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ASSESSMENT OF THE IMPACT OF CLIMATE CHANGE ON LAND USE IN THE EMIRATE OF ABU DHABI - AN ENVIRONMENTAL AND SOCIO-ECONOMIC PERSPECTIVE

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This dissertation is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Under the Supervision of Professor Taoufik S. Ksiksi

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Declaration of Original Work

I, Latifa Saeed Al Blooshi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this dissertation entitled "*Assessment of the Impact of Climate Change on Land Use in the Emirate of Abu Dhabi - An Environmental and Socio-economic Perspective*", hereby, solemnly declare that this dissertation is my own original research work that has been done and prepared by me under the supervision of Professor Taoufik S. Ksiksi in the College of Science at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my dissertation have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this dissertation.

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Abstract

This dissertation focuses on the impact of climate change on land use in the Emirate of Abu Dhabi – UAE. Climate change is a significant challenge resulting from natural and anthropogenic causes. Land use can stimulate changes in communities under climate change. The main objective of this dissertation is to assess the impact of climate change from an environmental and socio-economic perspective. In 2001, coastal sabkhas, mixed class and urbanized areas experienced an increase in temperature by (0.67, 1.14 and 1.16°C) respectively. In cities, urban areas are warmer than neighboring rural areas. Unexpectedly, urbanization in desert areas in UAE led to a decrease of 3–5°C in the overall LST. The maximum air temperatures are going to increase in the coming years based on the predictions according to the different scenarios in 2095 using MarksimGCM by more than 4°C in UAE. Urban expansion and changing lifestyles have led to an increase in energy consumption. Data was gathered from (321) residents in Abu Dhabi Emirate. More than 50% of the participants agreed that climate change is controlling their energy and water consumption. About 94% of participants believe that their energy consumption is increasing. About 50% of participants consider moving to another city if energy prices increased due to energy consumption and the effects of climate change. Changes in the global environmental conditions affect agricultural activities. Three hundred and one surveys were collected throughout Abu Dhabi Emirate. Approximately 68% of the respondents in Al-Ain agreed that it is currently much easier and more profitable to manage a farm than it was 20 years ago. Thirty-nine percent of the farmers agreed that both production quality and quantity have improved over the past 20 years. Farmers aged between 51-60 years agreed more that the groundwater levels and quality had changed over the past 20 years. The research covered past, present and future period of time that represented a firm timeline of the study. The study reflects the importance of awareness among people to overcome and cope with the effects of climate change.

Keywords: Climate change, Dryland, Land use, LST, UAE.

Title and Abstract (in Arabic)

تقييم تأثير التغير المناخي على استخدام الأراضي في إمارة أبوظبي - من منظور بيئي واقتصادي اجتماعي

الملخص

تهتم هذه الأطروحة بتأثير التغير المناخي على التغير في استخدام الأراضي في إمارة أبوظبي – دولة الإمارات. حيث يعد التغير المناخي تحديا كبيرا ناتجا عن أسباب طبيعية أو عن طريق تدخل البشر. يمكن أن يكون تأثير التغير في استخدام الأراضي كبيرا على المجتمعات في ظل آثار التغير المناخي. تهدف الأطروحة إلى تقييم هذا التأثير من منظور بيئي واقتصادي اجتماعي. حسب هذه الدراسة في عام 2001، ارتفعت درجات الحرارة في تصنيف السبخات البحرية بـ (0.67) والتصنيف المختلط (عمران ومسطحات خضراء) بـ (1.14) وتصنيف العمران بـ (1.16) درجة مئوية. في المدن تكون المناطق العمرانية أكثر حرارة من الضواحي والمناطق المجاورة. على عكس المتوقع، أدى إعمار المناطق الصحراوية في دولة الإمارات إلى انخفاض درجة حرارة سطح الأرض من 3 إلى 5 درجات مئوية. في 2095 سترتفع درجات الحرارة العظمى حسب السيناروهات المختلفة باستخدام MarksimGCM بما يقارب الـ 4 درجات مئوية في دولة الإمارات. قاد التوسع العمراني والتغير في نمط الحياة إلى زيادة استهلاك الطاقة. تم جمع البيانات من (321) من المقيمين في إمارة أبوظبي. ووافق قرابة نصف المشاركين في الاستبيان على أن التغير المناخي يتحكم في استهلاكهم للطاقة والمياه. ما يقارب 94% من المشاركين يعتقدون أن استهلاكم للطاقة في ارتفاع وخمسون بالمئة منهم يفكرون في الانتقال لمدن أخرى في حال ارتفعت الأسعار بسب زيادة استهلاك الطاقة وتأثيرات التغير المناخي. تؤثر التغيرات على الأحوال البيئة في العالم على النشاطات الزراعية. تم جمع (301) استبيان في إمارة أبوظبي ووجد أن 68% من المشاركين في مدينة العين يوافقون على أن إدارة المزارع حاليا أسهل وأكثر ربحية عما كان عليه قبل عشرين عاما. تسعة وثلاثون بالمئة من المزارعين يوافقون على أن كمية وجودة الإنتاج الزراعي تحسنت خلال العشرين عاما الماضية. وافق المزارعون في الأعمار بين 51-60 عاما على أن مستوى المياه الجوفية وجودتها قد تغيرت خلال العشرين عاما الماضية. تغطي هذه الدراسة الفترة الماضية، الحالية والمستقبلية مما يجعلها تمثل خطا زمنيا متينا للدراسة. كما تعكس الدراسة أهمية الوعي بين الناس من أجل التغلب والتكيف مع تأثير التغير المناخي.

مفاهيم البحث الرئيسية: التغير المناخي، الأراضي الجافة، درجة حرارة سطح الأرض، درجة الحرارة، دولة الإمارات العربية المتحدة.

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Dedication

To Mom and Dad

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List of Abbreviations

AA	Al-Ain
AD	Abu Dhabi
AT	Air Temperature
BAU	Business as Usual
GCMs	Global Climate Models
GDP	Gross Domestic Product
GHGs	Green House Gases
GIS	Geographical Information Systems
IPCC	The Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LST	Land Surface Temperature
LULC	Land Use Land Cover
NOAA	National Oceanic and Atmospheric Administrative
RCMs	Regional Climate Models
SDSM	Statistical Downscaling Model
UAE	United Arab Emirates
UHI	Urban Heat Island
USGS	U.S. Geological Survey
WRF	Weather Research and Forecasting Model

Chapter 1: Introduction

1.1 Overview

Climate change is a challenge facing the planet. It is manifested as a change in the rainfall frequency and intensity, within or between year changes in temperature, among others. Alternatively, it could be a change in a place's or earth's usual temperature for a month or a season (NASA, 2018). According to Cohen et al. (2009), climate change is a significant change in climate over a long period of time, a decade or longer, and it results from natural or anthropogenic causes. Recently, there has been a worldwide concern about climate change and global warming, especially with the recent anti-globalization movements (Aboelenein, 2006). Many reasons and causes are behind climate change. The scientific community has not yet fully agreed on those causes. Some scientists consider climate change as normal variability while the majority believe that human activity is the main cause of rising concentrations of greenhouse gases (GHGs) and the subsequent changes in climate (Radhi, 2009).

Climate change impacts are expected to be more noticeable year after year, because of which the region will experience higher stresses (Elhakeem and Elshorbagy, 2015). Based on Verner (2012), climate change forecasts suggest that average temperatures in the Arab countries will increase by up to 3°C by 2050. This increase will lead to different changes in evaporation and rainfall rates, sea level rise, vegetation areas, consumption of water and electricity. UAE is part of the Arabian Peninsula which is an arid region where rapid global population increase joined with urbanization and industrialization led to the deterioration of water quality and shortages of fresh water supplies (Mohamed and Al-Mualla, 2010). To study the change in climate, LULC is the best indicator.

LULC change has significant effects on biodiversity, water quantity and quality, soil conservation and world climate (Iida and Nakashizuka, 1995; upadhyay et al., 2005; Karnieli et al., 2008). LULC changes are universal in a way that when combined globally, they ominously affect key aspects of earth system functioning, causing major changes such as; global climate warming (Lambin et al., 2003). Climate has the largest influence on vegetation distribution on a global context (Prentice, 1990).

The relationship between rainfall and vegetation has frequently been used to differentiate between land degradation occurred due to climate and human-induced activities (Archer, 2004; Evans and Geerken, 2004). Many areas were degraded in the Arab region due to different factors. Based on the IUCN 2008 statistics, UAE has 42 threatened species including mammals like the Arabian leopard and Arabian tahr and several marine species like green turtle, and the numbers can increase due to changes in climate (Tolba and Saab, 2009). Moreover, UAE deserts are considered as simple ecosystems with basic food chains, a low primary production and a low biodiversity because of the high temperatures and low rainfall (Tourenq and Launay, 2008).

Additionally, the increased temperature rates, due to GHGs, create unavoidable biological complications (Pimm, 2008). Such complications may include biodiversity loss. Biodiversity is an escalating concern and conservationists pay a specific attention to disruption and loss as well as to climate change as a major threat (Mantyka-Pringle et al., 2015). Loss and fragmentation of habitat can brutally hold back the movement of species and their ability to survive climatic changes. Habitat destruction via land-use change is the key driver of biodiversity loss (Jantz et al., 2015). During the last thirty-three years, a decline of 29 percent was noticed in the three main ecosystems:

terrestrial, freshwater and marine when examining the population trends of 1,313 species such as; fish, amphibians, reptiles, mammals and birds in the world (Tourenq and Launay, 2008). The mean global surface temperatures for instance, are expected to rise as high as 4°C by 2100, this will definitely affect biodiversity and create new challenges to the ability of species to seek and find suitable climatic conditions (Riordan and Rundel, 2014).

One major driver is converting natural vegetation areas to cultivated areas. The cultivated cropland has increased by factors of about 70 in the US and approximately 5 globally in the past 300 years. It is expected that the agricultural lands are going to increase by 20% in the next 50 years (Scanlon et al., 2005). Agriculture has an effect on ecosystems that occurs due to the use and release of limiting resources that influence the functioning of ecosystems such as nitrogen, phosphorus and water. In addition to these resources, agriculture releases pesticides and converts natural ecosystems to croplands, which may oppose climate change in environmental and societal impacts (Tilman et al., 2001). The main drivers of agricultural responses to climate change are biophysical effects and socio-economic factors. Crop production is affected biophysically by rising temperatures, changing rainfall rate, and increased atmospheric CO_2 levels (Parry, 2004).

Climate change will have an uneven impact on poor people in rural areas where the majority depend directly on natural resources (Fischer et al., 2002). Based on the Intergovernmental Panel on Climate Change IPCC, the influences of climate change on food security is considered to be very serious, particularly if the global mean temperature continued to rise (Porter et al., 2014). It is believed that without addressing the issues of sustainable agriculture and rural development, it will be impossible to tackle food-security and poverty concerns (Fischer et al., 2002). Fortunately, UAE is considered as one of the richest countries in the world because of oil industry. However, climate change is expected to have socio-economic impacts on the country.

It is surely believed that climate change is one of the major threats facing the UAE (Verner, 2012). Schweikert et al. (2014) reported that developed countries are facing major fiscal costs for adapting or reacting to climate impacts. Future world will be very dissimilar from now even if the impacts of climate change are neglected, because of socio-economic and political changes (Holman et al., 2005). Yet, most of the human societies and activities are somehow influenced by climate because of its impact on people's livelihood and wealth (Adger et al., 2003). Climate can shape human cultures with its influences on people's lifestyles, which has been happening in the Arab countries.

1.2 Statement of the Problem

The purpose of this research is to assess the impact of climate change on land use change in Abu Dhabi Emirate from an environmental and socio-economic perspective. Figure 1.1 shows the graphical frame work of the study. This research specifically intended to answer the following questions:

1. What is the impact that climate change has on the UAE land use/ land cover?
2. Does climate change have an effect on the changing land surface temperatures in parts of Abu Dhabi Emirate?
3. What is the impact of climate change on land prices and water and energy consumption in Abu Dhabi Emirate?
4. Does climate change have an influence on the agricultural and livestock production in Abu Dhabi Emirate and can this be detected from the groundwater characteristics?

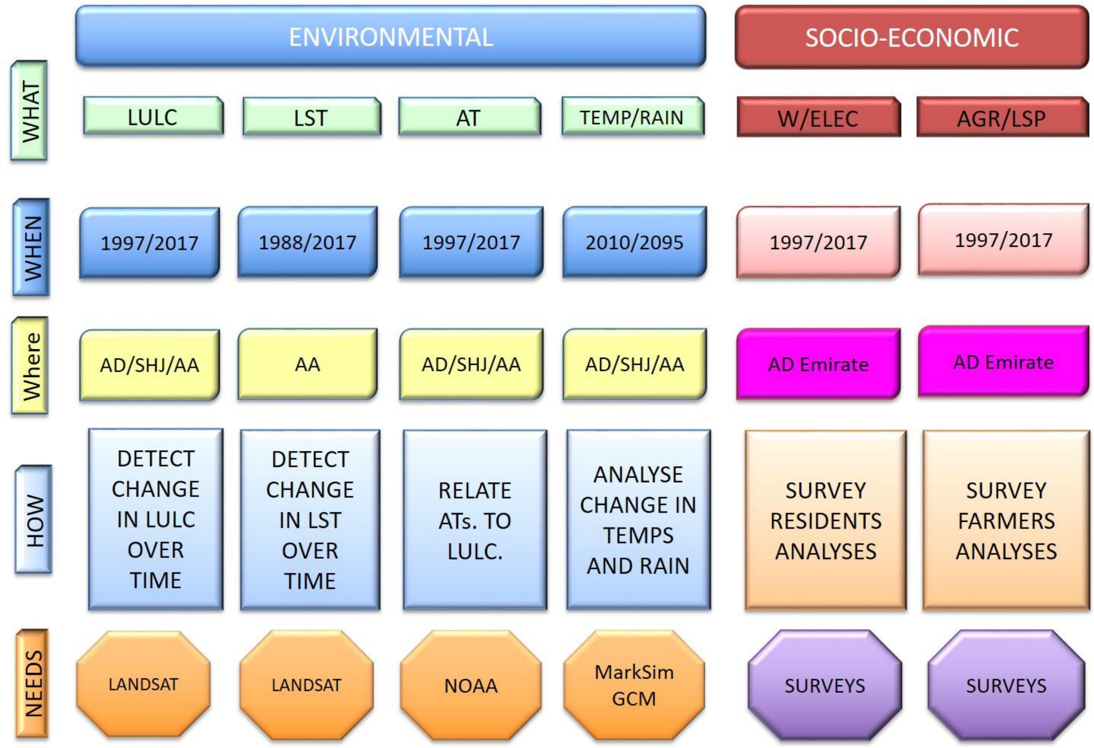


Figure 1.1: Conceptual framework of the study

1.3 Relevant Literature

In recent years, many authors addressed the issue of climate change and its impact on all life sectors. For example, Al-Maamary et al. (2017), reported that in the Arabian Gulf region the current main problem is the uncertainty in determining the impact of climate change, and alleviating it, or even dealing with it. They also added that the current studies are limited in the capability to put up on the uncertainty in regional climate projections. Because of the frequency and intensity of droughts and hot weather conditions in the Middle East it has the tendency to be affected by climate change (Ohunakin et al., 2015). UAE is one of many other Arab countries that depends on tourism for revenue, employment, and foreign currency. The impacts of climate change such as coastal erosion and flooding, saline intrusion, temperature increase, and extreme events would definitely affect tourist attractions and facilities.

One threat to tourism is the large losses in biodiversity caused by high temperature rates. These rates are expected to increase significantly by the end of this century (Tolba and Saab, 2009). Generally, there is lack of models that are used and tested in the region. Also, as researchers in the Arab region, difficulties are faced in data availability and sources of previous related studies. There are few studies that were done on the Arabian Gulf region countries. In Saudi Arabia for example, Almazroui (2011) used regional climate models to study the heavy rainfall event in Jeddah, which helped to generate high-resolution climate variables in that region. Another study done on KSA, found that the temperature increase in the period 2021–2050 is applicable to most locations, with an increase of about 0.4°C in the south and about 0.3°C in the northern parts of the country (Almazroui, 2013). In Oman, during the occurrence of hurricane Gonu in 2007, the total rainfall reached 610 mm near the coast (El Rafy and Hafiz, 2008). This made the scientists pay more attention to the precipitation rates as well as temperature rise in Oman. In their study, Gunawardhana, et al., (2014), daily precipitation and temperature data in Muscat, Oman, were analyzed using a set of climate indices, defined in the RClimDex software package.

The French mathematician Jean-Baptiste-Joseph Fourier, was the first who linked between CO_2 concentration in the atmosphere and earth's temperature in 1824 (McBean et al., 2001), while the scientific measurements showed that the atmospheric CO_2 concentrations were steadily rising in 1958 (Rehan and Nehdi, 2005). The Kyoto Protocol was the first legally binding international commitment to GHG emissions reduction, it was adopted in 1997 and entered into force in 2005 (O'Neill, et al., 2009). Over the last two centuries and by the start of the industrial revolution, the atmospheric CO_2 concentration rose from about 280 ppm to 368 ppm (McBean et al., 2001). This is applicable to other harmful gases emissions. It is expected that the intensity of the climatic events such as El Niños is likely to increase as GHGs increase. Hence, slowing the growth rate of GHGs should reduce the chances of intense tropical storms occurrence (Hansen, et al., 2006). Human influences on the global environment are functioning at extraordinary magnitudes and spatial scales. For example: the level of carbon dioxide increased by 25% and the methane content of the troposphere has doubled since pre-industrial times (Turner et al., 1994).

A study on a sample of people affected by the change in the groundwater sources due to climate change in the period from 1961 up to 1990 was carried by Al-Maamary et al. (2017), to evaluate human exposure to declines in existing groundwater resources. Several areas of the Gulf countries depend heavily on groundwater. The future estimations have shown that all the countries will be suffering from a lack of water availability (Menzel and Matovelle, 2010). This will lead to alteration in many aspects including demand and consumption of water.

For most Arab countries, climate models show lower precipitations and higher temperatures under changing climate conditions, which will lead to major reduction in stream runoff, which will result in reductions in natural water supplies. At the same time, the demand on water is to be increased due to population growth (Lelieveld et al., 2012). The Arab region faces enormous climatic variations, particularly precipitation, which is mainly very low over large areas (RICCAR, 2017). Projections suggest that there is a clear expected warming with more marked increases for RCP8.5 and that climate warming in the region is much stronger in summer than winter (RICCAR, 2017). In the UAE, population is rising steadily and its climate is changing with an increase in atmospheric CO_2 and temperature as well as the abnormalities in rainfall events (Dougherty et al., 2009). In a study by Evans (2009) on the impact of climate change in the Middle East, he reported that the overall temperature is expected to increase between 1.4 to 4°C by the end of the century. The GCMs indicate a significant increase in daily temperatures, which indicate a rise in the risk of severe heat waves (Field et al., 2012).

