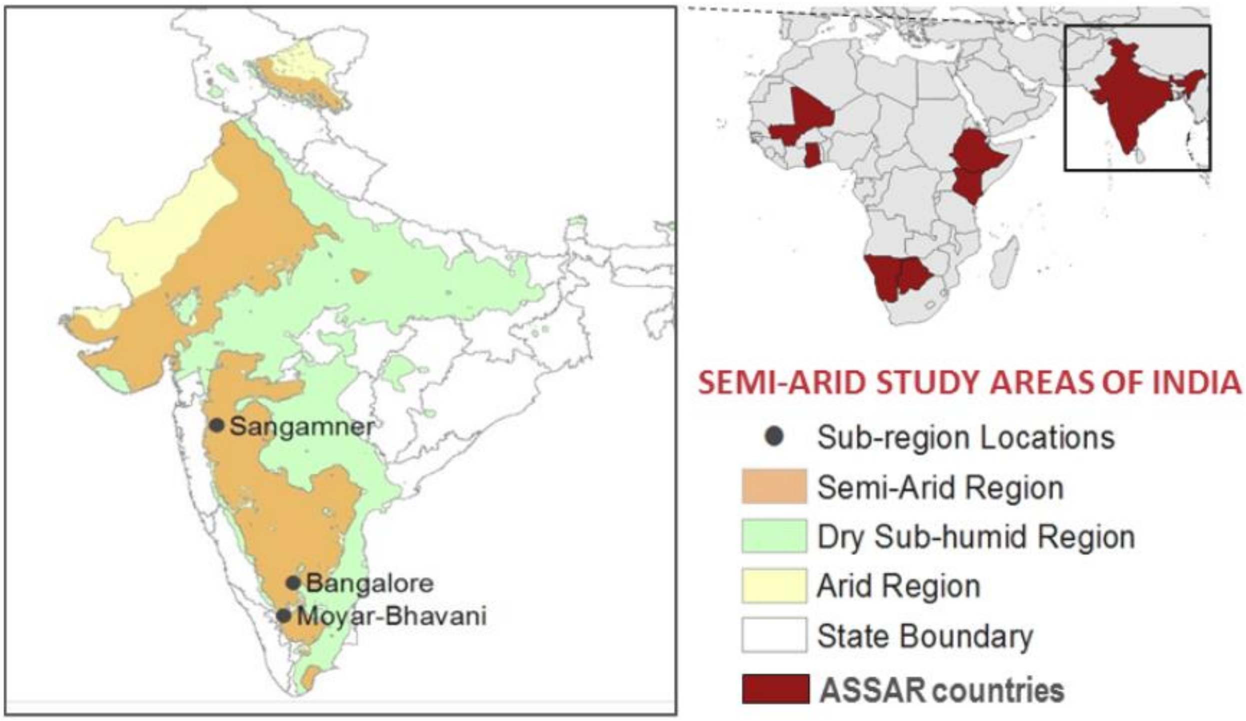

Figure 3: ASSAR (2016) designation of different climate regions in India. The Sangamner region of western India is classified as a semi-arid region: "characterised by low erratic rainfall and periodic droughts associated with high temperatures, which impose fundamental limits on animal and plant populations, and on human activities such as agriculture" (ASSAR, 2016).

Since the Sangamner region specializes in agriculture, the impacts of climate change have the potential to drastically reduce productivity in the area. This region is known to be semi-arid, meaning it receives a relatively low amount of rainfall, and this increases the region's susceptibility to climate variability in that any shift in precipitation could seriously hinder the productivity of the region (ASSAR, 2016). Since the Sangamner region is recognized mainly for its agricultural production (Deshmukh, 2012), the greatest issues that the people living here may face include poor productivity in the agricultural sector and an extremely high dependence on water in this semi-arid, rain-fed region (see Figure 3, ASSAR, 2016). With a new reliance on surface irrigation, which supports the success of the economy as mentioned earlier, the rain-fed agricultural system will need a certain amount of precipitation to be maintained.

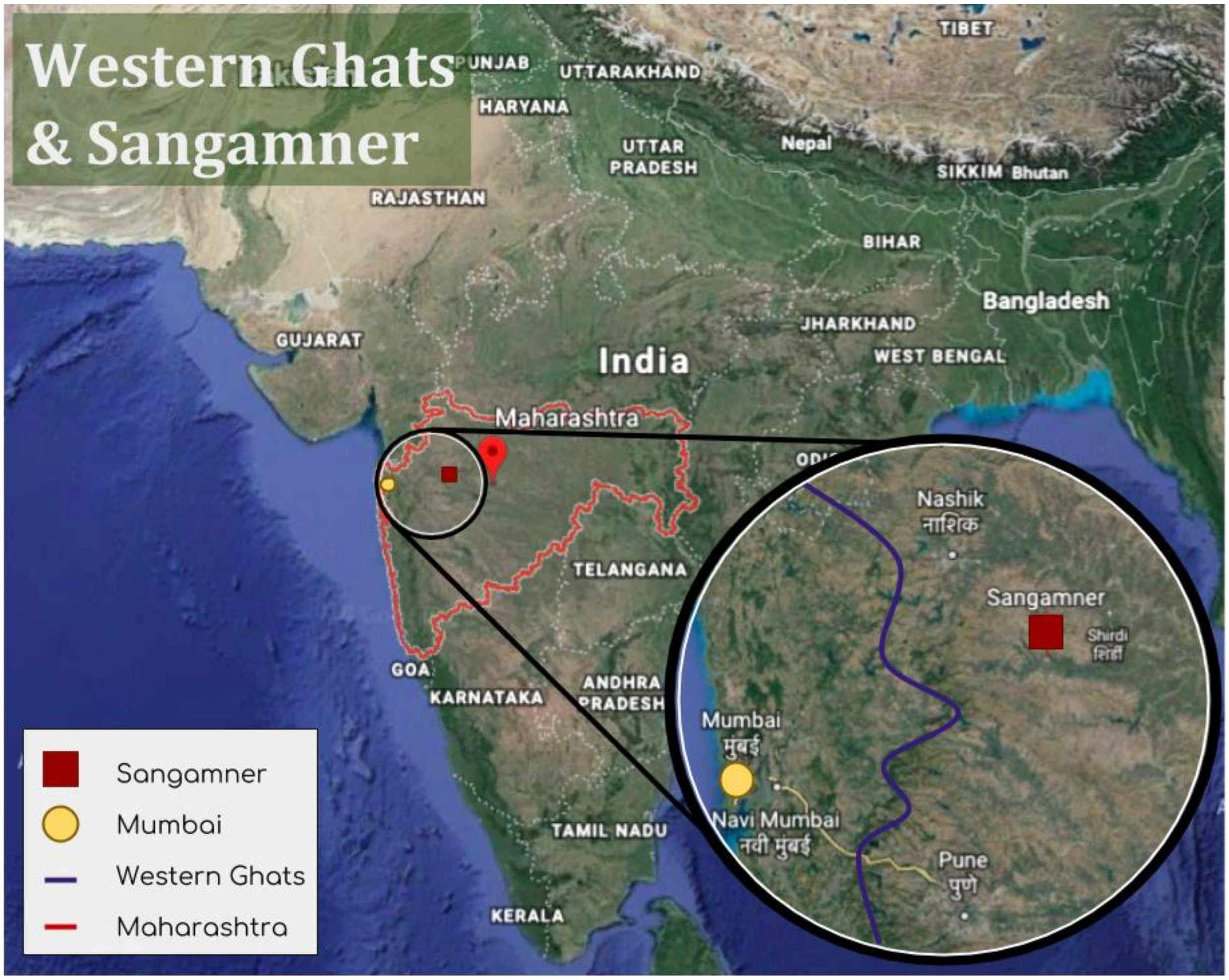

Figure 4: This figure, titled Western Ghats and Sangamner, depicts a cutout of the study area within Maharashtra, India and the major geographic characteristics surrounding it. As seen in the detailed circle, the Sangamner region is situated on the opposite side of the Western Ghats from present-day Mumbai, and this mountain range plays a major role in the climate gradient between the region and the coastal area. (Map components obtain from Google Earth).

Considering climate variability in such a region as this, it is clear that any change in precipitation has the potential to significantly impact the entire economy. Not only is precipitation an issue to be concerned with, change in temperature is shown to be a defining factor in the production of crops as well (Carlton & Hsiang, 2016; Hsiang et al., 2013; Hsiang & Meng, 2015). There are projections of temperature and precipitation trends that show a great uncertainty in this particular region, but there is some hope with an observed, yet modest, increase in precipitation over that last two decades (see Figure 5; ASSAR, 2016). With so much uncertainty in the data, a true understanding of past variability may give insight into the current climate change the region is confronted with today.