Climate change projections are created using global climate models. GCMs are used to study a variety of climate attributes, such as surface temperature, atmospheric temperature profiles, rainfall, wind patterns, etc. (RICCAR, 2017). Chou et al. (2014) found that as expected in higher equivalent CO_2 concentrations, larger warming occurs in RCP8.5. Lelieveld et al. (2016) compared the mid-century period (2046 to 2065) and the end-century period (2081 to 2100) with the recent period (1986 to 2005). Based to RCP8.5 scenarios, they found that by the end of the century many countries in the Middle East and Northern Africa in summer are projected to experience a temperature increase more than 6°C compared to the period 1986-2005.

Climate scientists downscale their models to describe limited areas of the world, to offer better understanding, through the use of regional climate models (RCMs) (RICCAR, 2017). Jacob et al. (2014) study also showed a strong and statistically significant warming, with regional differences, in the range of 1 to 4.5°C for RCP4.5 and of 2.5°C to 5.5°C for RCP8.5. This will definitely affect the demand of energy for cooling in buildings.

The UAE’s energy consumption has enormously increased because of high population growth rates and low-energy cost, which makes it one of the highest energy consumers in the world (Radhi, 2009). UAE consumed 52.6 Billion kWh in 2006. Accordingly, the total annual CO_2 emission from the fossil fuels consumption was 137.8 million metric tons. Urbanization in the GCC has been recently known as forms of imported western architecture which makes it difficult to put in harmony with the Arab social, geographical and climatic conditions (Tolba and Saab, 2009). They also reported that high rise buildings, for instance, with their large areas of glass frontage, and enormous energy demand for cooling systems and air conditioning can be seen in all new urban centers such as Dubai and Abu Dhabi.

There are many factors that general energy consumption depends on; climate, physical dwelling characteristics, appliances and system characteristics ownership and occupancy behavior (Sartori et al., 2009). Lebassi et al. (2010) found an irregular increase in summer between the coastal and inland regions of California during the 35-year period (1970 to 2005). Another study focusing on impacts of climate change on the California energy sector by Miller et al. (2008), reported energy-demand growth and increase in summertime electricity consumption for cooling. The situation in developing countries is less depending on cooling technologies, yet serious actions are needed. Because developing countries depend on agriculture in their economy they are more vulnerable to climate change than developed countries (Fischer et al., 2005), and the impacts of climate change will be more severe in tropical semiarid developing countries than other countries in the world.

According to Mendelsohn and Dinar (1999), when adaptation is fully implemented, it was found that results of farm level analyses on the impact and adaptation to climate change showed a huge decline. Crop sensitivity to climate change is vital regional issue that should be taken into consideration as opposing climate conditions can lead to significant alterations in general water consumption (Duulatov et al., 2016). Agriculture’s demand on water has increased with the substantial desert greening programs undertaken by the countries (Sommariva and Syambabu, 2001).

This planet was considerably reshaped by agricultural land-use activities. Forty percent of the global land surface is presently used as cropland or grassland (Popp et al., 2017). Among 733 respondents to a survey made in UK by Pandve et al. (2011), 91.68% respondents commented that global climate is changing. Based on the findings of Lorenzoni and Pidgeon (2006), the third environmental issue most people in Europe worry about is climate change and its importance in relation to other environmental, personal and social issues climate change is considered to be secondary.

To be able to adapt to climate change, farmers with traditional agricultural techniques need to consider climate change as a threat to their production (Quiroga et al., 2015). They also find that the increased temperatures have a direct effect on crop suitability and productivity, and can accelerate the growth of pests and diseases. Adger (1999) in his study on Vietnam, built a conceptual model of social vulnerability to climate change to clearly understand the processes of social adaptation to the influences of climate change in rural agrarian societies, through testing present day vulnerability to extreme events. Based on Ibrahim et al. (2015), agriculture depends on environment to provide humanity with their demand of food and fiber, while climate is the primary controller of agricultural productivity. Over several centuries, the world has witnessed exceptional changes in the speed, scale and spatial extent of changes in the land use (Sivakumar, 2007). Land-use is the human activity on the land, influenced by many factors including; economic, cultural, political, historical, and land-tenure factors (Rozenstein and Karnieli, 2011).

It is common that some plants, animals or birds, which are part of the natural ecosystems, have ecological and biodiversity values (Ksiksi et al., 2006). Recently, the number of species is changing rapidly. In a study by Mousa and Ksiksi (2009), they found that the variation in species number as a result of land use was insignificant. This kind of studies can be conducted using remote sensing techniques. Remote sensing is a feasible option in urban LULC change mapping due to its repetitive coverage, reliability in image quality, cost efficiency and the development of change detection algorithms. Those benefits are important for understanding past, present and future drivers and forms of urban landscape changes (Odindi et al., 2012).

Remote sensing is used in modeling landscape changes. The remotely sensed multi-temporal imagery proved their efficiency in providing wide repetitive coverage over large areas, with useful geospatial and biological information (Abuelgasim et al., 2005). A study by Keshtkar and Voigt (2016) in Central Germany aimed at monitoring the trend of landscape change to simulate future changes in forests and urban areas that are considered as obstructions and inappropriate locations to monitor plant dispersal. Studying the land surface temperature at large scale usually gives a useful insight for both environmental studies and climate applications (Labbi, 2018).

Climate change is happening but studies in the region and specifically UAE are scarce. Although climate change has an impact on the socio-economic status of humans and it can affect their lifestyles in the future, there is lack of human perception of the climatic changes based on the research findings, and this shows the significance of this research. In objective 2, a comparison between LST and AT was to be done to understand the relationship between the increasing air temperatures and the changing land surface temperatures. This was not done because of the burdens that were faced during this research, such as the difficulty in accessing the data. The change in AT through the past 20 years was studied in Chapter 2 with respect to the change in land use / land cover classes in Abu Dhabi, Al-Ain and Sharjah.

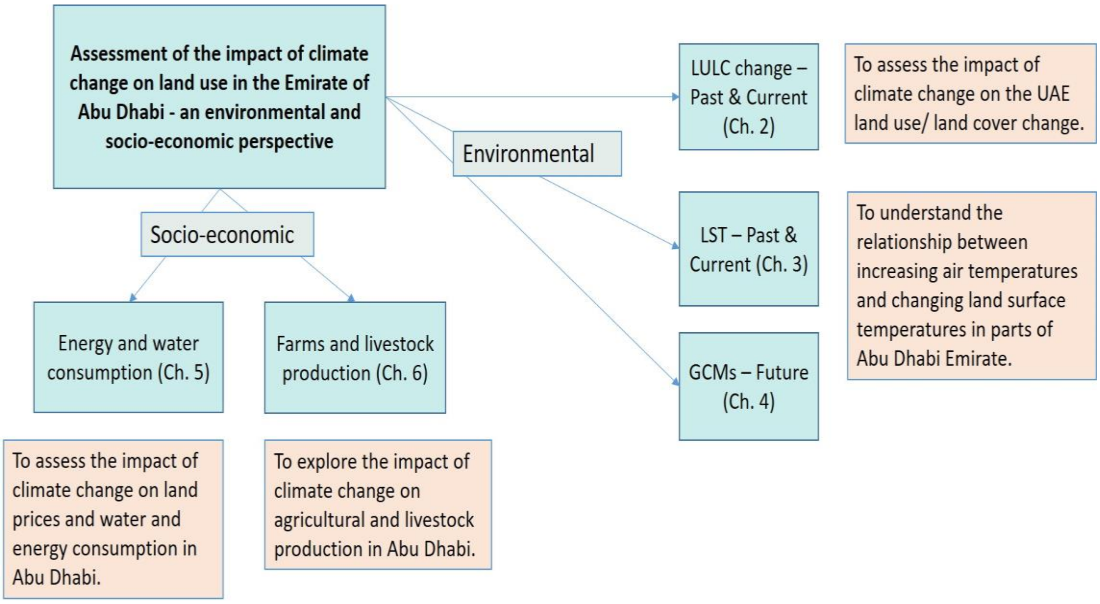


Figure 1.2: Research chapters linked to the objectives

This research is focusing on the impacts of climate change on the Emirate of Abu Dhabi. Adding Sharjah as a city of study in Chapters 2 and 4 will allow a better understanding of the different areas and provides a different environment for climatic assessment. Sharjah has coastal areas similar to Abu Dhabi and it has farms and internal cities and towns that are similar to Al-Ain city in terms of topography and weather. Additionally, Sharjah has a long term climate data that Sharjah Airport weather station can provide data from 1977. Figure 1.2 shows the five chapters included in the study linked to the objectives of the research.

The research was started with a review paper titled: Assessing the Environmental Impact of Climate Change on Desert Ecosystems: A Review. To understand the effect of climate change on the study area. One hundreds forty research papers in topics such as; climate change, desert ecosystems, desert species and remote sensing and GIS were reviewed. The conclusion was that climate change is affecting the desert ecosystems, yet the effect is not very much known in the Arabian Gulf region due to very few sources and lack of research studies covering the area. The paper was published in Advances in Ecological and Environmental Research Journal in February 2020 (Al-Blooshi et al., 2020).

Chapter 2: The Impact of Climate Change on the UAE Land Use

2.1 Overview

Population growth and changes in land-use practices affected the dryland ecosystems of the world. Land use can stimulate changes in communities under climate change. The aim of this chapter is to study the impact of climate change on land use in UAE (Abu Dhabi, Al-Ain and Sharjah) by assessing the change in air temperatures through the different land use classes. The research question is; what is the relationship between the increase in the air temperatures and the change in the land use/ land cover classifications through the past 20 years. Eight classes are recognized in the study area; costal sabkhas, inland sabkhas, mixed class (urban and vegetation), urban, rock outcrops, rocky surfaces, type 1 soil (sand dunes) and type 2 soil (bare land). In 2001, coastal sabkhas, mixed class and urban experienced increase in temperature by (0.67, 1.14 and 1.16) respectively. In 2008 there was a drop in the temperatures from 35.43°C to 33.65°C in mixed class (1.78°C) and from 35.62°C to 33.54°C in urban class (2.08°C).

2.2 Introduction

Climate change impacts are expected to be more noticeable by time, because the region will experience higher stresses (Elhakeem and Elshorbagy, 2015). Based on Verner (2012), climate change forecasts suggest that average temperatures in the Arab countries will increase by up to 3°C by 2050. This increase will lead to different changes in evaporation and rainfall rates, sea level rise, vegetation areas, consumption of water and electricity. UAE is part of the Arabian Peninsula which is an arid region where rapid global population increase joined with urbanization and industrialization led to the deterioration of water quality and shortages of fresh water supplies

(Mohamed and Al-Mualla, 2010). To study the change in climate, LULC is among the best indicators.

Recently, LULC change analysis has become an essential tool used to measure the environmental and ecological consequences of human activities (Flamenco-Sandoval et al., 2007). Industrial breakdown accompanied with LULC change donate globally systemic changes as GHG buildup in the troposphere, and stratospheric ozone depletion (Turner et al., 1994). LULC changes are universal in a way that when combined globally, they ominously affect key aspects of earth system functioning, causing major changes such as; global climate warming (Lambin et al., 2003). Many areas were degraded in the Arab region due to different factors such as drought and urbanization crawling. IPCC reported that over the past two decades, the land surface temperatures warmed at a rapid rate compared to oceans of about 0.27°C vs. 0.13°C per decade (Solomon et al., 2007).

Long trends in temperature and precipitation in the Arabian Peninsula is not clearly known. This is because the region covers a wide range of countries, with poor data availability, quality and consistency in some countries (Zhang et al., 2005; Kwarteng et al., 2009; Nasrallah and Balling, 1993). The United Arab Emirates UAE has narrow arable land, harsh climate, and limited renewable water resources. Consequently, the country has limited land use types. In addition, since 1970s, the human population growth and economic development put an increasing pressure on land use (Ammar, 2013). Human activities influence land use change in various ways; high population density, growing demand of land for agriculture, prohibited forests cutting, and overgrazing (Wakeel et al., 2005; Kadıo˘gulları, 2013; Kennedy and Spies, 2005).

In the UAE, the land use change impacts both water resources and the environment (Ammar, 2013). Land use change for expanding agricultural areas, resulted in direct habitat loss, but also caused fragmentation of remaining habitat and magnified agrochemical inputs into surrounding habitats (Oliver and Morecroft, 2014). In 2008 the total cultivated areas in the UAE have increased to over 200,000 ha compared to 1991 (40,000 ha). This expansion was close to the existing agricultural farming area in Al Ain; by time, the expansion occurs to the other surrounding arable areas (Ammar, 2013).

Recently, population growth and changes in land-use practices affected the dryland ecosystems of the world, which increased the concern over the human impact on drylands (Evans and Geerken, 2004). Varghese and Singh (2016) reported that, Jodhpur region showed that the increase in human population (by 400%) and livestock population (by 127%) during the past century caused a major alteration in land use pattern and put great pressure on surface and ground water resources (Rao, 1996). In the UAE, forestry plantation was made following the government policy to combat desertification and moderate climate affect and to clean the environment with the slogan “greening the desert.” Natural or wildlife forests do not exist in the UAE. Most of the mangrove forest areas are located in Abu Dhabi (305,000 ha) and Dubai (47,000 ha) emirates (Ammar, 2013).

According to Turner et al. (2007), the causes, impacts, consequences, and dynamics of socio-ecological systems, can be better understood through LULCC integrated research across different fields. Mendoza-Ponce et al. (2018) has conducted a research into complex LULCC phenomenon focusing on analyzing historical trends and patterns. Few case studies consider collaborating feedback between LULCC and climate change under different scenarios (Oliver and Morecroft, 2014). Land use change has a close link between access to land as affected by land tenure, and land value. What binds all these together is that land is becoming scarce and essential, which become a principal tool for wealth and income generation (Alqurashi and Kumar, 2013; Muringaniza and Jerie, 2016). Land use can stimulate changes in communities under climate change. For example; extreme climate events, such as intense prolonged drought, can lead to a severe impact on the structure of communities and this is with no doubt facilitated by land use (Oliver and Morecroft, 2014).

Many researchers focused on land use and land cover changes and conducted studies on several parts of the world (Muringaniza and Jerie, 2016). It is believed that land use change is expected to continue to be a major driver especially in the tropics, while the amount of change in temperature is projected to be highest towards the poles (Oliver and Morecroft, 2014). Moreover, some of the studies focused on the reasons behind the occurrence of land use changes through a socio-economic perspective (Muringaniza and Jerie, 2016). The aim of this chapter is to study the impact of climate change on land use in UAE (Abu Dhabi, Al-Ain and Sharjah) by assessing the change in air temperatures through the different land use classes. The research question is; what is the relationship between the increase in the air temperatures and the change in the land use classifications through the past 20 years.

2.3 Methodology

2.3.1 Study Area

This study focuses on average monthly temperatures collected from NOAA (https://www.ncdc.noaa.gov/cdo-web/datatools/findstation) Land-Based Station Data, for Abu Dhabi, Al-Ain) and Sharjah. Each location represents a different bio-climatic zone within the UAE. The study area is shown in Figure 2.1. Because Dubai is located between Sharjah and Abu Dhabi it was included in the area and was covered in the analysis.

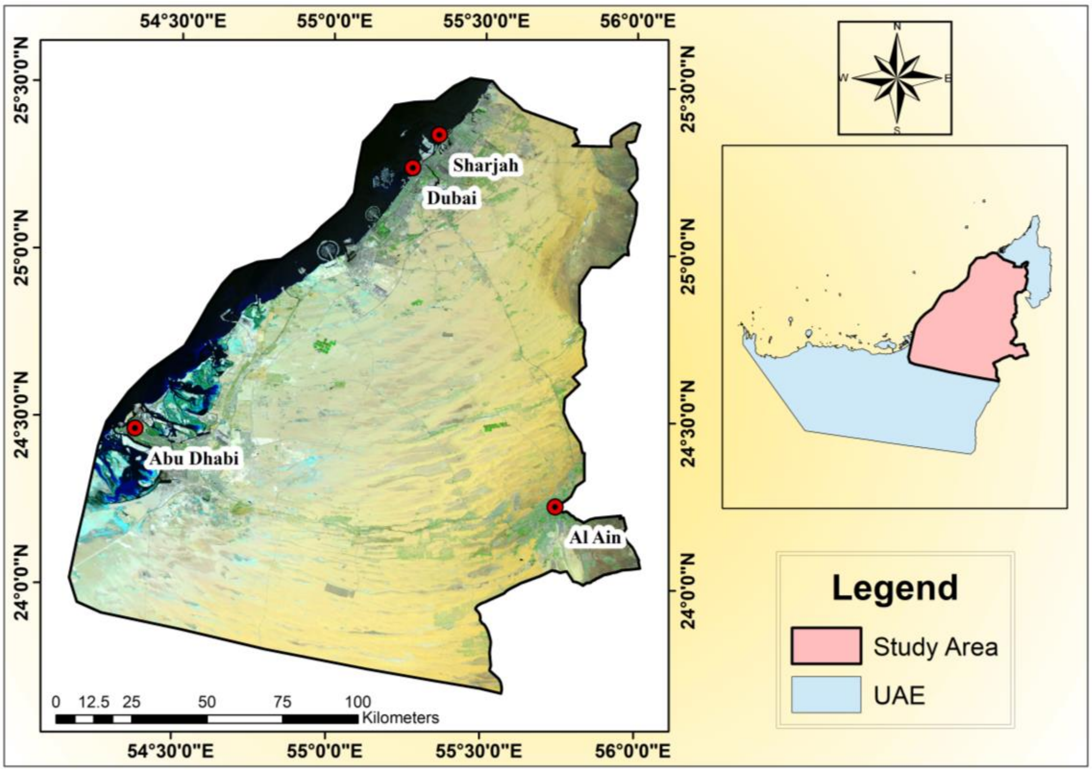


Figure 2.1: Study area (Abu Dhabi city, Al-Ain and Sharjah)

2.3.2 Data and Method

The period of the historical data is between June 1997 and June 2017. In this study, the used Landsat images were downloaded from USGS and captured in summer (see Table 2.1) (USGS, 2018).

Table 2.1: Landsat images used in the study

Image	Path	Row	Date
Landsat 4-5	160	42/43	20-06-1997
Landsat 4-5	160	42/43	02-08-2001
Landsat 4-5	160	42/43	17-06-2008
Landsat 8	160	42/43	16-06-2013
Landsat 8	160	42/43	11-06-2017

The average monthly temperatures of the three cities (Abu Dhabi, Al-Ain and Sharjah), was downloaded from NOAA (https://www.ncdc.noaa.gov/cdo-web/datatools/findstation). NOAA provides weather data from airport stations. The study period was decided to be a 20 years' period from 1997 to 2017. That is due to the availability of the historical weather data and accordingly the Landsat images were downloaded. Table 2.2 shows the airport station sites that average temperature used in the study are taken from.

Table 2.2: List of airport stations sites with their geographic coordinates

Location No.	City	Lat	Long
1	Abu Dhabi	54.651	24.433
2	Al-Ain	55.609	24.262
3	Dubai	55.364	25.255
4	Sharjah	55.517	25.333

The following steps were followed for the Landsat images downloaded from USGS:

1. Image mosaic to combine the two images in different rows (42/43) in one.

2. Atmospheric correction was done to reduce the effects of atmospheric components and to retrieve spectral reflectance from hyperspectral radiance images. Using FLAASH in ENVI which incorporates the MODTRAN radiation transfer model to compensate for atmospheric effects.

3. An unsupervised classification was done using k-mean algorithm using 10 iterations to generate eight recognized classes which were combined from 10 classes. The recognized classes were; costal sabkhas, inland sabkhas, mixed class (vegetation and urban), urban, rock outcrops, rocky surfaces,

type 1 soil (sand dunes) and type 2 (bare land). Classification maps are shown in Figure 2.2.

4. Ground truthing was done with a combination of two methods; visiting the areas that are reachable and visualizing the unreachable areas using google earth high resolution images with historical tool.

The average monthly temperatures downloaded from NOAA, were used to create maps that show the differences in atmospheric temperatures in the three cities (Abu Dhabi, Al-Ain and Sharjah). The following steps were done:

1. Interpolation between the 4 stations (Abu Dhabi, Al Ain, Dubai and Sharjah) was applied.
2. The atmospheric temperature maps were overlaid with the classification maps to find the attribute table of the classes in relation to atmospheric temperatures.
3. To generate the maps, standardization for the temperature was applied to make sure that all the maps show the same pattern of temperature change, where the minimum temperature was set to 32°C and the maximum to 39°C (see Figure 2.3).

2.4 Results

The results show that there is a trend of temperature increase for all classes (Figure 2.4). Year 2001 experienced an increase in the temperatures through all classes. The increase is from 33.70°C to 34.37°C by 0.67°C for class coastal sabkhas and from 34.29°C to 35.43°C by 1.14°C for vegetation and urban mixed class.

Table 2.3: Mean monthly temperature (°C) change over time in the different eight classes

Year	Coastal Sabkhas	Inland Sabkhas	Mixed	Urban	Rock out Crops	Rocky Surfaces	Sand Dunes	Bare Land
1997	33.70	33.71	34.29	34.46	34.25	34.11	34.25	34.47
2001	35.37	35.38	35.43	35.62	35.52	35.60	35.53	35.82
2008	32.77	32.77	33.65	33.54	33.47	33.49	33.49	33.46
2013	32.62	32.70	33.16	33.47	33.38	33.39	33.38	33.25
2017	34.95	35.11	35.67	35.76	35.68	35.69	35.77	35.62

Urban class the temperature was 34.46°C in 1997 and it has increased to 35.62°C by 1.16°C. In 2008 there was a drop in the temperatures from 35.37°C to 32.77°C for coastal sabkhas 2.6°C, from 35.43°C to 33.65°C in mixed class 1.78°C and from 35.62°C to 33.54°C in urban class 2.08°C. Another slight drop was noticed in 2013 by 0.15 degrees in coastal sabkhas and by 0.49°C and 0.07°C for mixed and urban respectively. In 2017, the temperatures increased again by 2.33°C from 32.62°C to 34.95°C in coastal sabkhas, 2.51°C from 33.16°C to 35.67°C in mixed class and by 2.29°C from 33.47°C to 35.76°C in urban class (see Table 2.3).

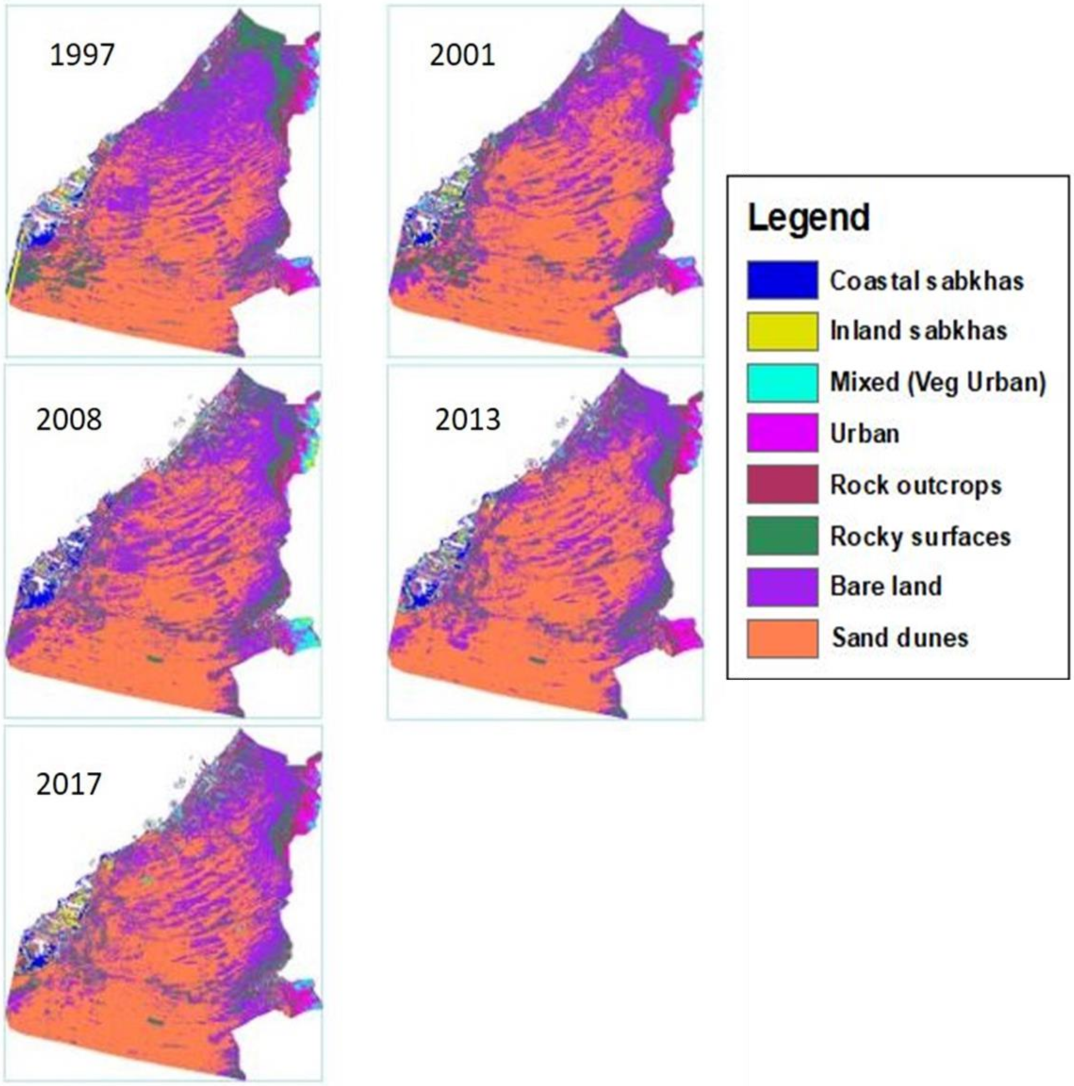


Figure 2.2: The eight recognized classes change in the study area over time

Table 2.4: Area (Km^2) change over time in the different eight classes

Year	Coastal Sabkhas	Inland Sabkhas	Mixed	Urban	Rock out Crops	Rocky Surfaces	Sand Dunes	Bare land
1997	338	244	404	771	1155	2627	6969	9107
2001	335	209	384	770	1191	2199	5869	10746
2008	288	288	732	956	1302	2121	6195	9552
2013	319	197	404	945	1230	1915	5500	11302
2017	181	309	565	969	1277	2042	6050	10324

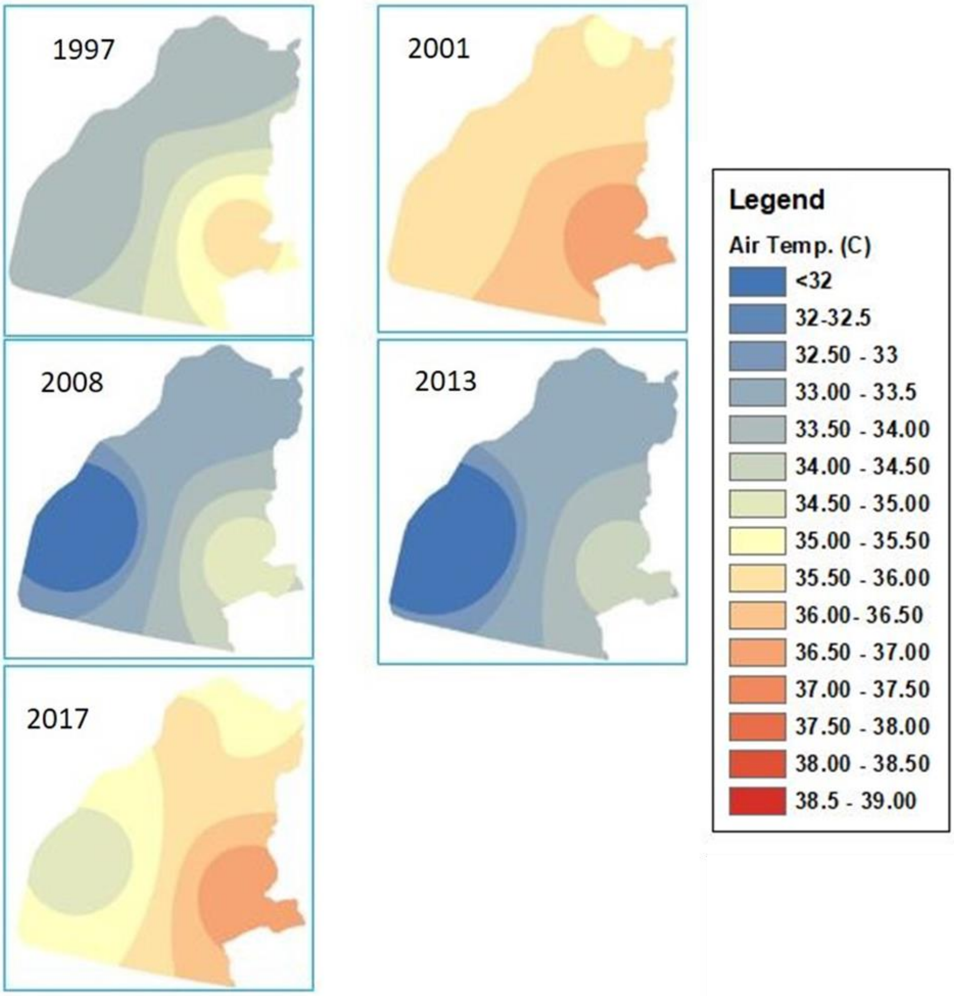


Figure 2.3: Mean temperature change in Abu Dhabi, Al-Ain and Sharjah over the study period

The area has changed through the eight classes from 1997 to 2017. The results show that coastal sabkhas has decreased in area from 338 km^2 in 1997 to 181 km^2 in 2017. The mixed class (urban and vegetation) increased from 404 km^2 to 732 km^2 in 2008 then drops to 565 km^2 in 2017. The urban class increased from 771 km^2 in 1997 to 969 km^2 in 2017, while rocky surfaces decreased from 2627 km^2 to 2042 km^2. Bare land area has increased from 9107 km^2 to 10324 km^2 in the past 20 years (see Table 2.4).

2.5 Discussion

This study results show that the mixed class (urban and vegetation) increased from 404 km^2 to 732 km^2 in 2008 then drops to 565 km^2 in 2017. It was hard to separate vegetation from urban areas because the reflection of both is similar due to planted areas surrounding built-up areas. Figure 2.4 shows the change in the mean monthly temperature over time. The explanation of the increase in the area from 1997 and 2008 is because of the spread of the urban areas through UAE. The drop in the area can be due to loss of vegetation in abandoned farms. Urban areas increase by 198 km^2 in twenty years. Figure 2.5 shows the land cover classes over the study period. The results showed that, in 2001, the coastal sabkhas, the mixed class and the urban areas experienced increase in temperature by (0.67, 1.14 and 1.16) respectively. While in 2008 the same classes became cooler by (2.6, 1.78 and 2.08) respectively. Coastal sabkhas decreased in area, while both mixed and urban classes has increased from 1997 and 2008. Coastal sabkhas are located on the coasts of Abu Dhabi, which has dramatically changed in terms of urbanization in the past 20 years. The artificial islands and other projects along the coast has undeniably influenced the coastal sabkhas. Only (36%) Of the 150 km of coastal sabkha present along the Abu Dhabi coastline in the 1960s, remains today (Lokier, 2013).

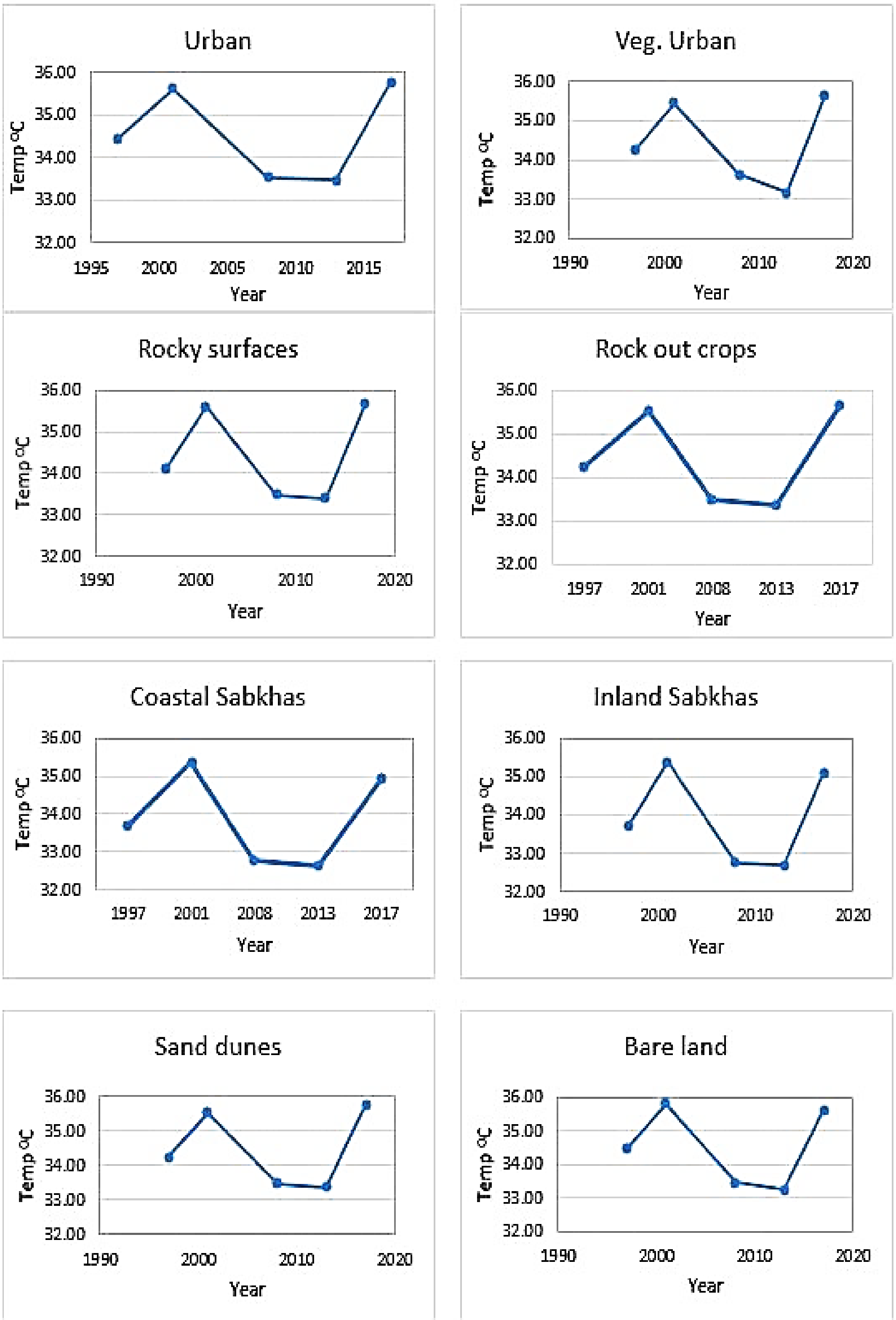


Figure 2.4: Change in the mean monthly temperature over time

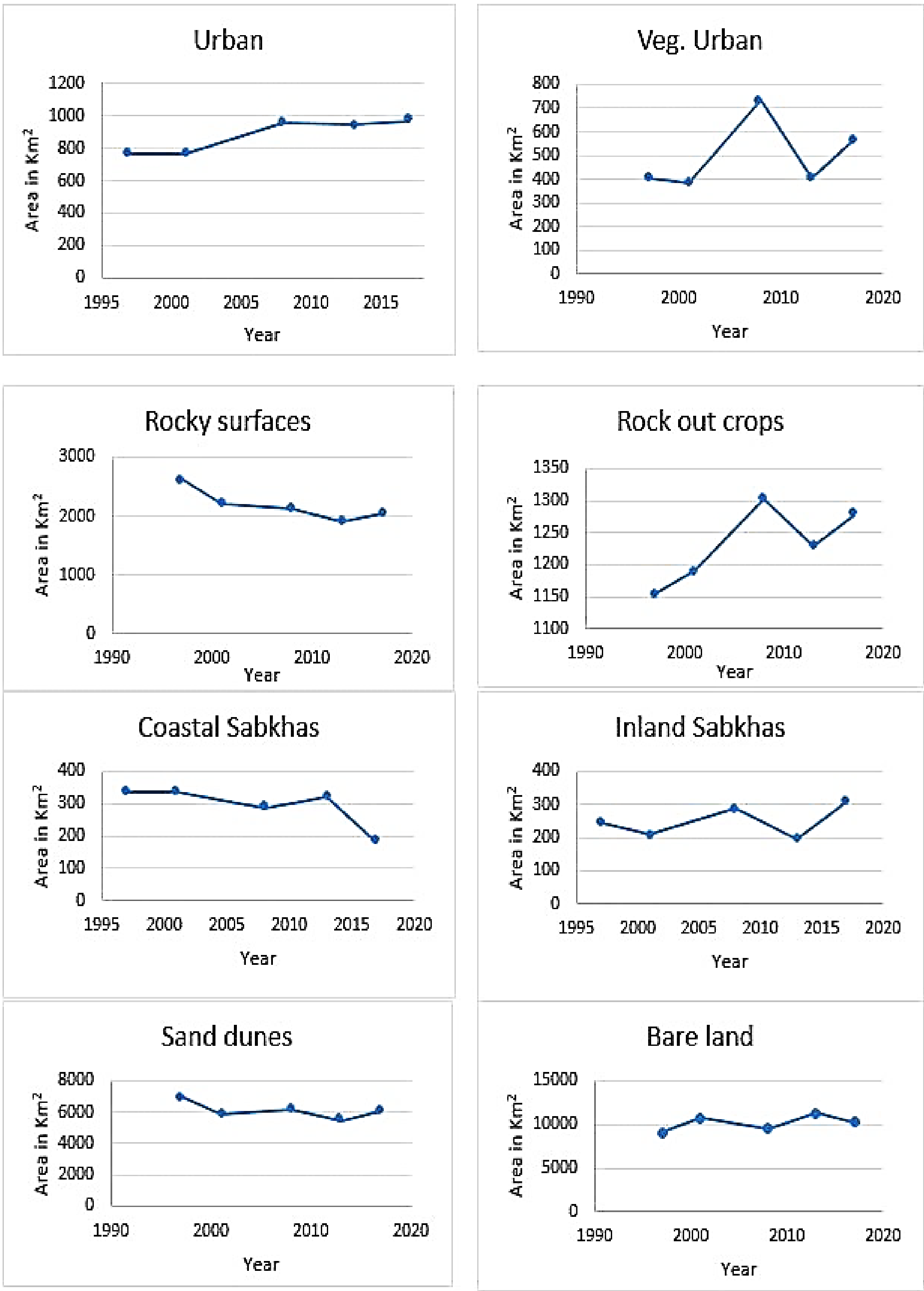


Figure 2.5: The change in land cover classes area over time

Figure 2.6 shows the mean temperature and area comparison in the urban class and the mixed class (vegetation and urban). In UAE, vegetation comes with urbanization. Buildings and roads are often accompanied with plantation except in industrial areas. The drop in temperature can be a reason of the increase in vegetation in the mentioned areas. In 2017, the mixed and the urban classes became warmer. It is probably because of the UHI effect or other factors. Figure 2.7 shows the change in the eight recognized classes areas over the study period.