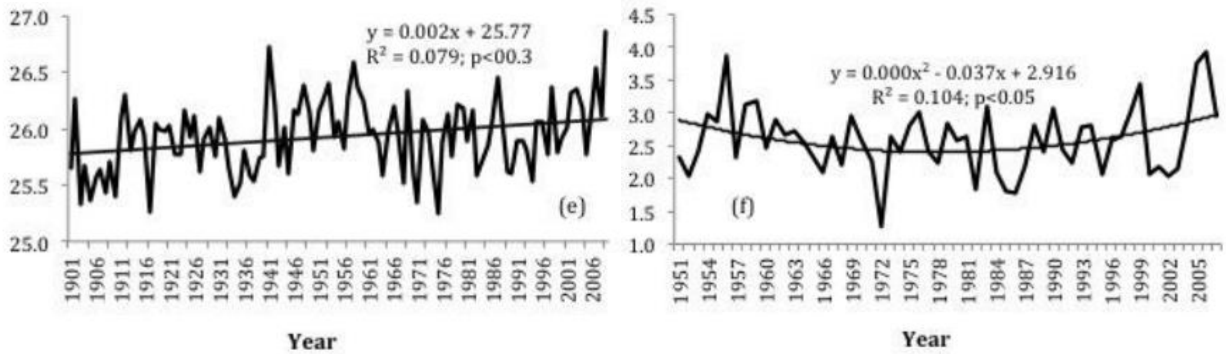

Figure 5: The graph on the left, labeled (e), shows the mean annual temperature from the Sangamner region. It is increasing at a positive rate of 0.002. The graph on the right, labeled (f), shows the mean annual precipitation from the Sangamner region. It has been increasing from the mid-1970s at a rate of 0.037 (ASSAR, 2016).

Direct Impacts

As reviewed earlier, the impacts of climate change and the potential intensity and frequency of climate events will surely have a significant effect on agriculture. Due to the fact that the foundation of the society is based on natural resources — such as water — any negative shift in precipitation could have a disastrous outcome for the region (ASSAR, 2016). It is also true that everyday agricultural production does not rely on precipitation so much as it does temperature: even if there was enough rainfall, it could not counter the impact of changing temperatures (Birthal et al., 2014; Carleton & Hsiang, 2016). The projected global climate includes problems like a higher likelihood of temperature extremes and an increased risk of drought as a result of anthropogenic forcing (IPCC, 2007). Climate change is also projected to impact extreme climate events, such as droughts, floods, and storms. In a semi-arid region like Sangamner, droughts seem to be the biggest threat to agricultural production.

The major crops being grown in this region are coarse cereal crops including pearl millet, sorghum and fodder crops, but the increased use of surface water irrigation has led to the production of more cash crops (ASSAR, 2016). The impact of climate change on cereals in both the wet and dry season in India varies widely, but there is evidence that irrigation has the potential to counter the effects of the changing climate (Birthal et al., 2014). This evidence suggests that the cereal crops in Sangamner may be protected from some of the severely negative impacts that other non-irrigated areas will encounter. If the irrigation system is reliant on rainfall, this could be detrimental to the entire region and beyond. Despite this possible downfall, it is important to understand that the communities within India have proven to be resilient in the face of deficient monsoon rainfall in the past (Adamson, 2014). The ability for the society to maintain this resilience may still be in question, though, as vulnerability to stress increases.

The recorded relationship between climate change and crop yields is also important to understand in the context of the region's vulnerability. Through both climate models and controlled experiments, the relationship has proven to be non-linear (Schlenker & Roberts, 2008; Hsiang et al., 2013; Birthal et al., 2014). This conclusion implies that the average crop yield will not immediately be impacted by the changes in climate; rather, the negative impact will be revealed after the climate changes to a certain degree. Although this may give the Sangamner region an incentive to continue as usual, without preparation for the potential catastrophe, the society should be planning for a more sustainable future. If they continue on the path of denial without proper preparation, the consequences may be insurmountable.

Indirect Impacts

Along with the direct impacts of climate change on agriculture, there are also indirect impacts that are just as harmful, if not more so, to the Sangamner region of western India. Due to the effects of changing temperature and precipitation on agriculture, the economy of the region has the potential to collapse (Hsiang & Meng, 2014). A decrease in agricultural productivity can lead people to seek other means of employment, draining the industry of its labor force and enhancing the problems of food security in the region. Another consequence of climate change is migration induced by natural disasters. With more extreme climatic events projected for the future, there is a higher likelihood that people will permanently migrate out of the region — a more drastic solution than resorting to temporary migration as people have done in the past (Bohra-Mishra et al., 2014; Hsiang & Sobel, 2016). Although these projected indirect impacts are not set in stone, the possibility of risk should be enough to encourage people to act.

This review provided all of the information currently known about the Sangamner region and its susceptibility to climate change. Unfortunately, this is not enough to accurately account for the impacts of the changing climate seen today. The knowledge gaps, such as the high uncertainty of the future temperature and precipitation changes and the lack of real life understanding of the potential impacts, must be addressed. These impacts, both direct and indirect, have the potential to destroy the region's economy and the livelihoods of the people who live there. In order to safeguard the Sangamner region and other developing economies from any controversial consequences, one question must be answered: By understanding the stresses of long-term climate variability using historical data, what steps can the society of the Sangamner region of western India take in order to prepare for the current degree of anthropogenic climate change?

Methods

In order to conduct my research on the impacts of climate variability of Sangamner, I analyzed not only the area in question, but a closely related area as well: Mumbai, Maharashtra. By looking at Sangamner in the context of a larger record (refer to Figure 4), the impact of the moisture gradient over the country could be more clearly seen. With this I was able to further understand the implications of climate stress in the region. I began by gathering data that has been currently collected for the two regions of Mumbai and Ahmednagar, the latter being the district in which Sangamner is located. I found this data from two sources: the Indian Water Portal and the Open Government Data (OGD) Platform in India (originally derived from the Indian Meteorological Department). I began by taking the raw data of the larger area of Maharashtra (Figure 6) in order to get a broad idea of the climate in the region, finding that rainfall histories were more common in the twentieth century than temperature histories. This data was sourced from the OGD. Next, I used the raw data that I retrieved from the Indian Water Portal and graphed the temperature and precipitation trends of Ahmednagar (Figure 7) and Mumbai (Figure 8).

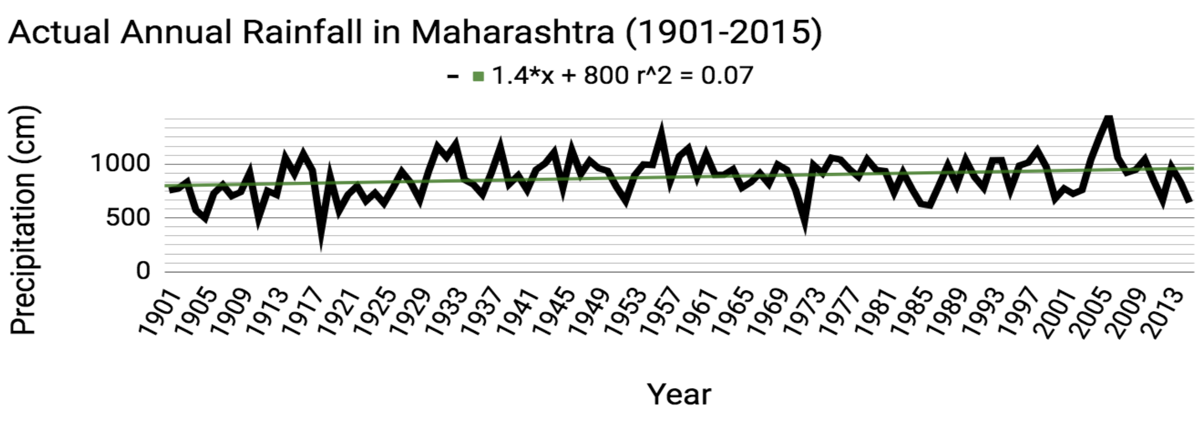

Figure 6: Actual Annual Rainfall in Maharashtra (1901-2015) shows a decent increase at a rate of 1.4. Understanding the topography of Maharashtra shows how even though there is an overall increase in the state, there are locations such as Sangamner that are not receiving much rainfall. The monsoon rainfall overcompensates for the lack of rainfall in this region and does influence the overall precipitation measurement in any way.