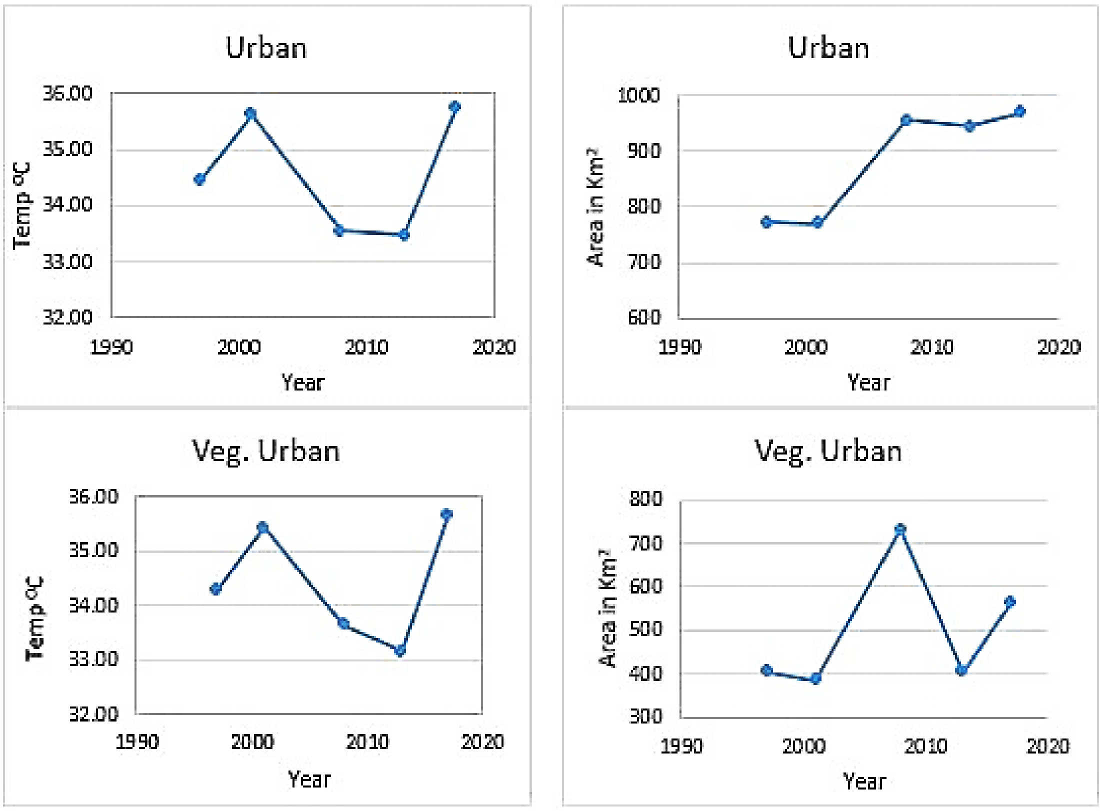


Figure 2.6: Mean temperature and area comparison (Urban and mixed classes)

On a case study in Altay Prefecture, China by Fu et al. (2017), it was found that the primary land use change was the spreading out of cropland and the drop of bare land areas. Where humans started to exploit desert resources, instead of exploiting mountain resources.

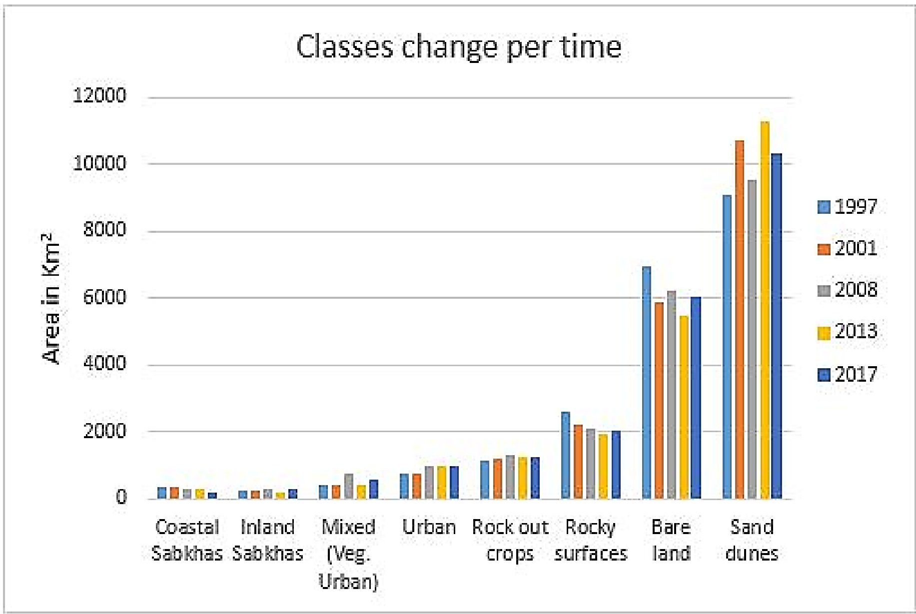


Figure 2.7: Change in classes areas over time

In Abu Dhabi, Managed lands (plantation and improvements) from 1990 to 2000, expanded due to regular social forestry and plantation activities (Yagoub and Kolan, 2006). This was not noticed in the findings due to different study period. In the same study, they reported that, built-up areas have been increased from 1990 to 2000, which is a period of rapid urbanization (Yagoub and Kolan, 2006). The results show that from 1997 to 2001 the urban area was the same and increase by 184 km^2 in the next seven years (in 2008). In a study by Shanableh et al. (2018) they found that there is an overall expansion of built areas and shrinkage of open areas in Sharjah during the study period of 1976–2016 (Shanableh et al., 2018). The results showed expansion of urban areas and decrease in both rocky surfaces and sand dunes (Table 2.4). The explanation can be the urban and industrial expansion, where different types of rocks in mountainous areas are crushed and used in building materials. Sand dunes soils are used as rangelands for camels, the increase in temperatures in the past 20 years can lead to abandoning the areas that lost the types of plants that camels feed on.

2.6 Conclusions

Land use change is a good indicator to study the potential climatic changes. Human activities influence land use change in different ways such as the increasing populations, high demand for agriculture and urban expansion. Trends in temperature and rainfall in the Arabian Peninsula is hard to clearly detect due to limited related studies. In 2001 Abu Dhabi, Sharjah and Al-Ain experienced an increase in the temperatures through all classes. The increase was 0.67°C for coastal sabkhas and 1.14°C for vegetation and urban mixed class. In 2017, the temperatures increased again by 2.33°C in coastal sabkhas, by 2.51°C in mixed class and by 2.29°C in urban class. The area of coastal sabkhas has decreased from 338 km^2 in 1997 to 181 km^2 in 2017. While the mixed class increased from 404 km^2 to 732 km^2 in 2008 then dropped to 565 km^2 in 2017. The urban class increased from 771 km^2 in 1997 to 969 km^2 in 2017, while rocky surfaces decreased from 2627 km^2 to 2042 km^2. This can be related to the use of rocks in building materials to fulfil the urbanization and increasing population demand. Detailed research in the area to monitor the change in land use due to climate change and vice versa is a good opportunity for the researchers who are interesting in the region.

Chapter 3: Impact of Desert Urbanization on Urban Heat Islands Effect

3.1 Overview

The United Arab Emirates (UAE) has undergone major urban transformation after the establishment of the country in 1971. One noticeable change is urban expansion in terms of massive infrastructure, including new residential areas, highways, airports, and sophisticated transportation systems. Major landscape changes and disturbances, such as urban development, are among the major contributors to global climate change. Urban areas can be 3.5–4.5°C warmer than neighboring rural areas, a phenomenon known as urban heat islands (UHIs). As such, urban development in the UAE was expected to follow a similar pattern and to be a major contributor to the country's impact on global climate change. Analyses of multi-temporal (1988–2017) land surface temperature (LST) data obtained from Landsat satellite datasets over a desert city in the UAE showed unexpected results. Urbanization of desert surfaces in the study area led to a decrease of 3–5°C in the overall LST. This was attributed to the associated expansion of green spaces in the newly developed urban areas, the expansion of date plantations and perhaps a cooling in the previously desert surface. Therefore, the UHI effect was not well demonstrated in the studied desert surfaces converted to urban areas.

3.2 Introduction

Knowledge of land surface temperature aids understanding of the temporal and spatial variations in global land surfaces (Li et al., 2013). This is because LST and emissivity are vital parameters in earth surface characteristics for energy budget estimation and land cover assessment (Srivastava et al., 2010). Global LST estimates have commonly been retrieved from high to medium and low spatial resolution remote sensing data (Tomlinson et al., 2012). LST data are typically retrieved from raw Landsat datasets by converting the digital number values of the thermal bands into absolute radiance values (Chander et al., 2009; Weng, 2009). These radiance values are then used to find satellite brightness temperatures, calculated under the assumption of unity emissivity and using pre-launch calibration constants (Chander et al., 2009; Weng, 2009, Estoque et al., 2017). Emissivity-based methods have been applied to urban areas (Nichol, 2009) and vegetation cover–based methods to agricultural areas (Merlin et al., 2010).

Current understanding of spatial thermal patterns and their association with surface characteristics is based on numerous studies of urban surface temperatures over the past two decades (Buyantuyev and Wu, 2010). Based on Zhang et al. (2017), urban areas are generally 3.5–4.5°C warmer than surrounding rural areas. Seto et al. (2012) projected that more than 5.87 million km^2 of land globally will probably be converted into urban areas by 2030, and 20% of this area has a probability of less than 75% of further urban expansion. Buyantuyev and Wu (2010) used detailed land-cover maps with reasonably similar surfaces to help in measuring temperature gradients across a region. This is because surface temperature is uniquely related to surface properties. Estimating thermal conditions of land surface using satellite images requires the relationship between surface temperature, surrounding topography, and land use and land cover to be determined (Muthamilselvan et al., 2016; Weng, 2009).

Cities experience direct environmental impacts, such as uneven effects from temperature increases, variations in glacial melt, and sea-level rise. Possible future increases in temperature are expected to worsen the urban heat island (UHI) effects (Corburn, 2009), where cities become warmer than their surrounding area (Choudhary et al., 2019; Stewart and Oke, 2012). This warming is of particular concern for urban areas due to the UHI effects (Skelhorn et al., 2016). The UHI effect results from the retention of solar energy in building materials during the day and lower rates of radiant cooling at night. Urban areas commonly experience lower wind speeds, less convective heat loss and evapotranspiration, and more energy from surface warming (Wilby, 2007). As a product of urbanization and industrialization, UHI is believed to be one of the main dilemmas of the century (Shen et al., 2016).

Rapid urbanization has led to the replacement of natural landscapes, which can significantly change the surface radiation, thermal properties, and humidity (Wang et al., 2007). Transformation of natural land cover and the need for urban materials lead to climatic changes (Muthamilselvan et al., 2016). According to Buyantuyev and Wu (2010), the UHI effect occurs when land cover is transformed, mostly via the replacement of natural vegetation and agricultural land by concrete, asphalt, and building walls related to urban land uses. Extreme heat in cities is constantly generated and released into the atmosphere by building infrastructure and transportation (Bonan, 2015). Urban areas have consequently become vital drivers of local and regional climatic and environmental changes, with harmful consequences for social and ecological processes (Wu, 2008).

Commercial and residential buildings, roads, and parking lots covered by impervious surfaces worsen the UHI effect, whereas vegetation, such as trees, grass, and shrubs, can alleviate it (Cao et al., 2010). Al-Yaqoob (2012) found that large parks in Dubai City had significantly lower temperatures than the rest of the city during summer. Increasing the proportion of green spaces, such as public parks, gardens, trees, and green roofs, is an effective strategy for urban areas to adapt both climate change and the UHI (Bowler et al., 2010; Cao et al., 2010; Noro and Lazzarin, 2015). The objective is to detect and study the change in LST with respect to the change in Land cover in the past 30 years in Al-Ain City.

3.3 Methodology

3.3.1 Study Area

Al-Ain City is located in the eastern part of the Emirate of Abu Dhabi, United Arab Emirates (UAE). The area is characterized by an arid climate of extremely hot summers and warm winters, with an average annual temperature of 27°C and a mean annual rainfall of 96.4 mm (Jorgensen and Al-Tikiriti, 2003). The city is considered one of the largest oases in the Arabian Peninsula. The study area covered the airport area in the northwest, Buraimi border (Oman) in the northeast, central district in the east, Sanaeya industrial area in the southeast, Maqam in the west, and Jabal Hafeet and cement factory in the south. The central residential area includes some palm plantation farms and parks. Figure 3.1 shows the Landsat false color images of the study area in Al-Ain City.

3.3.2 Data and Method

Landsat images captured during the summer (June 18, 1988; June 12, 1994; August 2, 2001; June 16, 2013 and June 11, 2017) were used in this study (Table 3.1) (USGS, 2018). Images were selected during the summer to portray the peak LST of the study area.

Table 3.1: Landsat images used in the study

Image	Path	Row	Date
Landsat 1-5	160	43	11-06-1988
Landsat 4-5	160	43	12-06-1994
Landsat 4-5	160	43	02-08-2001
Landsat 8	160	43	16-06-2013
Landsat 8	160	43	11-06-2017

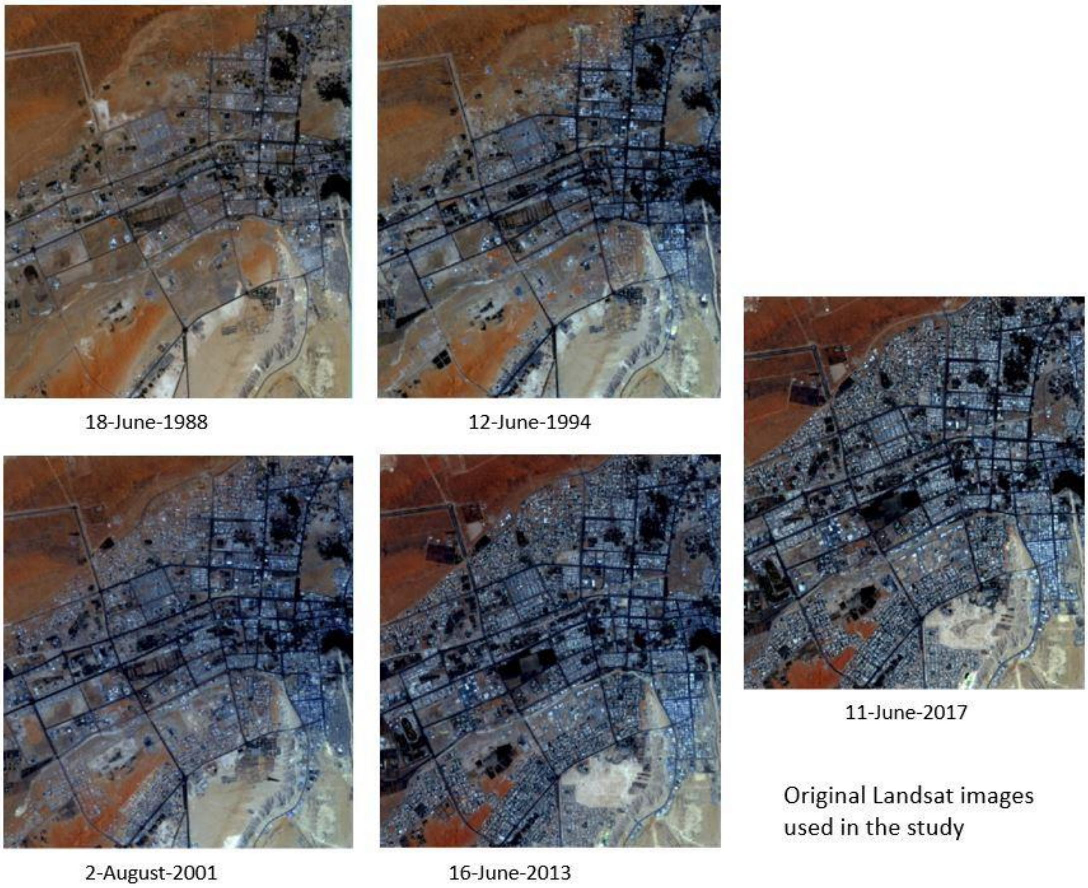


Figure 3.1: Landsat false color images of the study area in Al-Ain City

The image processing workflow shown in Figure 3.2 was followed:

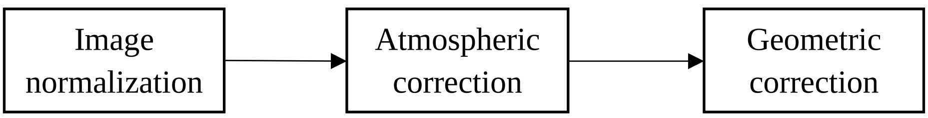


Figure 3.2: Image processing workflow followed in this study

1. Image normalization was applied to eliminate the effect of different sensors and dates. The image normalization techniques developed by Hall et al. (1991) were used to reduce artificial LST changes introduced by sensor technology, illumination, and viewing geometry changes on the thermal bands of the images.
2. Using the equation (mb1 + b). m = (Br Dr) / (Bs Ds), b = (Dr x Bs) (Ds x Br) / (Bs Ds), b1 is the thermal band of the sub image, Br is the mean temperature of the bright pixels of the reference image, Dr is the mean temperature of the dark pixels of the reference image, Bs is the mean temperature of the bright pixels of the sub image, Ds is the mean temperature of the dark pixels of the sub image. Corrected values are shown in Table 3.2.

Table 3.2: Al-Ain City normalization equation variables

	1994	2001	2013	2017
Bs	321.23	322.11	328.03	333.168
Ds	311.78	309.44	307.99	311.09
M	1.614	1.204	0.761	0.691
B	-187.457	-56.685	81.482	100.989

3. Atmospheric correction and LST retrieval was done. LST retrieval from satellite data is considered an important but challenging topic in thermal studies of urban environments (Nassar et al., 2017). A single-channel algorithm developed by Jimenez-Munoz et al. (2009) was employed, which includes an updated fit using MODTRAN4 radiative transfer code (Berk et al., 1989). This algorithm has proven its effectiveness for Landsat 8 thermal infrared sensors (band 10) (Jimenez-Munoz et al., 2014). In this algorithm, the emissivity effects were corrected using an approach developed by Snyder et al. (1998).

LST values were then converted from Kelvin to degrees Celsius. Table 3.3 shows the corrected mean temperatures.

Table 3.3: Al-Ain City corrected mean temperatures in study period

Temp	1988	1994	2001	2013	2017
K	326.52	325.59	325.68	328.07	327.83
°C	53.37	52.44	52.53	54.92	54.68

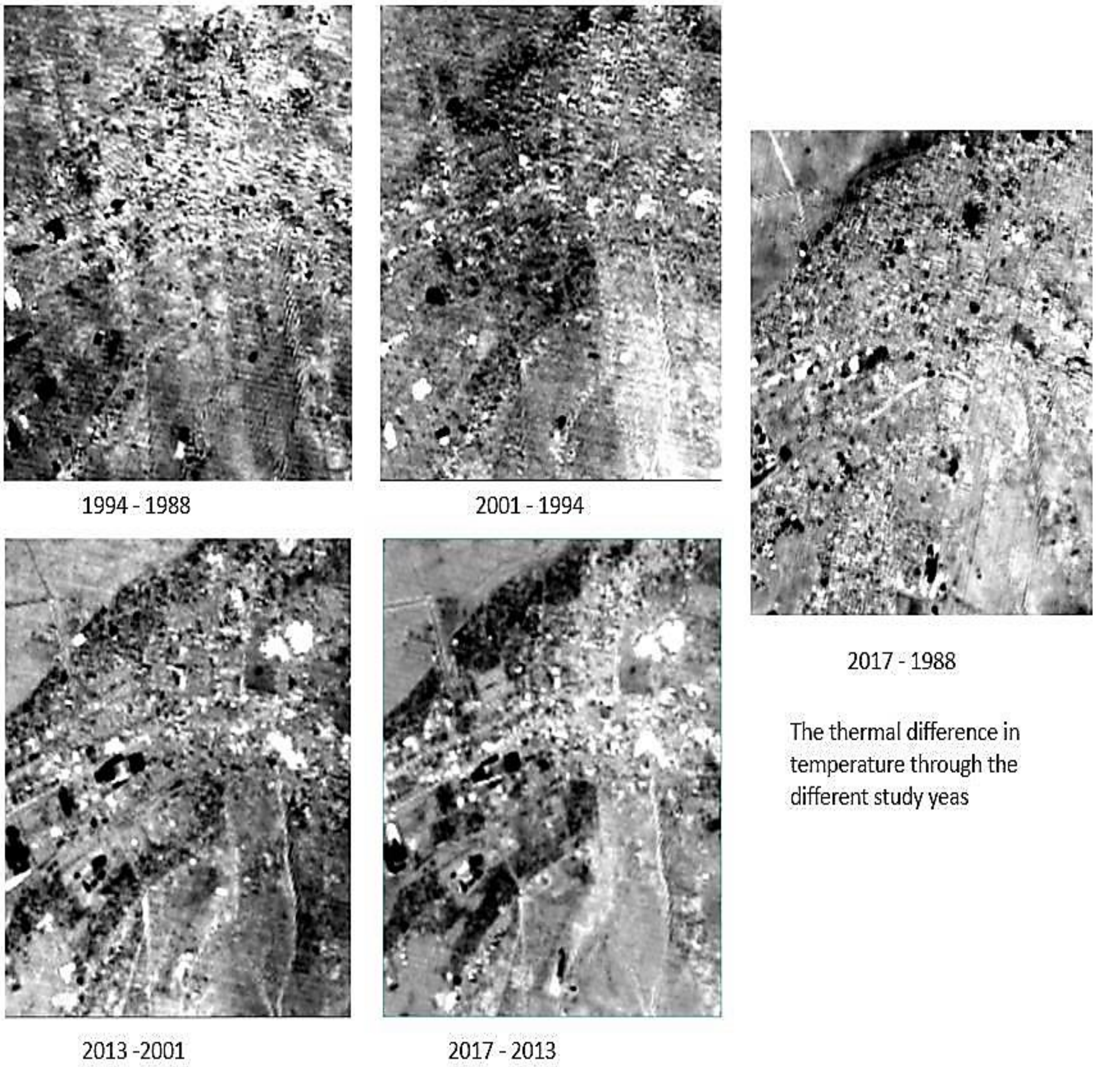


Figure 3.3: Thermal difference images of Al-Ain City throughout the study period

4. Image warping was performed to locate and match the tie points in a base and warp image to ensure that they were in the same location that was changed after normalization. The thermal differences are shown in Figure 3.3.
5. Raster color slicing was applied by setting the temperature change value based on multiple trails and chose the most likely proper values for each difference image. Blue color indicates the cooler areas and red indicate the warmer areas (Figure 3.4).

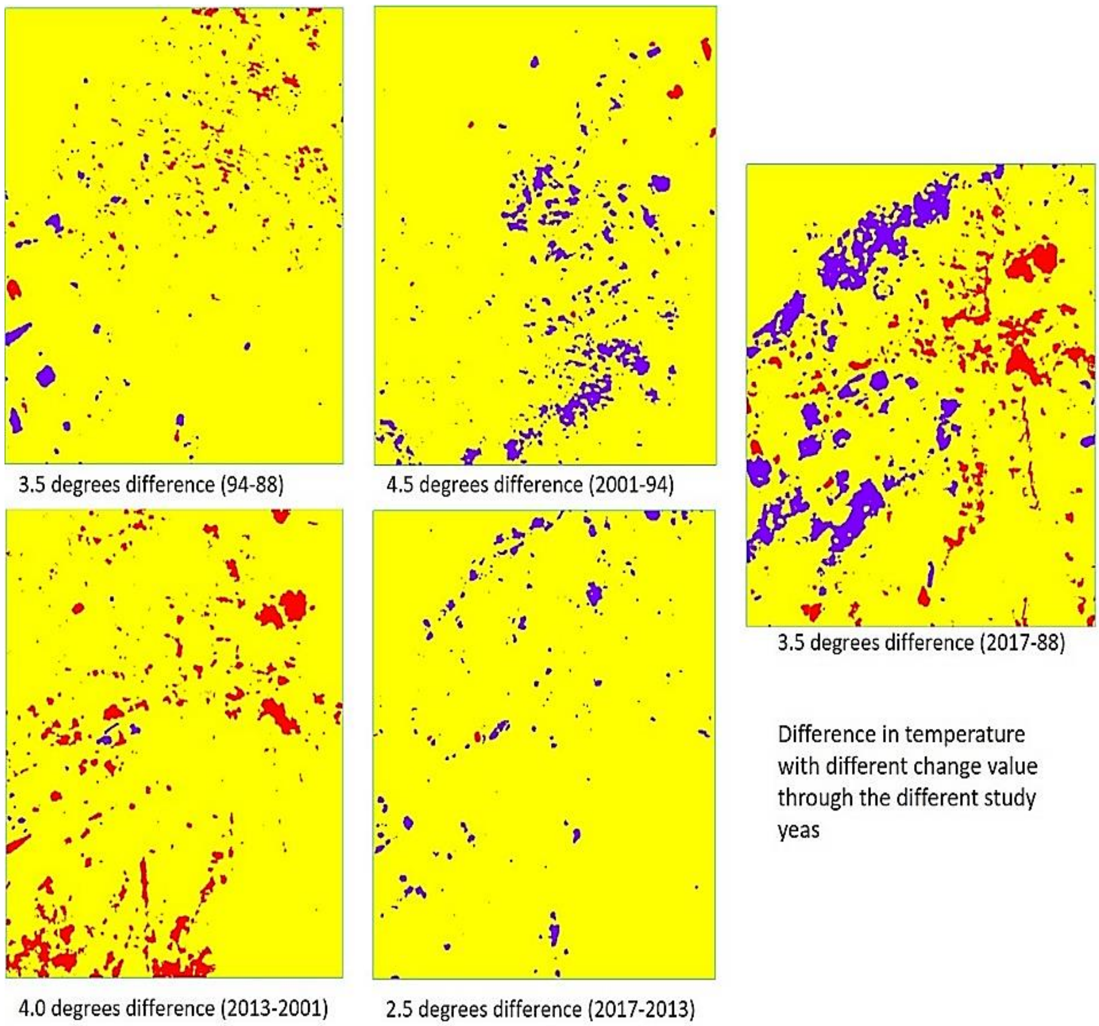


Figure 3.4: Difference in land surface temperature in Al-Ain City throughout the study period

6. The green space areas in km^2 of the study area was found using NDVI by applying the equation (NIR – R) / (NIR + R), taking into consideration that for images taking from Landsat 4-7, NIR is band 4 and R is band 3 while in Landsat 8 the NIR is band 5 and R is band 5 (see Table 3.4).

Table 3.4: Green spaces in the study area

Year	Area (km^2)
1988	2.4
1994	3.3
2001	1.1
2013	8.7
2017	13.53

3.4 Results

The mean LST in Al-Ain city has increased by 1.31°C from 53.37°C in 1988 to 54.68°C in 2017. The difference in LST from 1988 to 2017 was 3.5 degrees the largest difference is from 2001 to 1994 by 4.5 degrees (Figure 3.4). Table 3.5 shows the changes in mean temperature in four areas in Al-Ain City, namely the airport area, Falaj Hazzaa, Sanaeya industrial area, and Maqam rugby club.

Table 3.5: Mean temperature change (°C) in Al-Ain City

Year	Airport	Falaj Hazzaa	Sanaeya	Rugby club
1988	56.85	53.99	50.00	53.64
1994	55.69	52.61	49.58	53.85
2001	52.80	49.91	51.06	52.66
2013	54.88	50.24	53.72	49.49
2017	53.36	48.89	54.15	49.29

The temperature in the airport area decreased by 3.49°C from 1988 to 2017. In Falaj Hazzaa, the temperature decreased by 5.1°C between 2017 and 1988. In contrast, the temperature in Sanaeya has increased by 4°C since 1988. The temperature in the rugby club area decreased by 4.39°C during the study period. It was noticed that the green space in the study area over the study period decreased in 2001, was 3.3 km^2 in 1994 and dropped to 1.1 km^2 in 2001 (Table 3.4).

3.5 Discussion

Taha (1997), reported that the hottest urban surfaces are paved areas during both day and night because of their high thermal inertia, which allows them to absorb and store more sunlight. In addition to the presence of factories, metal workshops, and other related services in the industrial area (Sanaeya), the high density and high traffic as well as the absence of plantations and green areas, Sanaeya experienced increased temperature compared to other areas in Al-Ain. The rugby club in Maqam was established in 2007, and the plot was previously bare land. Changes in temperature could have been due to the vegetation cover in the rugby course and surrounding urbanized areas. Figure 3.5 shows the temperature trends in Al-Ain City.

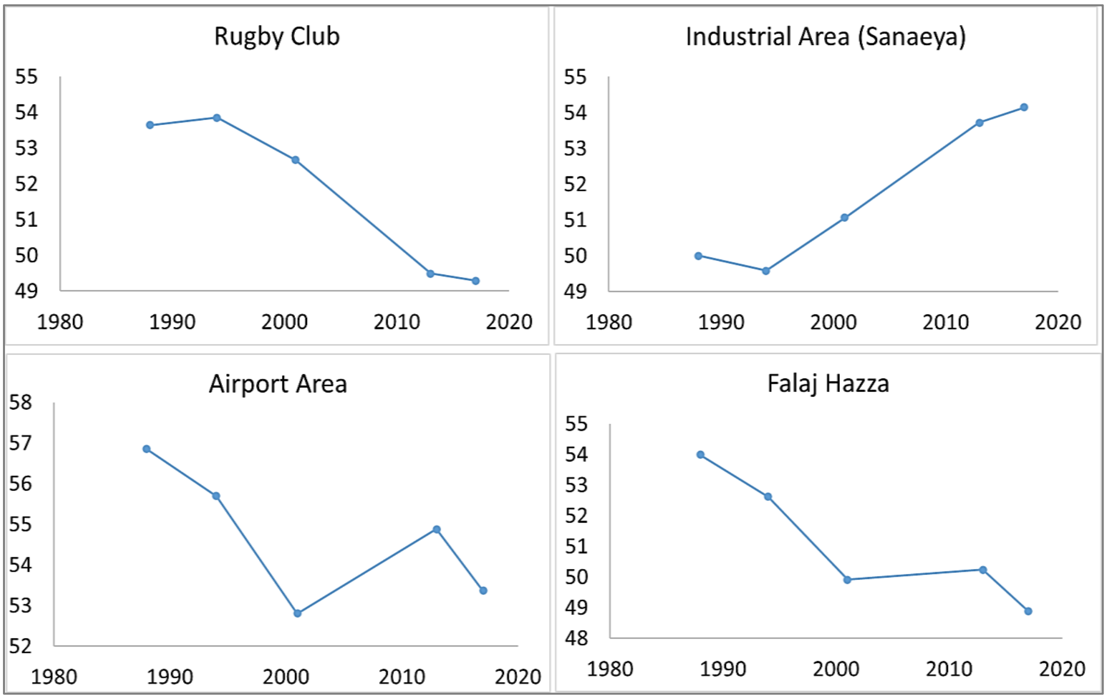


Figure 3.5: Temperature trends over the study period in Al-Ain City

In a study by Lazzarini et al. (2013) on Abu Dhabi city, they found that in desert area the UHI phenomenon is commonly inverted because of the high amount of vegetation in urban areas compared to suburban areas where bare ground and sand are found. They also reported that, during the night, the temperature of the different surfaces drops and the suburbs become cooler compared to downtown areas; consequently, the typical UHI effect can be detected only at night (Lazzarini et al., 2013). The difference in LST from 1988 to 2017 was 3.5 degrees the largest difference is from 2001 to 1994 by 4.5 degrees. This period experienced a drop in the green area which can explain the big variance in LST. The seasonal variation can be noticed clearly in downtown vegetated areas. vegetation is stressed due to high temperatures in summer months, accordingly NDVI values drop (Julien et al., 2011). In this study, the green space in the study area over the study period decreased in 2001 (Table 3.4). This decrease can be due to seasonal changes. The 2001 image was taken in August, whereas the other images were taken in June. It was not possible to use an image of

June 2001 because of the defects in the images from that month. The findings of a study by Nassar et al. (2017) on Dubai, showed that LST decreases when the urban areas are planted and the amount of green space influence the urban areas. In exception of the decrease in 2001, the green area was increasing with time. Which can explain the decrease in LST.

3.6 Conclusions

Urbanization is generally thought to lead to the replacement of natural landscapes, resulting in changes in surface radiation, thermal properties, and humidity. Urban areas can be 3.5–4.5°C warmer than neighboring rural areas due to the UHI effect. Contrary to previous studies, urbanization of desert surfaces in this study did not show a pronounced UHI effect. Generally, a decrease in LST was observed rather than an increase in the studied urban areas compared to surrounding desert surfaces. LST decreased by 3.49 in the airport area and 5.1°C in Falaj Hazzaa from 1988 to 2017. Green areas, such as the rugby club, also experienced a temperature decrease of 4.39°C over the study period. In contrast, Sanaeya industrial area has experienced an increased LST of about 4°C since 1988. The overall decrease was likely primarily due to a significant increase in urban vegetation, such as trees, public parks, and lawns in residential areas. The Sanaeya industrial area showed a classical UHI due to the absence of such urban vegetation cover.

Chapter 4: Modeling Current and Future Climate Change in the UAE using Various GCMs in MarksimGCM

4.1 Overview

Changes in climate have impacts on natural and human systems on all continents and across the oceans. Most countries, including the UAE, are expected to experience a huge impact of climate change, due to the undergoing rapid growth and huge urban developments. Representative Concentration Pathways, or RCPs, represent the latest generation of scenarios that are used as potential inputs into climate models to show imposed greenhouse-gas concentration pathways during the 21st century. Four emission scenarios have been used for climate research; namely RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5. This study focuses on the prediction based on RCP 4.5 and RCP 8.5. The aims of this study are to assess different RCPs and their appropriateness to predict temperatures and rainfall and to study the effect of climate change on three different cities in the UAE. The results show a strong correlation between the present T_{max} vs T_{max} 2020, T_{max} 2040, T_{max} 2060, T_{max} 2080 and T_{max} 2095 for both RCP4.5 and RCP8.5. This means that maximum temperatures are going to increase in the coming years based on the predictions according to the different scenarios using MarksimGCM. Precipitation projections show greater variation than temperature. The amount of increase in temperatures and precipitation change is shown for the end of the current century.