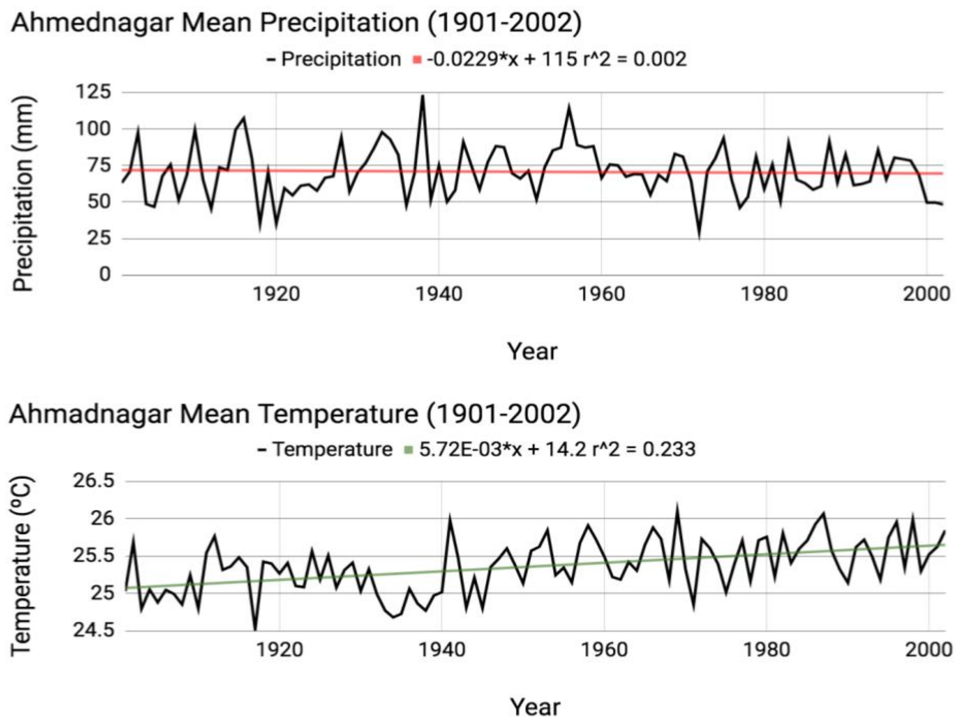

Figure 7: Mean Precipitation of Ahmednagar (1901-2002) shows a gradual decrease at a rate of -0.029, Mean Temperature (1901-2002) shows a negligible increase at a rate of 0.0057.

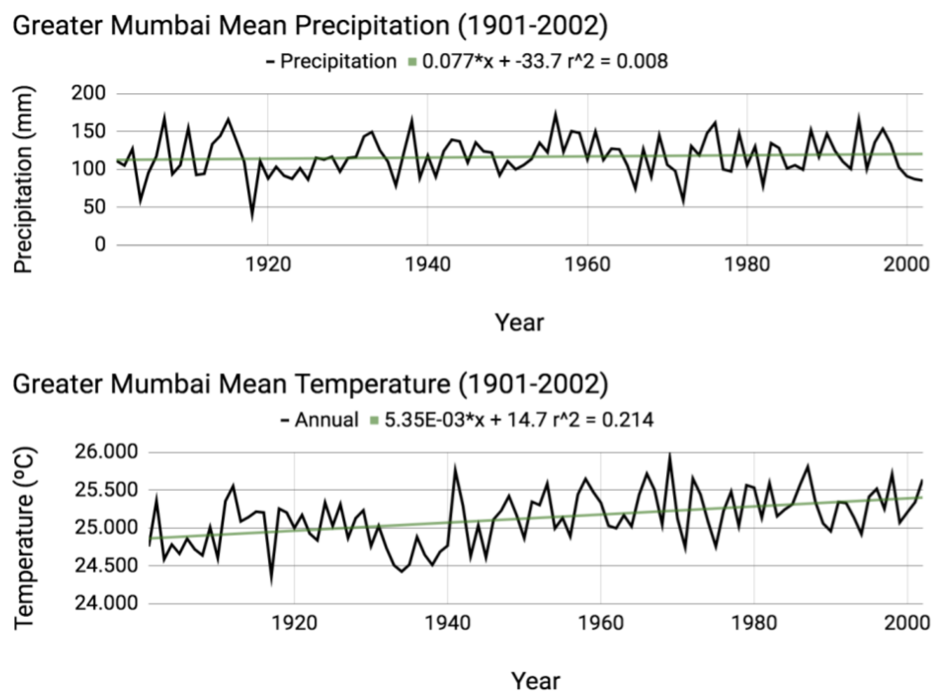

Figure 8: Mean Precipitation of Mumbai (1901-2002) shows a modest increase at a rate of 0.077, and Mean Temperature (1901-2002) shows a negligible increase at a rate of 0.0053.

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Moving on to the historical climate research that is the center of this thesis, I then shifted my attention to archival data. The data was derived from both natural archives and institutional archives. Details about each are as follows:

Institutional Archives

In order to retrieve this information, I collaborated with Dr. Ranjini Ray, a scientist from the Indian Institute of Human Settlements. Dr. Ray provided me with a refined catalogue of the documentation from the Dehli National Archive on a detailed spreadsheet. The information covered areas between Maharashtra and Madras (present day Chennai, Tamil Nadu) — in other words southern peninsular India — within the time frame of 1831-1889 (Table 1).

At the time I received the documentation, this data was semi-quantitative data that needed to be transformed into qualitative data. This means that there was not a specific measure of the amount of rainfall or an accurate account of temperature, but there are comments on three major climatic disasters: drought, famine, and flood. There are not many previous studies of institutional data in this location (Walsh et al., 1999; Hazareesingh, 2012; Adamson & Nash, 2013; Adamson & Nash, 2014; Adamson, 2014; Adamson, 2015; Adamson, 2016; Shanmugasundaram, 2017). For the assessment of these archives, I used each mention of a climate event as a data point. In cases where there was more than one mention of drought, famine or flood in a particular year, I indicated that the event was more severe (Table 2). The degree of severity could not be determined simply from what was detailed in each document, so it was based on how widespread the climatic events were. Where there are multiple data points for an event in a single year, the disaster is more severe. In this case, with a total of twenty-seven data points, the most severe event had only three data points.

Table 1: Details for archival data collected in Mumbai

Date	Area in Question	Report Content
1831	Bundelkhand (Madhya Pradesh, Uttar Pradesh)	Crop failure
1832-33	Madras Presidency	Famine
1835	Ootacammand (Tamil Nadu)	Description of Climate
1835	Madras Presidency	Mention of frequent occurrence of drought
1836	Palni Hills (Kerala, Tamilnadu)	Description of Climate, migration of people, description of thermometer
1837	Bombay	Tax abolition
1837	Khandesh (Maharashtra)	Flood of river Taptee
1838	Bellary (Karnatak), Cuddapah (Andhra Pradesh)	Drought
1838	Kathurbag, near Poone (Maharashtra)	Description of climate
1839	Madras Presidency	Scarcity
1840	Kaira District (Gujarat)	Flood
1842	Western Deccan- Khandesh, Mahabalshwar	Description of Western Deccan climate
1842	Western Deccan	Description of thermometer and rain gauge
1842	Nimar (Madhya Pradesh)	Description of climate, Geology
1844-45	Khandesh (Maharashtra) , Ahmedabad (Gujarat), Khaira(Punjab), Broach, Surat (Maharashtra)	Famine
1862	Ahmadnagar (Maharshtra)	Famine
1862	all the eastern districts in the Deccan and Khandesh	Famine
1864	Masulipatam and Cuddalore	Cyclone
1868	Distrcts of Madras, North and South Arcot	Unfavourable Prospect of the season
1868	certain districts of the Madras Presidency	Famine
1876	Kamptee floods and the Kanhan bridge	Flood
1877	Madras and Bombay Presidency	Famine
1878	Madras Presidency	Famine
1879	Bombay Presidency	Drought, Conflict
1882	Mysore	Condition and Prospects of crop
1884	Madras Presidency	Famine
1889	Native states around Bombay	Famine

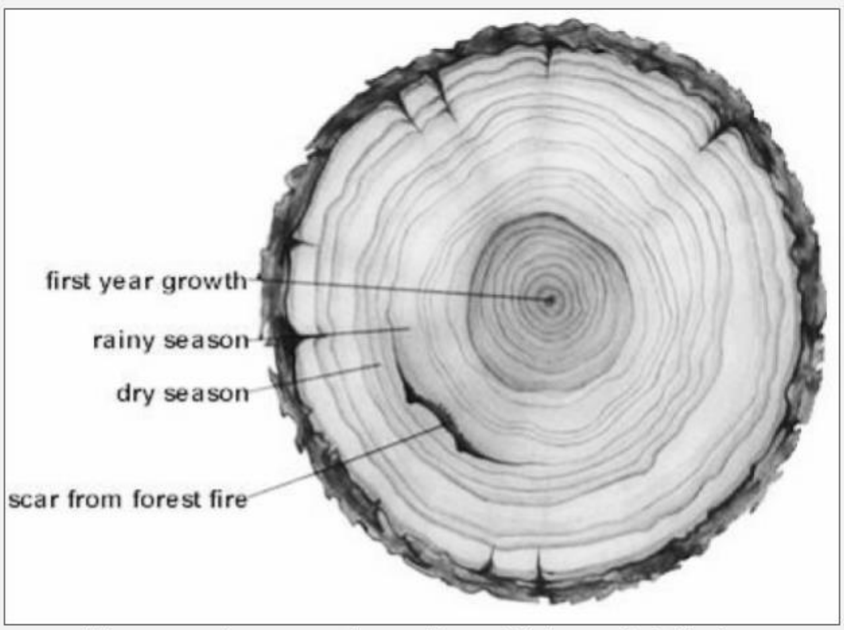
Date	Drought	Famine	Flood
1831	-	1	-
1832-33	-	1	-
1835	2	-	-
1836	1	-	-
1837	1	-	1
1838	2	-	-
1839	-	1	-
1840	-	-	1
1842	3	-	-
1844-45	-	1	-
1862	-	2	-
1864	-	-	1
1868	-	2	-
1876	-	-	1
1877	-	1	-
1878	-	1	-
1879	1	-	-
1882	-	1	-
1884	-	1	-
1889	-	1	-

Table 2: Institutional data in standardized form. The more data points for each year, the more severe that event is. The year with the most severe, or widespread, climatic event occurred in 1842 with 3 data points representing drought.

Natural Archives

Archives of nature, as opposed to instrumental data, are found in the environment in which we live. Common archives of nature include ice cores, sediments cores, and the growth rings in trees (Palgrave Handbook, forthcoming). For this research tree ring data was used to estimate the climate of the region in question, specifically in Maharashtra. As far as accuracy is concerned, we must understand that tree ring data is not exact like the instrumental measurement of precipitation nowadays. Instead, we must understand that climatic stress of any kind impacts the growth of trees, and there can be many reasons for the year to year variation in growth (see Excerpt 1 for more information). The majority of indigenous tree species do not have clearly defined growth rings (Adamson & Nash, 2014), so this must be taken into account as a knowledge gap.

Excerpt 1:



In order to read tree rings, you must start from the center and work your way out — the center is the first year of growth. From there you can see that there are dark and light rings that expand over the entire trunk of the tree. The dark and light together make up a single year where the larger, lighter section represents the amount of yearly growth. When climate conditions are decent and provide sufficient rainfall, the tree will grow much more than with the climate conditions are stressful and dry. Interior scorch marks also show periods of fire during the tree's lifetime (GSA, 2006).

In the case of Ram et al. (2008) the understanding of tree ring data came down to a moisture index, which correlated with periods of drought in areas of Maharashtra. This is the data I used for my research as well. From their analysis, a trend in long-term moisture variability was found using the growth rings from teak (Figure 9). Teak tree-ring chronologies have proven to be useful in the analysis of climate since rainfall is important in seasonal growth of teak trees (Ram et al., 2008; Ram et al., 2011). Unfortunately, the moisture index used from this tree-ring analysis is not perfect: periods of growth during times when there is a normal amount of rainfall have a relatively insignificant correlation. However, there is evidence that shows the statistical significance between years with little growth and low moisture availability, creating an adequate index for assessing drought (Ram et al., 2008; Borgaonkar et al., 2010). The correlation between the moisture index and the ring width index can be seen in the data I took from Ram et al. (2008) in Figure 10. Both the moisture index and ring width index will be explained next.

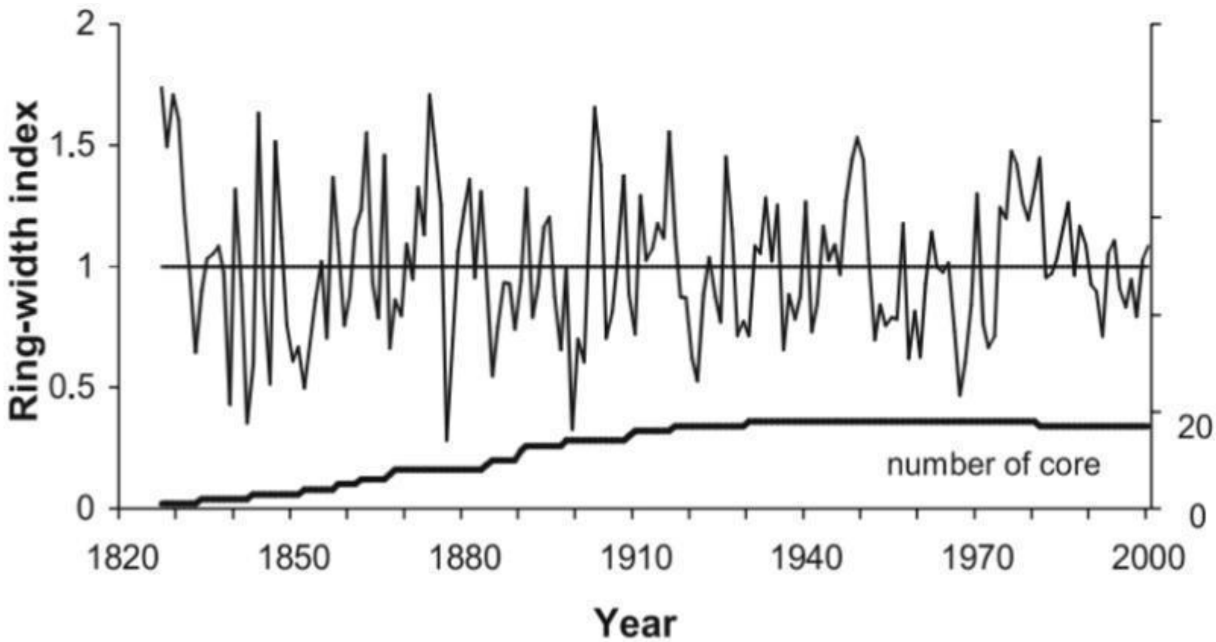


Figure 9: Maharashtra tree ring data from Ram et al. (2008) detailing the chronology of the ring width index between the years 1820-2000. This is the data used in the Results section. The number of tree cores used for each data point is graphed at the bottom, reaching a maximum of 20 cores per data point. The trend line has a slope of zero along the y-axis point 1.

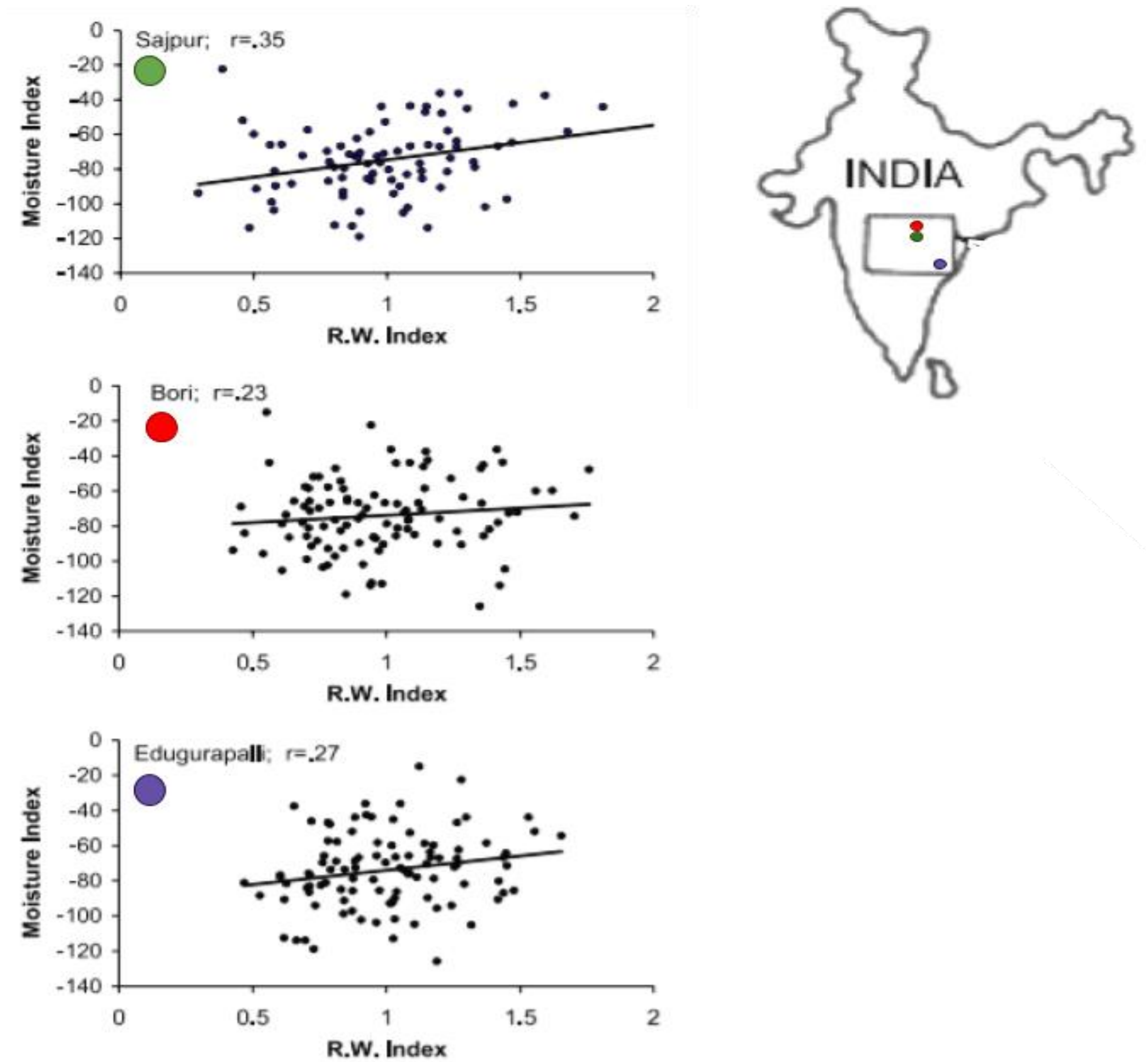


Figure 10: From the tree rings collected in three locations of central India — Sajpur, Bori, and Edugurapalli — the ring width (labelled R.W. Index) was plotted against the moisture index showing a positive correlation in all three areas (Ram et al., 2008). This relationship is the most significant when both ring width and moisture index are low.