4.2 Introduction

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (Stocker, 2014). The United Arab Emirates (UAE) and the Arabian Gulf region are no exception. The UAE, covering an area of 83000 Km^2, with extended coastlines and small islands, is consequently more prone to the impact of climate change, especially that it is also undergoing rapid growth and huge urban developments (SCAD, 2010). The UAE population is in a steady rise and its climate is changing like everywhere else, with the increase of atmospheric CO_2 and temperature and the abnormalities in rainfall events (Dougherty et al., 2009). In Abu Dhabi, by 2050, the average temperature will increase by around 2.5°C, while rainfall will change by between -21.2% and +10.3% using General Circulation Models (GCM) (Dougherty et al., 2009).

GCMs are numerical models predicting atmospheric physical processes, ocean dynamics and land surface processes, while presenting the most advanced predictive tools available to simulate the impact of increased greenhouse gas levels on the global climate system (Chen et al., 2012). Relying on such models, the Intergovernmental Panel on Climate Change (IPCC) reported that the last three decades were consistently warmer than any preceding decade since 1850 (Stocker, 2014). Consequently, some low-lying regions and islands are required to confront high impacts that could have a cost as much as several percent points GDP (Stocker, 2014). Unfortunately, this recent impact of climate change may have far reaching negative impacts. The combination of water shortages and high population growth rates accelerate the risks of the middle east to future climate change (Evans, 2009). Simulations results reported by Cramer et al. (2001) reveal large magnitude of possible biospheric influences of climate change. Biodiversity, coral species, coastal sustainability and water resources could be affected by climate change in the UAE (Dougherty et al., 2009).

The urgency of climate adaptations and mitigations require the use of these types of models to predict the impact of climate change (Merryfield et al., 2013).

GCMs are known to produce hypothesis-based predictions relying on well established and demonstrated physical principles (Randall et al., 2007). Randall and Colleagues also added that the confidence in these models have become stronger and provide credible outcomes. Care is to be taken as some components of climate may be poorly simulated which leads to problems in interpretations of results from such models (Lin et al., 2006). Nevertheless, in a study on the impact of climate change in the Middle East using 18 GCMs, Evans (2009) reported that the models predict an overall temperature increase of between 1.4 to 4°C. He also added that the smallest increases occur over the large water bodies. Red Sea and Arabian Gulf are estimated to have the more considerable change in temperatures. While the largest increases will be felt over land masses, away from water bodies (Evans, 2009). On a more recent time scale, Feulner (2006) reported that for Sharjah, the annual rainfall totals are very periodic, with June begin the driest month. He added that the years 2000-2003 had the lowest 4-year rainfall total, while 1995-1998 was the wettest period. For other Gulf countries, such as Saudi Arabia, rainfall was noted to decrease by about 48 mm per decade (Almazroui et al., 2012). While the mean temperature increase by 0.60°C per decade. Fortunately, in preparation for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), many international climate modeling centers assessed long-term simulations of climate change scenarios (Lin et al., 2006).

Rigorous evaluation were used for all models to improve their predictions (Lin et al., 2006). But the problem of linking large scale GCM to finer regional models still poses a challenge (McGregor, 1997). Such spatial linkages are the best approach to produce more reliable predictions at regional levels. RegCM, for instance, is part of network of collaborative modeling projects to improve predictions and understanding of climate change at regional scales (Giorgi et al., 2012). For many to use reliable predictive models, emission scenarios of climate change are to be assessed. The GCMs are applied to measure the 21st century climate change over the UAE and Arabian Gulf region. Yates et al. (2015) implemented simulations using version 3.5.1 of the Weather Research and Forecasting Model (WRF). Which is a fully compressible conservative-form that is able to resolve small-scale, the recent insufficiencies of GCMs and the fact that each model has strengths and weaknesses has led to a conclusion that no single model can be considered best (Kiwan et al., 2009). Results should be utilized from a range of coupled models for adaptation studies as well as regional impact (Allen et al., 2000). Tebaldi et al. (2005) used a statistical model that combines information from each GCM, including each models ability to re-create the regional climate over the period 1960 through 1990 and the agreement among models in future projections. Based on Yates et al. (2015), there is an increasing trend of precipitation that was shown by the collaborative of all the climate models, for the 21st century for the Arabian Gulf region. An upward trend starts around 1980. The per-day precipitation was about 0.38 mm in 1980, and expected to increase to about 0.43 mm by 2100.

The Representative Concentration Pathways (RCP) represent the latest generation of scenarios that are used as potential inputs into climate models that shows imposed greenhouse-gas concentration pathways during the 21st century, according to various radiative forcing stabilization levels by the year 2100 (Bjornaes, 2013; Nakicenovic et al., 2000; Giorgi et al., 2009). Adding that emissions scenarios are used to assess the contributions of human activities, such as population growth and economic developments, to future climate change.

In MarksimGCM, four emission scenarios have been used for climate research; namely RCP 2.6 (based on low emission), RCP 4.5 and RCP 6 (based on intermediate emissions) and RCP 8.5 (based on high emissions), with each assuming different radiative forcing and primary energy use levels (Bjornaes, 2013). In order for any climate models to be realistic and applicable, at regional as well as global scales, some type of downscaling is necessary. Statistically based downscaling approaches (referred to as SDSM) of climate data have been around for more than a decade (Wilby and Dawson, 2013). Wilby and Dawson also outlined five steps, starting with the proper selection of predictor variables, for such modeling protocol to be reliable. One SDSM interface used in such protocols is MarksimGCM (Jones et al., 2009). It was initiated by the International Center for Tropical Agriculture (CIAT) and it is for IPCC AR5 data (CMIP5). MarkSimGCM, initially reported as a weather generator by Jones and Thornton (2000), is now a web-based SDSM tool (currently referred to as MarksimGCM). It generates daily simulated weather data specifically designed for use in the tropics, including rainfall, maximum and minimum temperatures and solar radiation. MarkSimGCM uses 720 classes of weather, worldwide, to calculate the coefficients of a third order Markov rainfall generator. Which involves ’stochastic downscaling’ as it fits a Markov model to the GCM output and uses it to generate weather data for the site indicated. MarkSimGCM also provides options to select any combination of climate models and RCP scenarios for future years (Figure 4.1). The output can be a graphical display or downloadable raw data of solar radiation, maximum and minimum temperatures and rainfall predictions on a daily basis. As a consequence of the challenges presented by the global climate change, adaptations are urgently needed to minimize the risks on human health and ecosystem sustainability.

The UAE has been initiating various measures of adaptations to climate change. One of the major outcomes of such initiatives, is the development of the UAE National Climate Change Plan 2050 (MOCCAE, 2017). The plan aims to genuinely tackle climate change. However, the process by which adaptations to climate change are to be assessed will involve institutional practices (Adger et al., 2005). In order to succeed, any such attempts will require local data and predictions on the impact of climate change on ecosystem and human sustainable livelihood. In the present attempt, therefore, data from MarksimGCM is used to assess different RCPs and their appropriateness as GCM inputs to predict temperatures and rainfall and study the effect of climate change on specific cities in the UAE as it relates to both temperature and rainfall abnormalities.

4.3 Methodology

4.3.1 Study Area

The study was performed at three different regions within the UAE (with 8 different locations), covering a variety of climate regions. The list of locations sampled for their specific climate data are listed in Table 4.1.

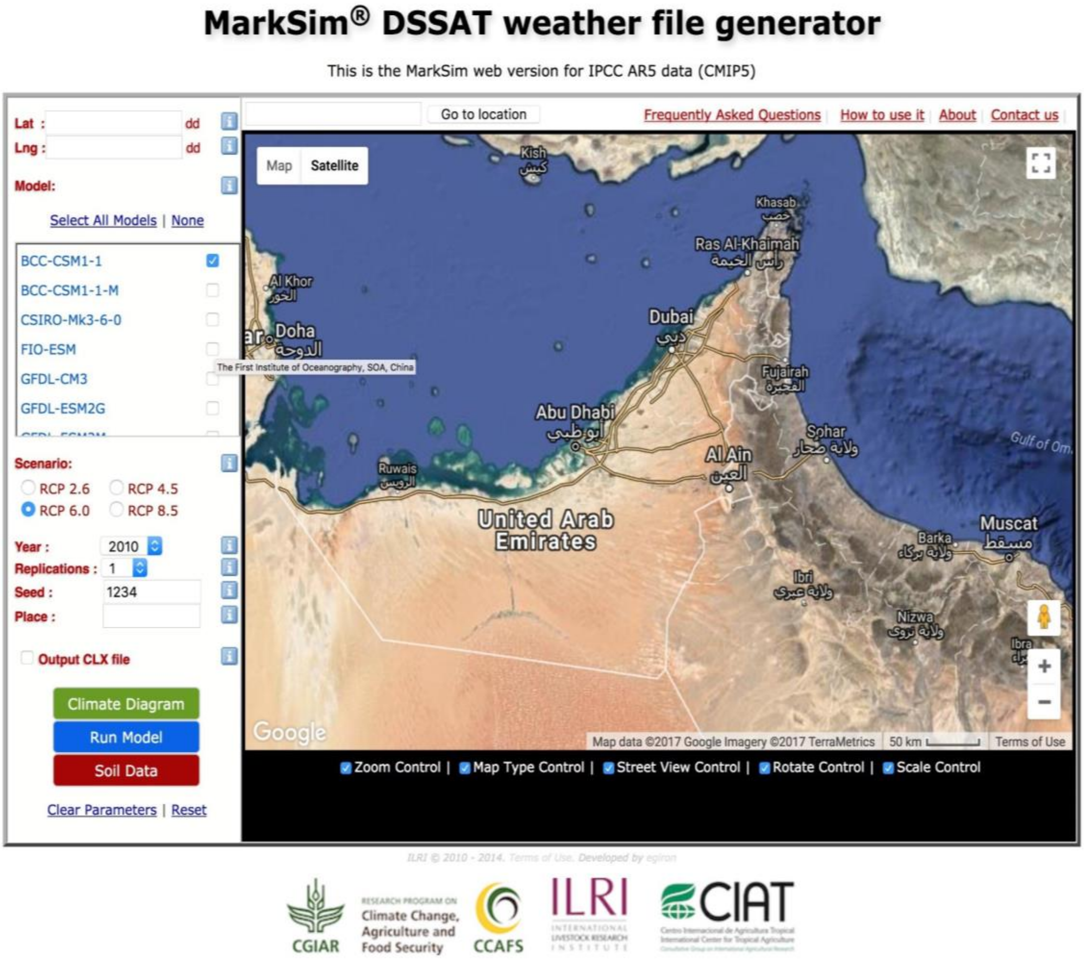


Figure 4.1: A screen-shot of MarksimGCM web interface, showing the different selection options available for the end-users

Table 4.1: List of sampling sites with their geographic coordinates. Site IDs are extracted from the United Arab Emirates Soil Information System

Location No.	City	Lat	Long
1	Abu Dhabi	55.094385	24.255033
2	-	55.626934	25.514761
3	-	55.73321	25.142376
4	Al-Ain	55.738963	25.176071
5	-	54.830366	23.86952
6	Sharjah	53.286785	24.025871
7	-	53.394047	24.003011
8	-	53.599539	23.083949

4.3.2 Data and Method

MarksimGCM was used to generate current year's data as well as future predictions of climatic data. MarksimGCM uses a combination of models (17 models), Representative Concentration Pathways or RCPs (RCP2.6, RCP4.5, RCP6 and RCP8.5), years (2010 to 2095) and replicates (1 to 99). For every location listed in Table 4.1, a climate data file was downloaded to the desktop for further analyses. The RCPs are four greenhouse gas concentration trajectories adopted by the IPCC - Fifth Assessment Report (AR5): RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The RCPs are named after the radiative forcing values by 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2; respectively). Radiative forcing is a result to a perturbation in the concentration of a gas at the tropopause (Ramaswamy et al., 2001). RCP 4.5 and RCP 8.5 were used in the study simulations for climate predictions in the UAE. One of the main features of this RCP 8.5 is that it is based on heavy use of fossil fuels, increasing use of croplands and declining use of grasslands (Bjornaes, 2013). On the contrary, RCP 4.5 is regarded as a "Business as Usual" (BAU) alternative. The list below describes all four scenarios as reported by Nakicenovic et al. (2000).

- RCP 2.6: It is a pathway representative of scenarios in the literature leading to very low greenhouse gas concentration levels. It is a so-called "peak" scenario: represents a strong mitigation scenario and is extended by assuming constant emissions after 2100 (including net negative CO_2 emissions), leading to CO_2 concentrations returning to 360 ppm by 2300.

- RCP 4.5: It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions.

- RCP 6.0: It is also a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employment of a range of technologies and strategies for reducing greenhouse gas emissions.

- RCP 8.5: It is characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels. The underlying scenario drivers and resulting development path are based on the A2r scenario.

For each of the three UAE regions, data was downloaded for every RCP/Model/Year combination separately, replicated five times. Downloaded data included rainfall, maximum and minimum temperatures and solar radiation. Excel was then used to append all data into one file for further analyses. The following steps were followed for each location selected from the UAE map on MarksimGCM.

1. A combination of RCP/Model/Year was downloaded form MarksimGCM
2. All downloaded files were combined in Excel.
3. A correlation analysis was performed for each present climate data vs data of RCP4.5 and RCP8.5 for the years (2020, 2040, 2060, 2080, 2095) using all 17 GCMs averaged. In this regard, the website states that using all GCMs together "it averages the polynomial functions that drive the GCM differences so that it produces correctly downscaled weather data for the average GCM".
4. All RCP predictions were assessed based on Pearson correlation coefficient, for both rainfall and temperature abnormalities.
5. Graphs of correlation analyses were made to present the trends of the curves and explain the correlations of the available data.

4.4 Results

The results of this study show a strong correlation between the present T_{max} and T_{max} 2020, T_{max} 2040, T_{max} 2060, T_{max} 2080 and T_{max} T_{max} 2095 for both RCP4.5 and RCP8.5 (Figure 4.2). In other words, maximum temperatures are going to increase in the coming years based on the predictions according to the different scenarios using MarksimGCM. Figure 4.3 shows the maximum temperatures in summer season (May to September). This period was selected based on the trend of the curve. The rising temperatures followed the same trend for the different years (2020, 2040, 2060, 2080, 2095). The highest present T_{max} is around 42.1°C while T_{max} in 2095 based on RCP4.5 is projected to be around 44.6°C. The increase in the maximum temperatures will be about 2.44°C by 2095.

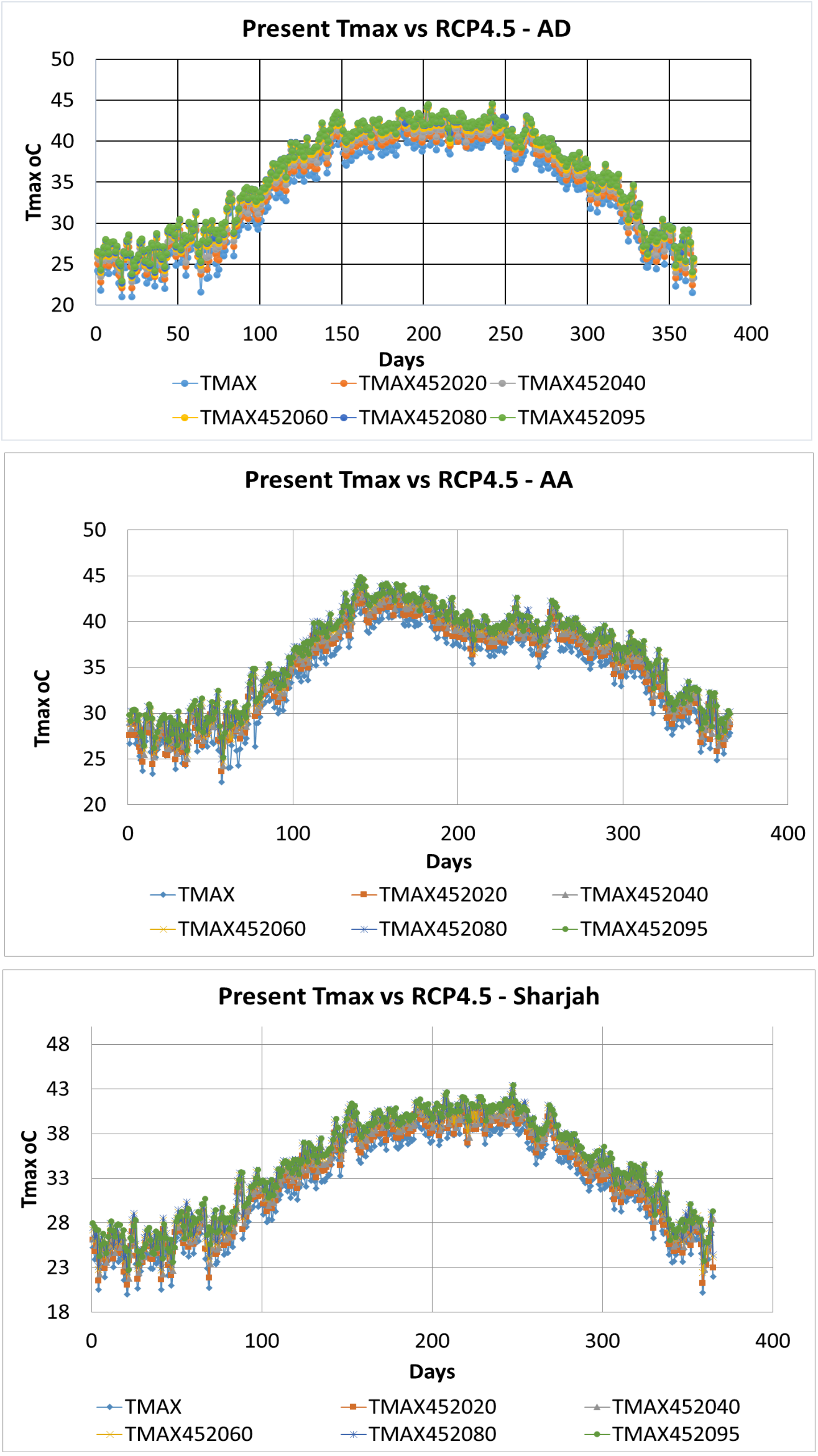
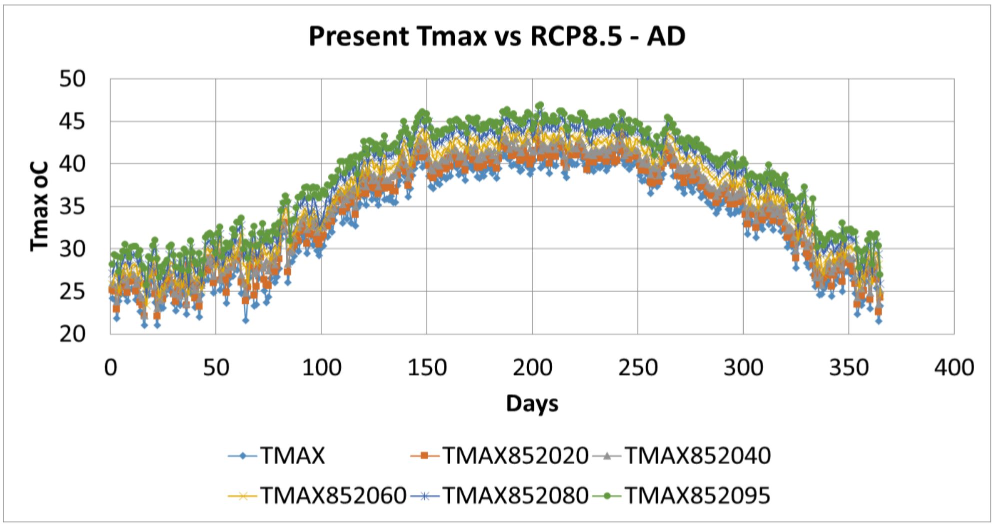
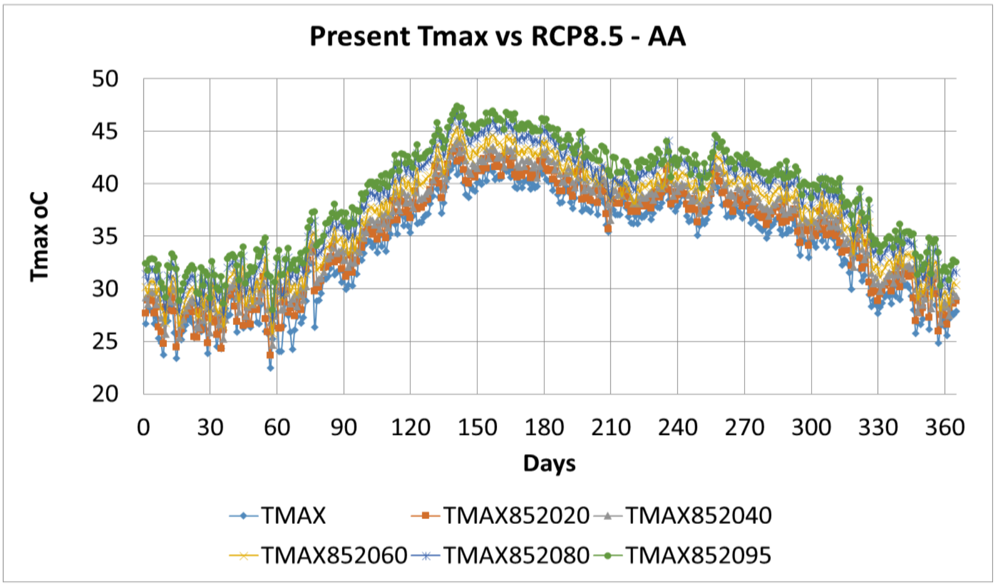