Moisture index is defined by the difference between the monthly rainfall and the potential evapotranspiration, which is a factor of temperature, day length, and the value of heat indices (Ram et al., 2008). In other words, the moisture index is determined by the rate of precipitation and the degree of temperature for each season — we can use this to represent overall climate of the region. Ram et al. (2008) emphasizes the lack of influence that seasonal temperature has on the observed tree ring variation — in this case it shows a negative relationship — but for the purposes of this thesis both temperature and precipitation will be considered. Ring width index is found by dividing the actual value associated with ring width over the smooth value of the standardized autoregression (Ram et al., 2008). Therefore, the correlation between the moisture index and the ring width index as described above will be assessing the relationship between the overall climate of western India with the standardized measurement of the tree ring data.

Composite Analysis

Although both the institutional and natural archive data tell a story on their own, the greatest understanding comes from combining the two. In an effort to show the accuracy of and provide greater insight into the data described thus far, I took the homogenized institutional data and overlaid it on the graph of the tree ring data (Figure 11). By doing this, I was able to see the correlation between the climatic events mentioned in the institutional data and the years of great or minimal growth.

Lastly, I extrapolated the analysis of the historical climate data and applied the findings to the current climate data of Maharashtra (Figure 12), Mumbai (Figure 13 & 14), and Ahmednagar (Figure 15 & 16). I analyzed specific years of stress and compared it to the tree ring data from Ram et al. (2008) as well. Although the tree ring data covers the bigger picture of central India, it can be scaled down to provide insight into the issues facing the Sangamner region as seen in the figures below. This extra assessment of the tree ring data using instrumental data between 1901-2003 provides legitimacy for the analysis of the institutional data. By conducting all of these analyses, the variability of the past was used to understand the climate change being witnessed today. I could then consider the climate change impacts that affect the Sangamner region and provide recommendations for the future.

Results

Due to the fact that the data I used for this research was gathered from other three disparate sources — institutional data derived from archives, tree ring data derived published word (Ram et al., 2008), and instrumental climate data from government databases — the majority of the analysis I did was conducted on the composite of the gathered data. I began with the creation of a figure showing the relationship between ring width and climatic event such as drought, famine and flood (Figure 11). The greatest correlation can be seen in the years 1835, 1838, 1842, 1862, and 1868 where there were *two* data points corresponding with drought in 1835, 1838, 1862, and 1868, while there were *three* data points corresponding with drought in 1842, in this case meaning that the climatic event was the most significant. It is not surprising that the years of 1838, 1842, and 1868 indicate a period of relatively widespread famine and drought due to the sharp decrease in ring width as seen in Figure 11.

Notice that the ring width associated with the year 1830 shows much greater growth followed by a steep decline in the ring width. Although there are not signs of severe, widespread drought, famine or flood (indicated by more than one data point), the drought of 1835 may be considered as a delayed reaction to the environmental stress. Even with the slight increase in growth seen after the low of 1834, the impacts of the stress continued as the 1830 growth levels were not resumed. The mention of drought persisted in 1836 and 1837, although not as widespread as the previous year. The year 1837 also experienced a flood even as the tree ring width began to drop, implying that there may have been some kind of correlation with the drought. The flood of 1876 was followed in the next years by two mentions of famine and a drought, and this occurred along a steady decrease in tree growth ending in 1879. The famines of 1882, 1884, and 1889 all took place on years of growth lower than the average.

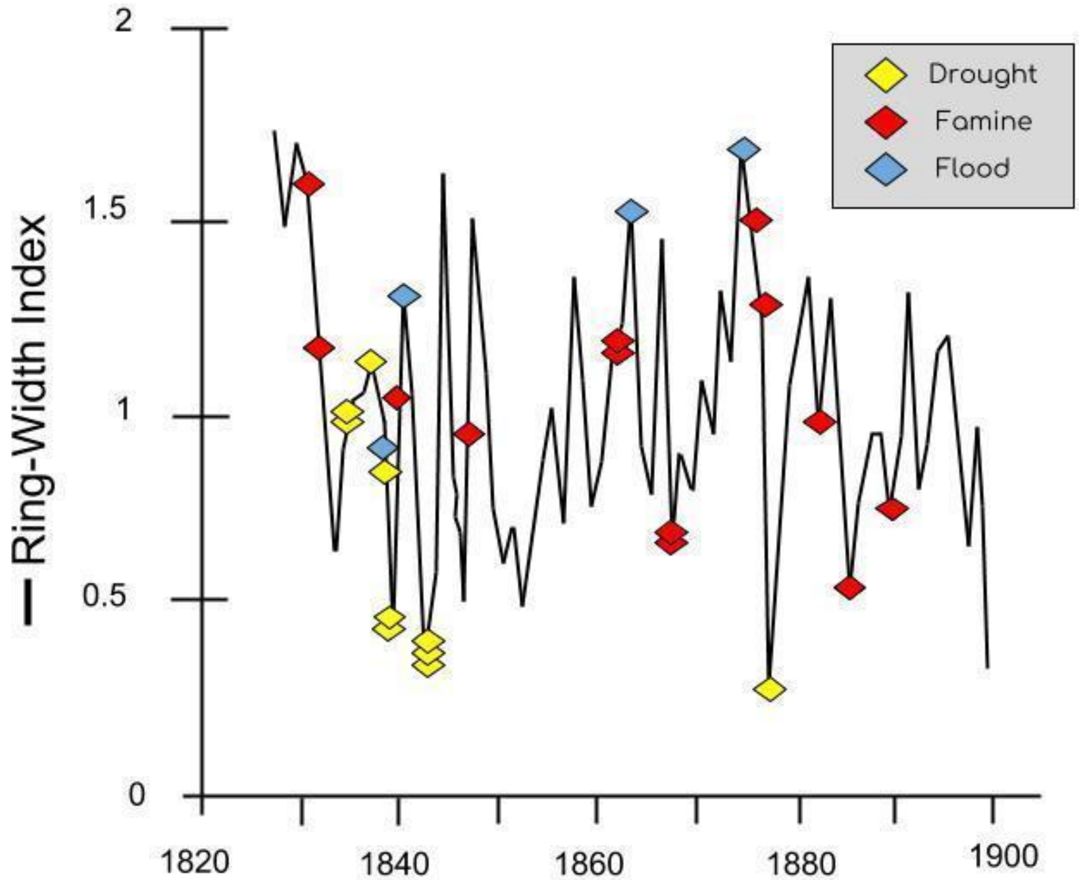


Figure 11: Institutional archive records of drought, famine and flood in southern peninsular India between the period 1831-1889 (see Table 1) depicted on top of tree ring data from Ram et al. (2008). Years with multiple records of a disaster in a single year are identified by diamonds stacked on top of each other — implying a more severe or widespread disaster.

Next, I observed the relationship between ring width and the instrumental data of the region. Starting from a broader scope, I compared the ring width to the measurement of precipitation in all of Maharashtra (Figure 12). The y-axis for precipitation shows a range between 0-1500 millimeters of rainfall annually. The climate of Maharashtra is only indicated by the precipitation data, unlike the regions of Mumbai and Ahmednagar, which have data for both precipitation and temperature. This is a knowledge gap that must be considered when analyzing the data. There are many instances where the precipitation data shows the inverse of the tree ring data, implying that in years of great precipitation there was little growth and vice versa —

especially seen in the years 1948-1976. This could be explained by the temporal implications of rainfall in the region: there is a somewhat perceptible lag in the impact of rainfall on tree ring width. As seen in the same period as mentioned before (1948-1976), there is a decrease in annual precipitation beginning around 1948, while the ring width shows an increase. Looking after 1950, the ring width index begins to decline as well. Similarly, in 1955 the annual precipitation of Maharashtra hits the highest peak in the timeframe being considered, but it isn't until 1958 that the ring width begins to grow again. This same pattern continues throughout the entire dataset, expressing a lagging pattern in regards to precipitation on ring width growth.

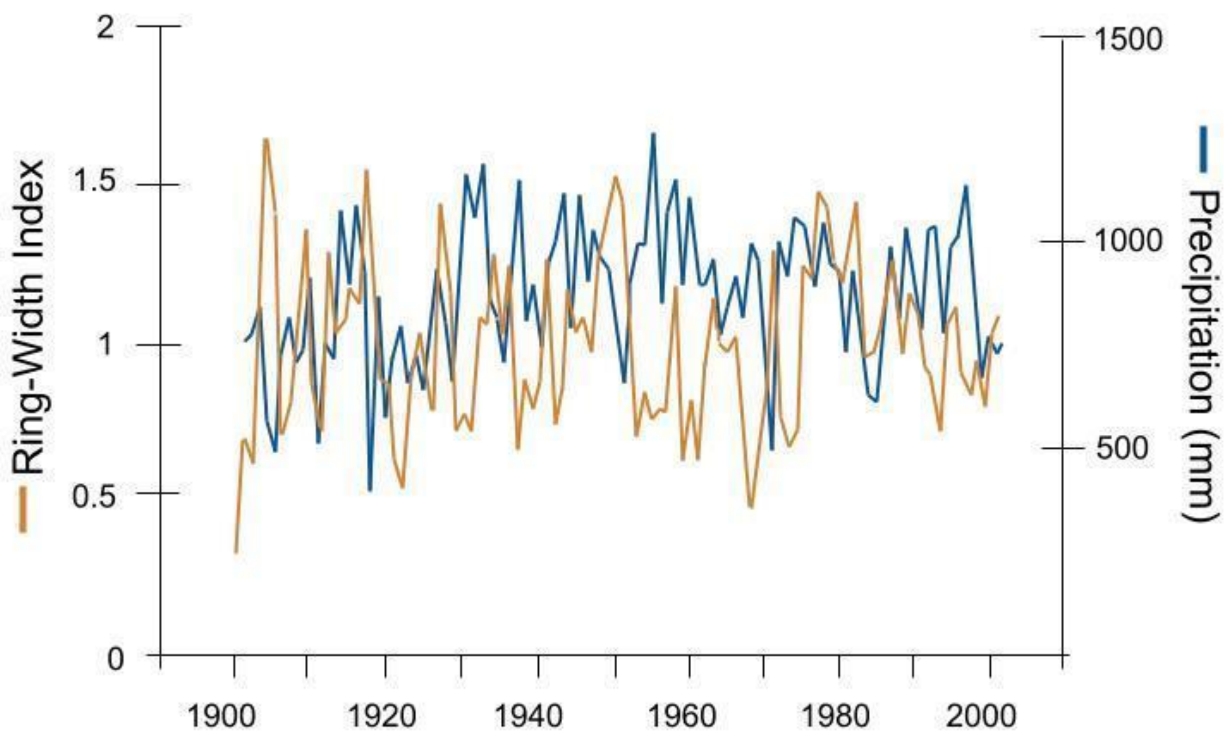


Figure 12: Maharashtra Precipitation and Ring Width Index of central India. Ring width (yellow line) on the left is proportional to the measurement of precipitation (blue line) on the right.

Narrowing my focus, I began to review the instrumental precipitation and temperature data against the tree ring data for Mumbai (Figures 13 & 14) and Ahmednagar (Figures 15 & 16). The y-axis for precipitation in the Mumbai figure shows a range between 0-200 millimeters of rainfall annually, and the y-axis for precipitation in the Ahmednagar figure shows a range between 0-125 millimeters of rainfall annually — this makes up a small proportion of the overall rainfall seen in Maharashtra. The annual rainfall in Ahmednagar was much less than that of Mumbai (approximately 75 millimeters/year), as expected from the geographical rainshadow.

Just as the relationship between precipitation and ring width in the Maharashtra, the corresponding figure for Mumbai shows the same lag pattern. The variation in precipitation was especially large in the beginning of the twentieth century, which was matched by a high variation in tree ring width at the same time. Meanwhile, the temperature during the beginning of the dataset (1904-1910) was at a relative low. The rest of the twentieth century precipitation pattern follows that of Maharashtra only to a muted extent. The correlation between temperature and tree ring growth is not significant and does not provide much information into the interpretation of the tree ring data. The years of low tree ring growth — such as 1901, 1922, and 1968 — corresponded with moderate temperatures and moderate levels of precipitation relative to the region. The years of high tree ring growth — such as 1905, 1918, and 1950 — corresponded with somewhat low levels of precipitation and did not have a particular relationship with temperature.

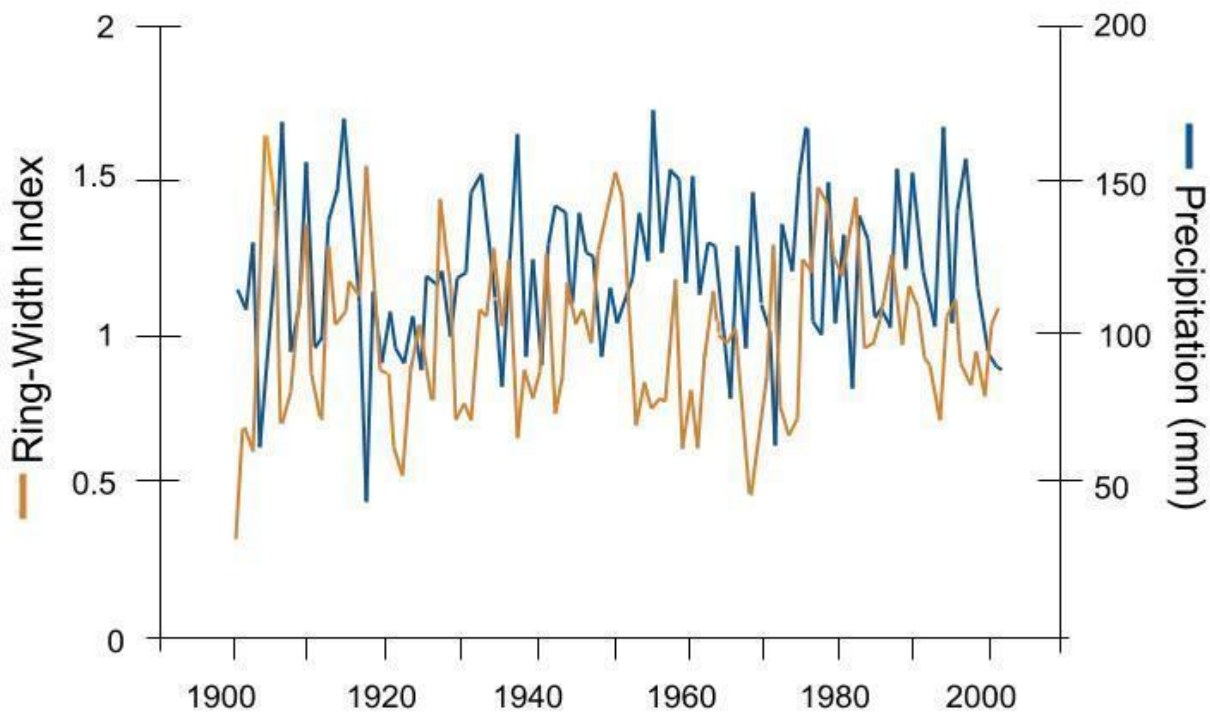


Figure 13: Mumbai Precipitation and Ring Width Index of central India. Ring width (yellow line) on the left is proportional to the measurement of precipitation (blue line) on the right.