Figure 4.2: Correlations between present T_{max} vs different T_{max} RCP4.5 and RCP8.5 in Abu Dhabi (AD), Al-Ain (AA) and Sharjah





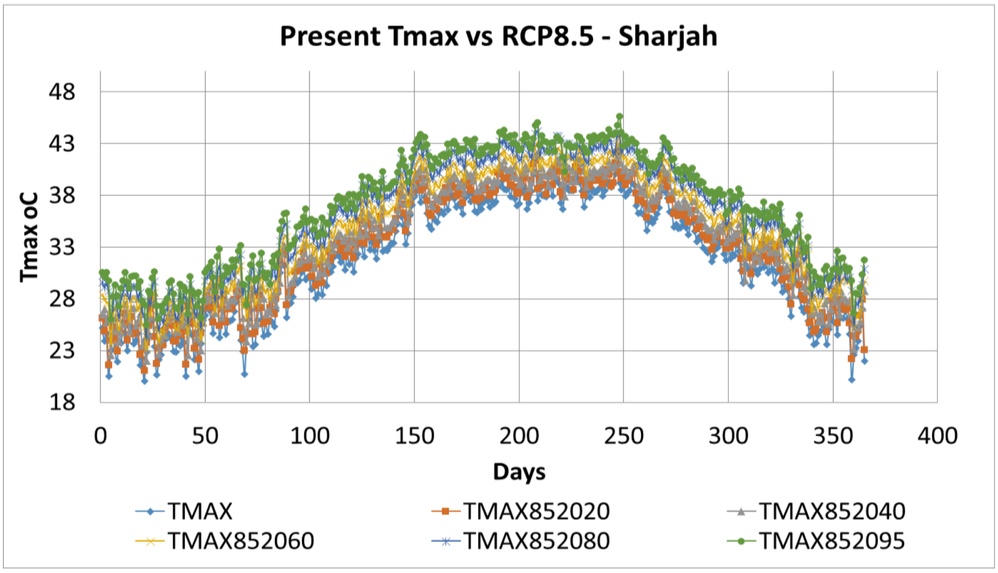


Figure 4.2: Correlations between present Tmax vs different Tmax RCP4.5 and RCP8.5 in Abu Dhabi (AD), Al-Ain (AA) and Sharjah (Continued)

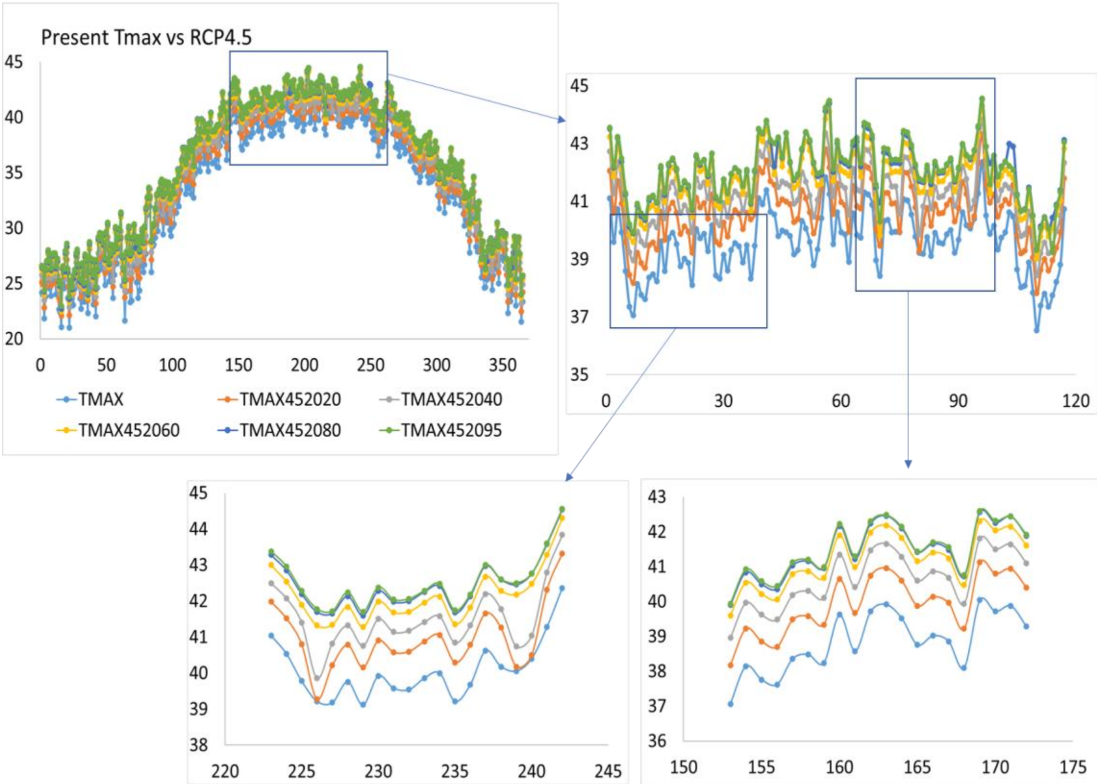


Figure 4.3: The max. Temps. in summer (27 May to 20 September in Abu Dhabi)

The correlation coefficient of T_{max} for RCP4.5 and RCP8.5 in the years (2020, 2040, 2060, 2080, 2095) is presented in Table 4.2. The correlation coefficient ranges between 96.8% and 99.6%, which indicates a high correlation between the present and the projected maximum temperatures. The projected T_{max} of 2020 RCP4.5, 2080 RCP4.5, 2020 RCP8.5 and 2060 RCP8.5 showed higher correlation coefficient. MarksimGCM Predictions for these years are more accurate than the prediction of T_{max} 2040 RCP4.5, 2060 RCP4.5, 2095 RCP4.5, 2040 RCP8.5, 2080 RCP8.5 and 2095 RCP8.5.

Table 4.2: Correlation coefficient and significance values of RCPs in years 2020-2095 in Al-Ain region

Year	RCP4.5 Corr. Coef.	RCP4.5 Sign.	RCP8.5 Corr. Coef.	RCP8.5 Sig.
2020	0.996	<0.001	0.996	<0.001
2040	0.969	<0.001	0.969	<0.001
2060	0.969	<0.001	0.969	<0.001
2080	0.996	<0.001	0.968	<0.001
2095	0.969	<0.001	0.968	<0.001

Figure 4.4 shows the correlations between present rain amount vs the predicted RCP rain amounts for all studied locations. In Abu Dhabi, rainfall rates are expected to be high in 2020 and 2080 by the end of February, using RCP4.5. While RCP8.5 scenario showed lower rates of rainfall except for 2095, which is expected to experience similar rainfalls to the present rates. Based on the results of RCP4.5 the maximum rainfall rate will occur by the end of February 2080, with an amount of 19.04 mm (Table 4.3).

Table 4.3: Highest Rain and Rain rate change in year 2095 for RCP4.5 and RCP8.5 in Abu Dhabi, Al-Ain and Sharjah

City	Rain RCP4.5	Rain (+)	Rain RCP8.5	Rain (+)
Abu Dhabi	19.04 mm	3.28 mm	14.84 mm	(-)0.92 mm
Al-Ain	7.58 mm	0.14 mm	8.56 mm	1.12 mm
Sharjah	5.54 mm	1.9 mm	5.96 mm	2.32 mm

RCP8.5 showed lower rainfall rate which will occur in the middle of February 2095, with amount of 14.84 mm, 0.92 mm than the present rate (15.76 mm). In other words, Abu Dhabi will experience the higher rainfall rates. In Al-Ain, rainfall rates are expected to be high in March by 2080 and 2095 using RCP4.5. Similarly, it will experience high rainfall rates for RCP8.5, in March of 2080 and 2095 with over

prediction in 2020, where the rainfall rate will be high in February, with some rainfall events in summer. In Al-Ain the highest rainfall rate for RCP4.5 will occur at the end of February with rate of 7.58 mm in year 2080. The next highest rate will occur in the middle of February 2095 with a rate of 7.44 mm. While for RCP8.5 the highest rate will occur in the middle of February 2020 with a rate of 8.56 mm. The next highest rate will occur in the middle of February 2080 with rainfall rate of 7.64 mm, which indicates that with RCP8.5 Al-Ain will experience more rains.

With RCP8.5, Al-Ain will experience more rainfall events compared to RCP4.5 (Figure 4.4). In Sharjah, the rainfall rate based on RCP4.5 are the highest in 2095 with rate of (5.54, 4.8, 4.1).

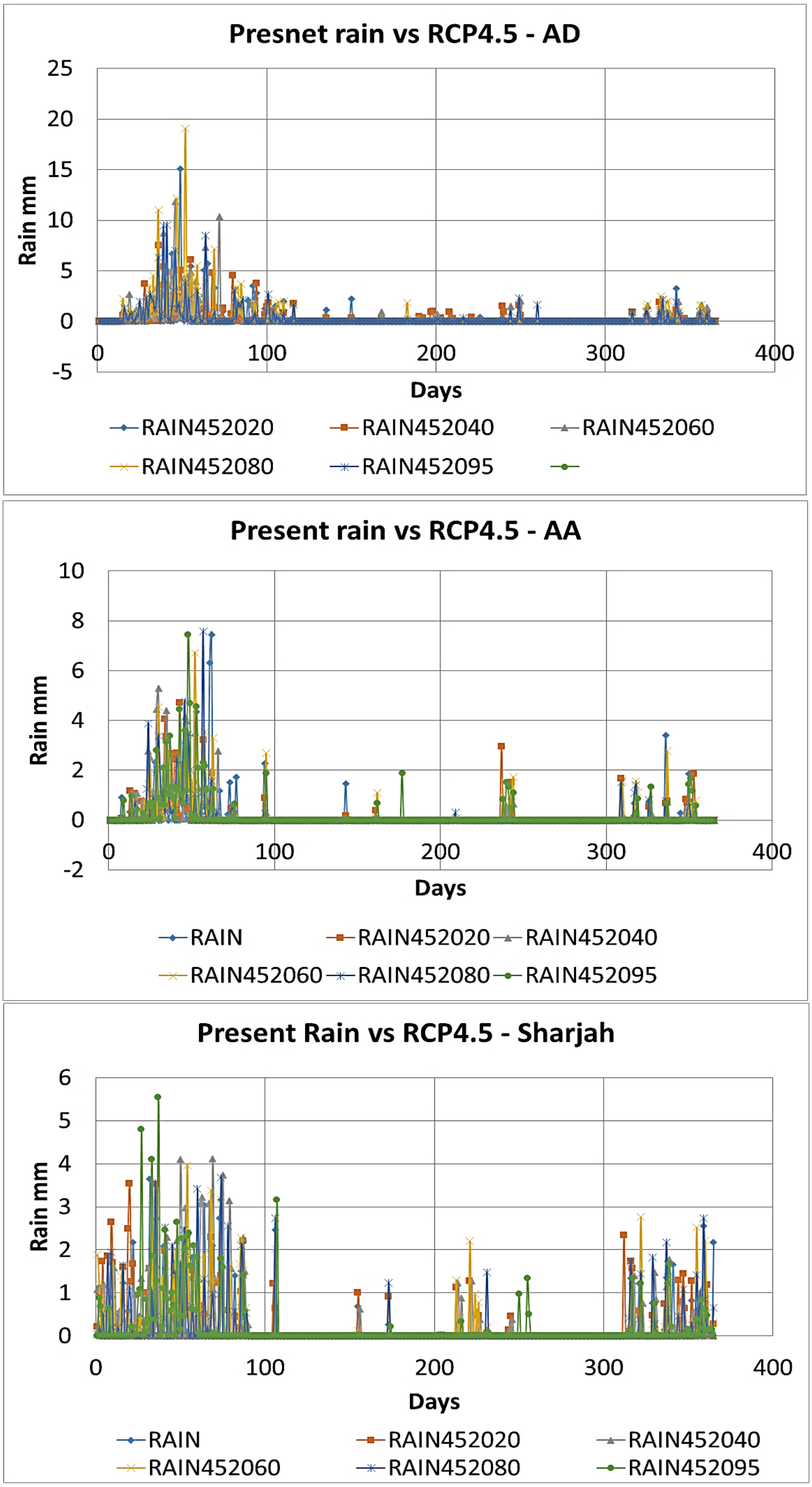


Figure 4.4: Correlations between present rain amount vs the predicted RCP rain amounts in Abu Dhabi, Al-Ain and Sharjah

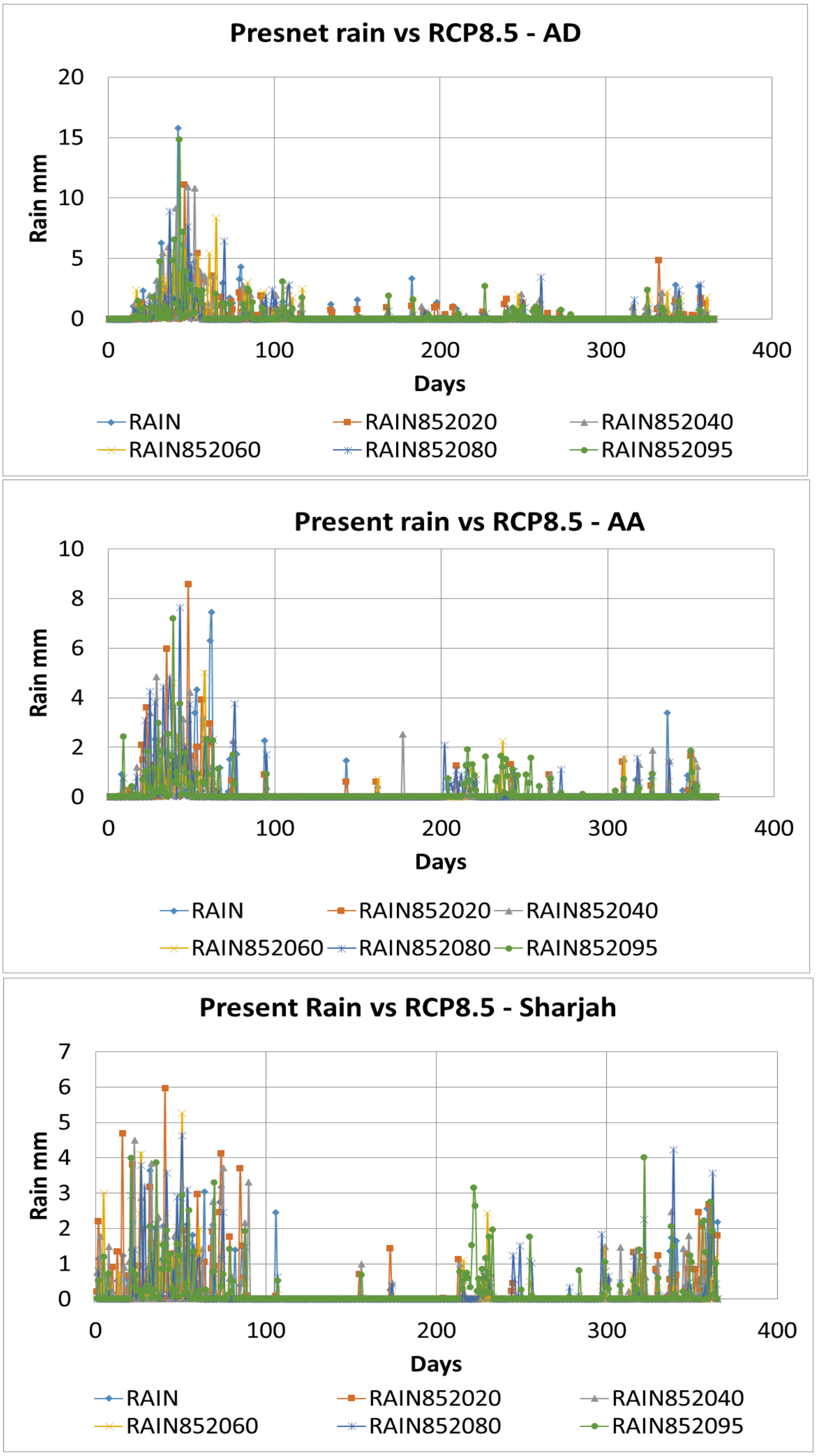


Figure 4.4: Correlations between present rain amount vs the predicted RCP rain amounts in Abu Dhabi, Al-Ain and Sharjah (Continued)

All events will occur by the end of January and the beginning of February. For RCP8.5, the highest rate occurs in the beginning of February 2020 with an amount of 5.96 mm, the next highest amount is by the end of February 2060 with a rate of 5.26 mm. Compared to Abu Dhabi and Al-Ain, Sharjah will experience lower rainfall rates, yet more frequent rainy events. Generally, the three cities will experience the highest rainfall events in January and February.