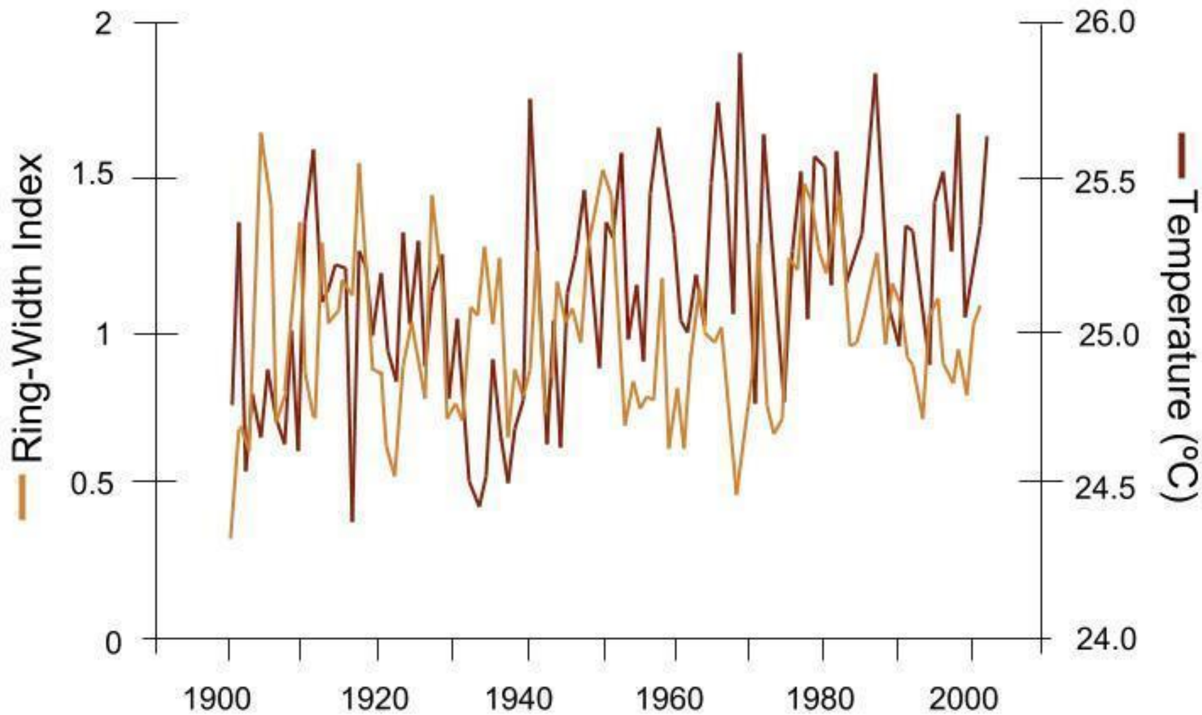


Figure 14: Mumbai Temperature and Ring Width Index of central India. Ring width (yellow line) on the left is proportional to the measurement of temperature (red line) on the right.

The trends in Ahmednagar were a bit different than those found in Mumbai. Besides a few outlier years (1917, 1938, and 1956), the precipitation trend in Ahmednagar showed relatively low variability. On the other hand, the temperature trend in Ahmednagar had high variability, starting relatively low in the beginning of the twentieth century and increasing to moderate temperatures at the end of the century. The years of low tree ring growth — such as 1901, 1922, and 1968 — corresponded with moderate levels of precipitation relative to the region and did not have a particular relationship with temperature. The years of high tree ring growth — such as 1905, 1918, and 1950 — corresponded with moderate to low temperatures and moderate to low levels of precipitation relative to the region.

In addition to this relationship, an important comparison can be made between the precipitation graphs from Maharashtra, Mumbai, and Ahmednagar— Figure 12, Figure 13, and Figure 15, respectively. The precipitation scale labeled on the right y-axis of each graph varies drastically. The greatest scale is greatest in the state of Maharashtra with a maximum of 1395.7mm in 2006, and this amount includes the precipitation rates of both Mumbai and Ahmednagar. Mumbai has the next greatest precipitation scale with a maximum reaching 172mm in 1956. Ahmednagar has a scale that reaches a maximum of 123mm in 1938. There is a clear disparity between the precipitation level in Mumbai and Ahmednagar.

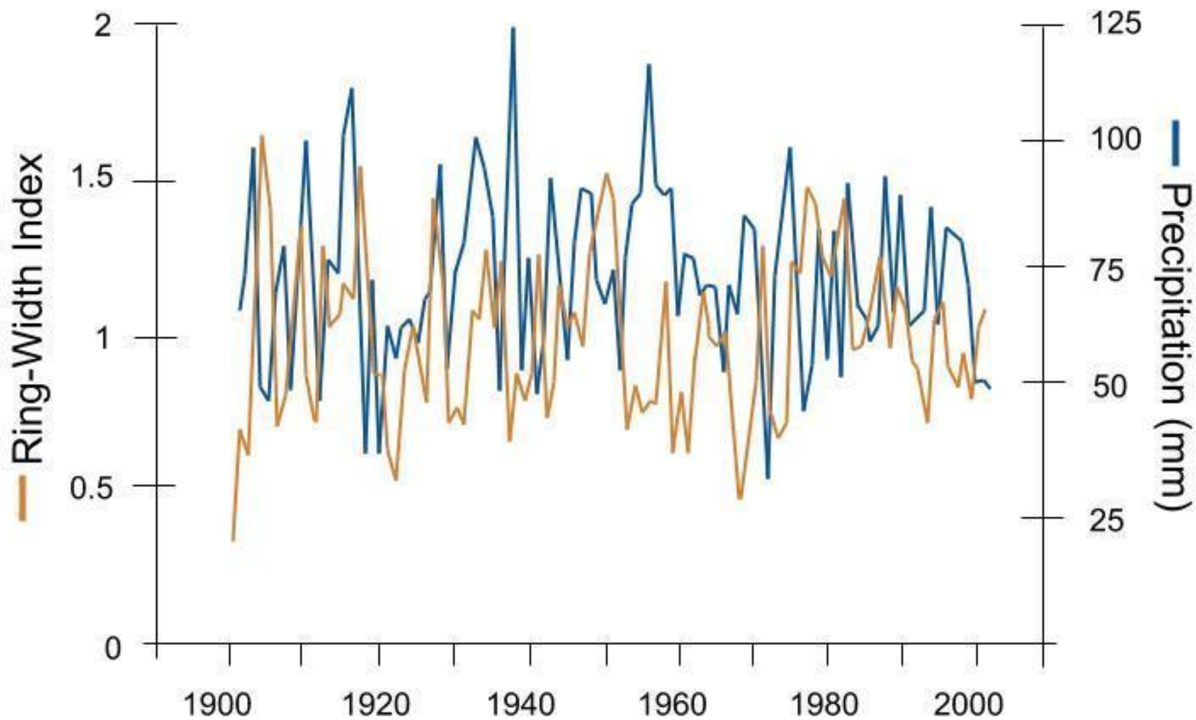


Figure 15: Ahmednagar Precipitation and Ring Width Index of central India. Ring width (yellow line) on the left is proportional to the measurement of precipitation (blue line) on the right.

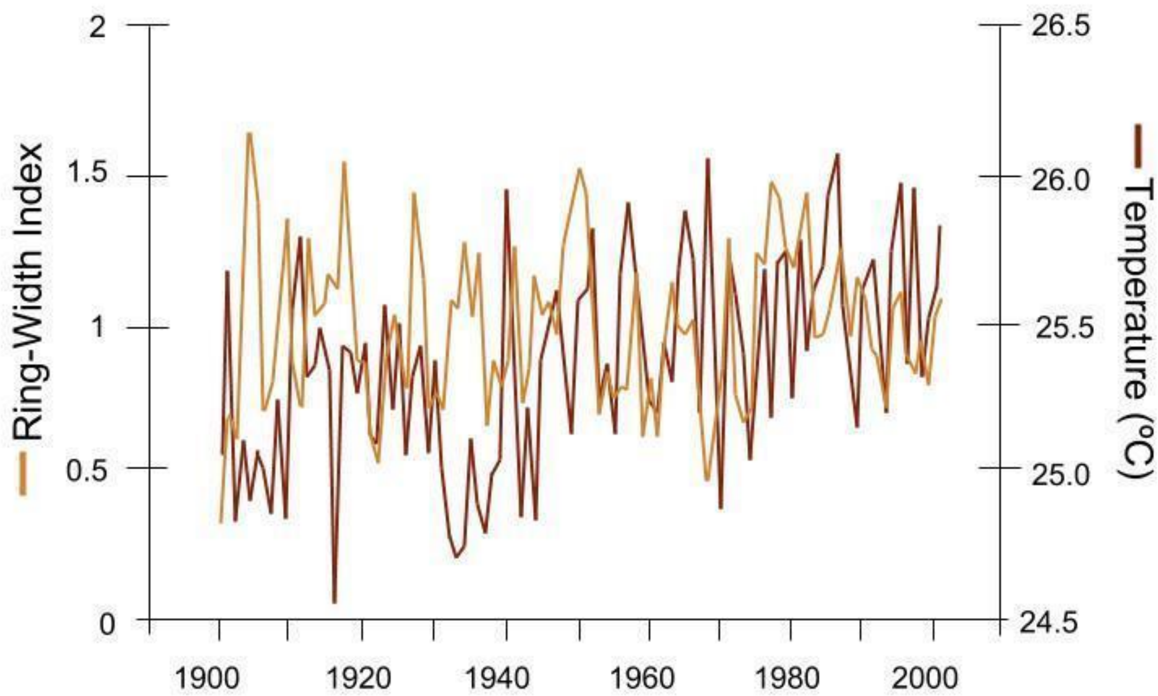


Figure 16: Ahmednagar Temperature and Ring Width Index of central India. Ring width (yellow line) on the left is proportional to the measurement of temperature (red line) on the right.

Discussion

Returning to the Environmental Adaptation Framework introduced in the Background section (Diagram 1), the Impacts of climate variability, climate change, and regional/local climate can be understood using the findings from the analysis above. I will begin with impacts derived from the current instrumental data analysis and then move on to the impacts of the historical data analysis. After there is an adequate understanding of the implications of this research, I will discuss the adaptation strategies that I recommend for the future.

Implications of the Data

Graphing the tree ring data with the instrumental data created a deeper understanding about how temperature and precipitation impact vegetation growth rates. In an area reliant on agriculture such as Sangamner, understanding this relationship is extremely important. In regards to the composite precipitation and tree ring data for Mumbai and Ahmednagar, there was a notable pattern. The ring width variability showed an indication of a time lag: when rainfall began to increase, ring width did not increase in the same year and, instead, began to increase after a couple years. The same time lag occurred in years when precipitation decrease, which was followed years later by a decrease in ring width. The correlation is prevalent, but the lag must be understood in the context of society. In a semi-arid region such as Sangamner, dependence on rain water for irrigation must be reserved not only for years of little rainfall, but for years following periods of little rainfall as well. Crops will experience stress from such variability in precipitation, so taking measures to mitigate the fluctuations in precipitation would be recommended.

The disparity in precipitation levels between Mumbai and Ahmednagar is depicted in the data as well. The coastal area of Mumbai receives a significantly greater amount of rainfall than the neighboring district of Ahmednagar. There is clearly a high rate of variability in the level of precipitation in both regions, but it does not account for the vast difference in mean rainfall. This regional disparity can only be attributed to the rainshadow effect — the presence of the Western Ghats is keeping the monsoonal precipitation from reaching Sangamner (Ratna, 2012). Although this thesis deals with raw precipitation data, the impacts of geography on regional microclimates need to be taken into consideration as well.

As opposed to the relationship between tree rings and precipitation, the temperature trends for Mumbai and Ahmednagar did not have such a strong correlation to the tree ring data. This finding contradicts the observations made by Birthal et al. (2014) and Carleton & Hsiang (2016) that argue there is a significant relationship between the two. Since their observations were made specifically about the impact of temperature on agricultural production and not on tree ring data representing growth in the region, further information is necessary to provide greater context. The trend of gradually increasing temperature over the last century cannot be overlooked, though. Despite there being an insignificant relationship between climate change and growth in my research, the implications of the capacity for agricultural practices to be sustained in Sangamner is a greater puzzle to solve. More information on the correlation between historical tree ring data and the capacity of agricultural production today is necessary.

The tree ring data and the institutional data were brought together to depict an image of climate stress experienced in regional Maharashtra. It was not surprising to see a significant correlation between years of low growth and extreme climatic events such as drought, famine, and flood. With the understanding that low growth years have a positive relationship with minimal levels of precipitation, certain direct impacts can be expected. The historical data analysis has reinforced the concept of the region's reliance on monsoonal rainfall as stated in ASSAR (2016).

In years when there is less rainfall, there is a higher likelihood of disasters such as drought and famine. In addition, climate stress seems to continue as the ring width begins to increase, implying that even when precipitation begins to increase after a low-growth period there is still potential for disasters to persist. Flooding is shown to occur after those periods of stress, which shows that oversaturation of land can have a negative impact on society as well.

The indirect impacts are not as clearly depicted in this data. Remembering the details of the Sangamner region from the Background section, it stated two important factors that provide insight into these indirect impacts: the area is primarily an agricultural economy and the crops tend to have a nonlinear relationship to climate change. Due to the fact that Sangamner specializes in agriculture, the impact of climate on vegetation growth has the potential to seriously hinder production. Variable rates of precipitation as seen in this research show an inconsistent rainfall pattern that is followed by a delayed response in growth. This implies that even in years of adequate rainfall there may be poor crop production. As for the nonlinear relationship between climate and crops, the gradually rising temperature will have a higher likelihood of negatively impacting production. Overall, the main source of income for the economy of the Sangamner region — agriculture — is not a guarantee.

If the economic staple of the region is ineffective in providing for the population, there will be devastating consequences. It can be expected that the number of famines will increase with the lack of production. Although this was not recorded in the institutional data in my research, the climate variability has been altered due to anthropogenic climate change since 1889, the last data point I used for my historical data analysis. The lack of food produced in the agricultural economy will not only leave people hungry, it will leave them out of work as well, a notion by Kelkar & Bhadwal (2008) that has been reinforced by this research. On top of this, with greater environmental stress projected for the future, the residents of Sangamner may resort to permanently migrating away from the area instead of using temporary migration as a coping mechanism. With the livelihoods of the people in Sangamner at risk, steps need to be taken in order to prepare and adapt to the changing, variable climate.

Adaptation Strategies

As the final section of the Environmental Adaptation Framework that this thesis is guided by, Adaptation Strategies present an opportunity to implement the analysis of this data in the real world. The framework provides two scales on which to assess the Adaptation Strategies: the Spatial scale and the Temporal Scale. Each of these scales are divided into two subcategories: Global and Local, and Short-term and Long-term, respectively. These Adaptation Strategies can be understood as recommendations made based on this research of climate variability and climate change in the Sangamner region of western India. An explanation of these strategies is detailed below.

Spatial-scale Adaptation

Adaptation measures on the spatial scale involve areas, communities, and even the human population as a whole working together to provide a better world for tomorrow. The most complex, yet the most important aspect of this is world-wide cooperation regarding climate change policy. In order for emerging economies like the Sangamner region to stand a chance against such severe consequences of environmental stress, a united movement must be taken to mitigate the impacts of climate change around the world. Therefore, global climate change policy, like that seen in the 2015 Paris Agreement, should be implemented on a global scale.

Regional and local adaptation measures can be taken as well within the Indian subcontinent and even within the Sangamner region. This research provided information about threats from climatic events in the past, and the projections into the future provide us with an understanding that these natural disasters are going to become more severe. In order to mitigate any potential damage from these events, emerging economies on the regional and local scales need to focus on preparedness. Preparing for the worst case scenario will ensure that these areas survive. Disasters will harshly impact the agricultural economies and rebounding from such devastation may be difficult. Sangamner should not have to stand alone in this poor condition — the government of India should cooperate with small agricultural regions like this and provide services and aid that will allow the areas to effectively come back after disasters strike.

Along with the international climate change policies that will be implemented in order to suppress the consequences of rising temperatures and variability in precipitation, there should be regional and local policies put in place as well. Regional, country-wide climate change policies will need to focus on the areas that will be impacted the most — such as major agricultural sectors — in order to offset the impending disasters. Local policies that regulate the use of common pool resources like water will need to be implemented, promoting foresight and preparedness for years of poor production. In other words, the years with the highest production cannot be taken for granted. The global, regional, and local scales must keep in mind that even in the most prosperous years the impacts climate is changing are inevitable. Preparedness for the future is essential for survival.

Temporal-scale Adaptation

Adaptation measures must also be taken on different timescales to reinforce the spatial-scale preparedness strategies and policies. Initially, areas such as Sangamner that will potentially face devastating consequences from climate change must consider what measures can be taken in the short-term timeframe. Understanding that Sangamner is a poor, agriculturally-based economy, we should not expect an immediate transition away from this ingrained way of life. Instead, short-term goals should involve facilitating sustainable agricultural production, enabling the industry to persist in the face of adversity. The regional government should provide aid for these efforts due to the fact that the high variability in precipitation and gradually increasing temperature trends have the potential to dry out this productive agricultural center. This short-term measure should strive for resilience, as this will provide the area with the ability to sustain itself for future generations.

Looking towards the future at long-term timescales, the best option for Sangamner with its projected detrimental climate is to completely move away from an agricultural economy. If a society relies heavily on agriculture, any variation in production has the potential to severely impact the livelihood of the people. This could result in loss of jobs or home, and people may resort to migrating out of the area altogether. This would apply additional stress to the society already dealing with resource scarcity and natural disasters. It would be beneficial to implement programs to educate and train current farmers, allowing them to move into new fields and, subsequently, raising the overall status of the society. Transitioning the economy to an industry that is not as susceptible to the changing climate will ensure the success of the people and the region as a whole.

Conclusion

Climate change is expected to increase both the temperature and the variability of precipitation, so the Sangamner region of western India must be prepared to address projected societal issues that result from the changing climate. Since there are clear links between years of low precipitation and natural disaster, the unpredictable variation in rainfall has the potential to severely affect this agricultural society. Further research should be conducted using institutional archives, such as those from colonial India, so that society's perspective of climatic events can be understood throughout history. There are limitations to this method because most records do not account for periods of uneventful climate phenomena — the only records of climate disasters and such are those that are deemed significant enough to be accounted for. There should also be further research about the differences between the varying perspectives found in societal archives; for example, the perspective of English colonists in India versus the perspective of the farmers impacted by the changing climate. The only way to ensure the success of Sangamner in the future is to act on multilateral scales, focusing on climate policy, sustainability and resilience, and the societal transition away from an agricultural economy.

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