4.5 Discussion

MarksimGCM is used for many research purposes, for example; Patel et al. (2018), used the data generated to assess the impact of climate change on phenology and yield of wheat crop. Their results showed that the impact was highest under RCP 8.5 in 2095. Another application is by Bekele (2015) where the daily rainfall data for RCP4.5 emission scenario using Marksim GCM for the period 2020-2049 were used to study the trend of annual and seasonal total rainfall and assess the impact on yield. In this study the focus is on temperature and rainfall rate changes through time and until the end of the century. Generally, the maximum temperature is increasing as was anticipated in higher concentrations of carbon dioxide, and the larger warming occurs in RCP8.5. Based on MarksimGCM predictions and the results of the current study, Al-Ain will experience the highest temperatures in 2095. The maximum temperature will reach 47.4°C, Abu Dhabi Temperature will reach 46.9°C and Sharjah 45.64°C. The increase in maximum temperatures in Abu Dhabi, Al-Ain and Sharjah is about (4.56, 4.74, 5.34°C) respectively. Sharjah will have the largest temperature increase by the end of the century. For RCP4.5, Al-Ain will have the largest increase (3.48°C), Abu Dhabi will have (2.44°C) and Sharjah will have (3.38°C) as shown in Table 4.4.

The temperature rise will range between 2.44 and 4.56 for RCP4.5 and RCP8.5 in Abu Dhabi, 3.84 and 4.74 in Al-Ain and 3.38 and 5.35 in Sharjah.

Table 4.4: Highest Temps. and Temps increase in year 2095 for RCP4.5 and RCP8.5 in Abu Dhabi, Al-Ain and Sharjah

City	Temp. RCP4.5	Temp. (+)	Temp. RCP8.5	Temp. (+)
Abu Dhabi	44.56°C	2.44°C	46.9°C	4.56°C
Al-Ain	44.14°C	3.48°C	47.4°C	4.74°C
Sharjah	43.44°C	3.38°C	45.64°C	5.35°C

The Arabian Gulf Region trends for the period 1950-2100 using RCP8.5, showed a temperature increase during the 21st century and with steeper trends after 2060 (AGEDI, 2015). Average future temperature increases are expected to be 2°C to 3°C higher over land areas and 1.5°C to 2°C over Gulf waters across the region (AGEDI, 2017). The GCMs indicate a significant increase in daily temperatures which indicate a rise in the risk of severe heat waves (Field et al., 2012). Chou et al. (2014) found that as expected in higher equivalent CO_2 concentrations, larger warming occurs in RCP8.5. The results showed that the largest changes in temperature occur between the present and the first period, (2011 to 2040) in RCP4.5, whereas in the RCP8.5 the highest degrees of temperatures occurs between (2041 to 2070) and (2071 to 2100).

Lelieveld et al. (2016) compared the mid-century period (2046 to 2065) and the end-century period (2081 to 2100) with the recent period (1986 to 2005). Based to RCP8.5 scenarios. They found that by the end of the century, many countries in the Middle East and Northern Africa in summer season are projected to experience a temperature increase more than 6°C compared to (1986 to 2005). Jacob et al. (2014) results showed a strong and statistically significant warming, with regional differences, in the range of 1 to 4.5°C for RCP4.5 and of 2.5°C to 5.5°C for RCP8.5.

Compared to 1971-2000, which is not applicable for RCP4.5, large parts of Northern Scandinavia, Eastern Europe and the Alpine ridge might be exposed to a warming of more than 4.5°C under RCP8.5. For UAE, AGEDI (2015) reported that, simulations of 2060 to 2079 showed that temperatures are projected to statistically significantly increase in all months and for both the RCP4.5 and RCP8.5 scenarios. There will be an increase of 2°C for RCP4.5 and 3°C for RCP8.5. Based on this study results, the warming is in the range of 2.44°C to 3.38°C for RCP4.5 and of 4.56°C to 5.35°C for RCP8.5.

Zhang et al. (2016) showed that the collective average of GCMs increased until reaching a maximum value of 3.9°C in T_{max} and 2.9°C in T_{min} under RCP8.5 in the 2080s. The same results reported by Chong-Hai and Ying (2012) showed that the expected time series of annual temperature has deviation trends similar to the emission pathway. They found that for RCP4.5, the temperature is increasing until 2070 and stabilizing from 2070 to 2100. On the other hand, for RCP8.5, the temperature will rise with the constant increase of radiative forcing. Based on Kiwan et al. (2009), The projections of temperature are mainly consistent for the next 20 years, with a 1°C increase, but show larger uncertainty in the 40-year projections. By 2100, the temperatures are expected to rise between 3.1 to 4.8°C. For RCP4.5, the warming in 2041 to 2070 is nearly 2.0°C, (0.5°C) less than at the end of the 21st century (approximately 2.5°C) (Chong-Hai and Ying, 2012). While for RCP8.5, the warming at the end of the 21st century (approximately 5.1°C) is extraordinarily greater than in 2041 to 2070 (approximately 3.0°C). Currently, maximum daytime temperature during the hottest days is about 43°C, it is expected to reach 47°C by the middle of the century, and nearly 50°C by the end of the century in the RCP8.5 scenarios (Lelieveld et al., 2016).

For the rainfall rate, it was found that the rate will range between (-0.92) and 3.32 for RCP4.5 and RCP8.5 in Abu Dhabi, 0.14 and 1.12 in Al-Ain and 1.9 and 2.23 in Sharjah. The UAE has experienced about 60% of time drought in 45 years (Sherif et al., 2014). Regional changes are more uncertain and could vary from region to region, with some location experiencing more and others less precipitation. Projections showed wide range of rates varying between -21% to +10% by 2050 and -38% to +18% by 2100 (Kiwan et al., 2009). Similar to the study findings, precipitation projections show even greater variation than temperature (Table 4.3). Some models project a dryer region with decreasing precipitation, while others project a wetter region with a significant increase in precipitation (Dougherty et al., 2009).

To verify that the current temperatures predicted by MarkSimGCM are in agreement with actual temperature measurements, the maximum temperature of March 2020 in Al-Ain was correlated with the maximum temperature predicted by MarkSimGCM of RCP4.5 and RCP8.5 as shown in Figure 4.5. The predicted temperature is different than the actual. There is a big variation between the actual and predicted. For rainfall rates the actual events were compared with the predicted. It was found there is a big variation in the dates and the amount of rain. Al-Ain has experienced rain fall events on January 10 and 11 with amounts of 0.55 mm and 3.98 mm respectively, and on March 21 and 22 with amounts of 0.17 mm and 0.28 mm. Predictions showed different rates and dates.

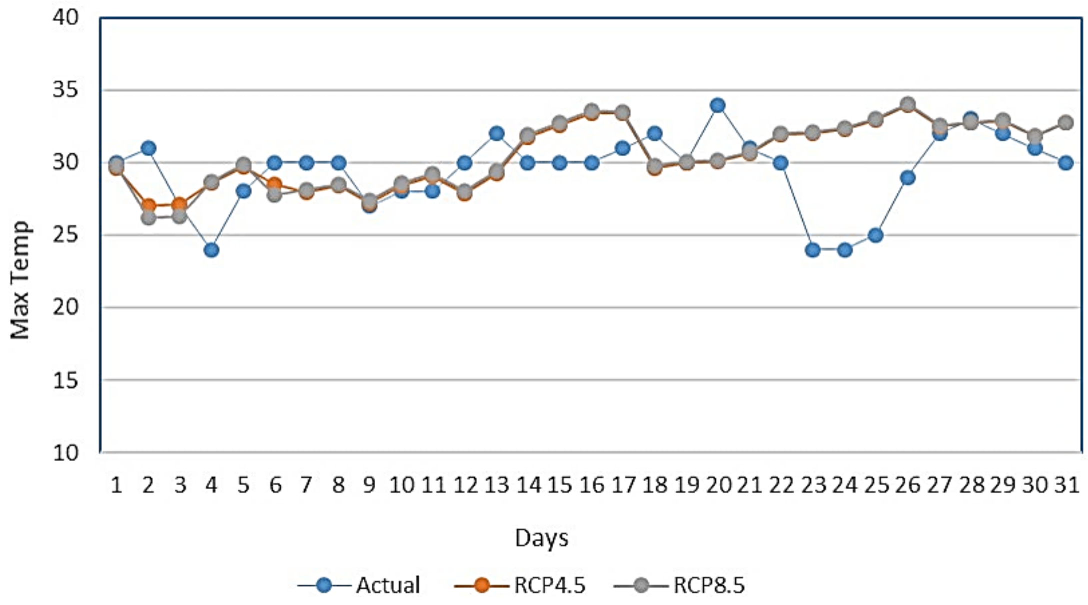


Figure 4.5: Actual T_{max} vs predicted T_{max} for RCP4.5 and RCP8.5 for March 2020 in Al-Ain

It was predicted for Al-Ain to experience rainfall events on January 8, 13 and 16 with amounts of 0.4, 0.28 and .06 mm and on March 12 with an amount of 0.04 mm and on March 17 with an amount of 1.72 mm. This means that MarkSimGCM does not show accurate prediction of the UAE. Furthur investigations using SDSM, could pinpoint the trend as well as the magnitude of change.

4.6 Conclusions

The urgency of climate adaptations and mitigations requires the use of GCM models to predict the impact of climate change (Merryfield et al., 2013). The results of this study show a strong correlation to temperature and no correlation to rainfall. The temperature will significantly increase in the coming 70 years, reaching the highest rates by the end of the century. According to RCP8.5, the maximum temperatures will increase by 4.56°C in Abu Dhabi, 4.74°C in Al-Ain and 5.37°C in Sharjah, by 2095. In Abu Dhabi the maximum rainfall rate will occur in 2080 with amount of 19.04%. In Al-Ain it will be 7.85% in 2080, and 5.96% for Sharjah in 2060.

Abu Dhabi will be having the lowest increase in temperatures and highest rates of rain. The difference in temperatures is not very high compared to the other two cities (0.18°C lower than Al-Ain and 0.81°C lower than Sharjah). Rainfall rates will also vary, but not significantly as discussed above. Compared to Abu Dhabi and Al-Ain, Sharjah will experience lower rainfall rates. Still to be assessed is the specifics of each major GCM and their powers to predict UAE climate. Also, more replicated can be applied for better and more accurate results. MarkSimGCM is used for tropical regions. It might not show accurate predictions for dry lands.

Chapter 5: Climate Change and Environmental Awareness: A Study of Energy Consumption among the Residents of Abu Dhabi, UAE

5.1 Overview

The rising levels of green house gases (GHG) have caused great concern about the impact of climate change on almost every aspect of our lives. Urban expansion and changing lifestyles have led to an increase in energy consumption. The main aim of this empirical study is to explore the environmental and socioeconomic impact of climate change on the energy consumption of a stratified random sample of the residents of three main regions in the Emirate of Abu Dhabi (Abu Dhabi city, Al-Ain city and Al Dhafra) and to investigate residents' awareness of this change. Data was gathered from (321) residents from these three regions. Descriptive statistical methods and nonparametric tests were used to compare quantitative data at different levels of the sociodemographic variables. The findings revealed that more than 50% of the participants agreed that climate change is controlling their energy and water consumption. About 94% of participants believe that their energy consumption is increasing, while 44% of the sample spent 30% more money on water and electricity bills in the past 20 years. About 50% of participants consider moving to another city if energy prices increased due to energy consumption and the effects of climate change. Respondents over age of 40 tend to be more conscious and aware of climate change. Eighty-eight percent (88%) of the Emirati respondents believe that weather and climate change are affecting their energy and water consumption.

5.2 Introduction

Rapid urbanization promotes the development of the construction industry and leads to an increase in energy demand, particularly the demand for electricity (Hu et al., 2017). Global energy use is rapidly increasing and has raised concerns in various fields; such as energy supply, energy exhaustion, resources and environmental impacts like ozone layer depletion, global warming and climate change (P´erez-Lombard et al., 2008). Some of the main factors that drive energy use in the construction industry are weather, house size, building services systems, indoor environment, building operation and occupant behavior (Gaetani et al., 2016). According to P´erez-Lombard et al. (2008), booming worldwide populations, the development of building services and individual comfort levels, have raised construction energy consumption to the levels seen in transport and industry. They also found that the energy usage of buildings will increase by 34% in the next 20 years at an average rate of 1.5% per year.

In hot regions, energy consumption for cooling is relatively high due to high temperatures and humidity levels. Bayomi and Fernandez (2018), reported that energy consumption in the Middle East is reaching extremely high levels when compared to the UK and Japan, which have similar GDPs per capita. Subtropical climates have shown a trend of increasing temperature over the past few decades, and due to heat waves in the summer, a higher demand has occurred (Lam et al., 2008, 2010). Consequently, an increase in electricity usage for air conditioning (AC) would lead to larger emissions, which would worsen climate change and the effects of global warming (Li et al., 2012).

Climate change has brought differences in heating and cooling consumption (Li et al., 2012). There are many factors on which general energy consumption depends; climate, physical dwelling characteristics, appliances and system characteristics, ownership and occupancy behavior (Sartori et al., 2009). According to Kalvelage et al. (2014), energy usage in cold climates would be reduced by about 10%

due to weather patterns, while in tropical climates, energy usage would raise over 20%. They also found that a shift from heating to cooling would occur in mid-latitudes. Climate change also has an increasing societal impact on how to live, work, build and generate energy (Waddicor et al., 2016). Construction prices and material usage were directly and indirectly affected by climate change (Estidama, 2010).

Atalla and Hunt (2016) analyzed six countries that are part of the Gulf Cooperation Council (GCC). The results of their study showed that pricing regime affects residential electricity consumption trends. They predicted that electricity demands will increase further in the future. Based on the 2016 annual publication by the Statistical Center of Abu Dhabi SCAD (2017) The population of the UAE is increasing annually by Average annual growth rate of 5.6, which results in an increased energy demand. Based on Bayomi and Fernandez (2018), the energy demands are projected to grow by an annual average of 2.9%, where the main sources of energy in the UAE are oil and natural gas and other sources of energy like coal and solar energy represent less than 0.1% of 45 the energy used.

The main contributor to electrical load in the UAE is cooling at about 40%, and it can reach 60% during the summer (AlAwadhi et al., 2013). Up to 80% of electricity is used to meet the air-cooling demand in Abu Dhabi (Shanks and Nezamifar, 2013). Lebassi et al. (2010) found an irregular increase during the summer between the coastal and inland regions of California over a 35-year period (1970 to 2005). Another study by Miller et al. (2008), focusing on the impacts of climate change on the Californian energy sector, reported an increased demand for energy in the summertime due to electricity used for cooling. Radhi (2009) also reported that air conditioning demands including cooling and fans in typical residential villas are expected to increase by approximately 10% to 35% by 2050, depending on which future carbon dioxide emissions scenario is considered.

The transition to a low-carbon economy is critically influenced by public perceptions and attitudes (Poortinga et al., 2011). Based on Leiserowitz (2005), public opinion can deeply induce political, economic, and social action to address particular risks. In a survey conducted by Eurobarometer (2009), 47% of the respondents considered climate change to be one of the most serious problems facing the world today. Another survey conducted in 2005 by Poortinga et al. (2006), found that the majority of respondents from the British public thought that global climate is changing and considered it as one of the most persistent environmental threats (Poortinga et al., 2011). Leiserowitz (2005) found that Americans are mainly not very concerned about climate change, which they consider to be a moderate risk, yet they think that people and places that are geographically and temporally distant would be affected. Additionally, they found that most Americans lack a clear and concrete concept of climate change.

Two questions have been formulated for this study: is energy consumption influenced by the climate change in Abu Dhabi? And are residents of Abu Dhabi aware of the impact of climate change on their energy and water consumption? The objectives of this chapter are: (1) understand the characteristics and trends of urban residential building energy consumption, (2) measure the climate change awareness of the citizens in the Emirate of Abu Dhabi and (3) understand the influences of climate change on the socio-economic status of the citizens in Abu Dhabi.

5.3 Methodology

5.3.1 Study Area

Abu Dhabi city is the capital of Abu Dhabi Emirate which is the largest emirate of the UAE by area (67,340 km^2), accounting for approximately 87% of the country's total land area excluding islands. Abu Dhabi also has the largest population of the seven emirates (about 2.908 million: 1,857,618 males and 1,050,555 females) (SCAD, 2017). The topography of the Emirate is dominated by low-lying sandy terrain dotted with sand dunes exceeding 300 m in height in some areas to the south. The eastern part of the emirate borders the western fringes of the Al-Hajar Mountains. Hafeet Mountain is the highest point in Abu Dhabi, reaching a height of about 1,300 m, which located south of Al Ain city. The emirate is located in the tropical dry region. The climate is arid, characterized by high temperatures throughout the year and very hot summers. Abu Dhabi has warm winters with occasional low temperatures. The air temperatures show variations between the coastal strip in Abu Dhabi city, the desert interior of Al Dhafra and Al-Ain city, and areas of higher elevation, which together make up the topography of the emirate.

5.3.2 Data and Method

To clearly understand energy consumption and the citizens' level of awareness of climate change effects on their consumption in different types of accommodations in the emirate of Abu Dhabi, the survey is designed with a content and coverage area as shown in Figure 5.1. The survey content includes general information about occupant and accommodation, prices, behavior and consumption rates and percentage increase, economic influence and climate awareness. Twenty-one questions, grouped in three sections, are included in the survey: questionnaire A, questionnaire B and questionnaire C (Appendix 1). Table 5.1 shows the different categories in the different questionnaires and their questions. Note that survey questions (Q12, Q13, Q14 and Q15) are relevant to two categories (consumption behavior and prices and economic influence).

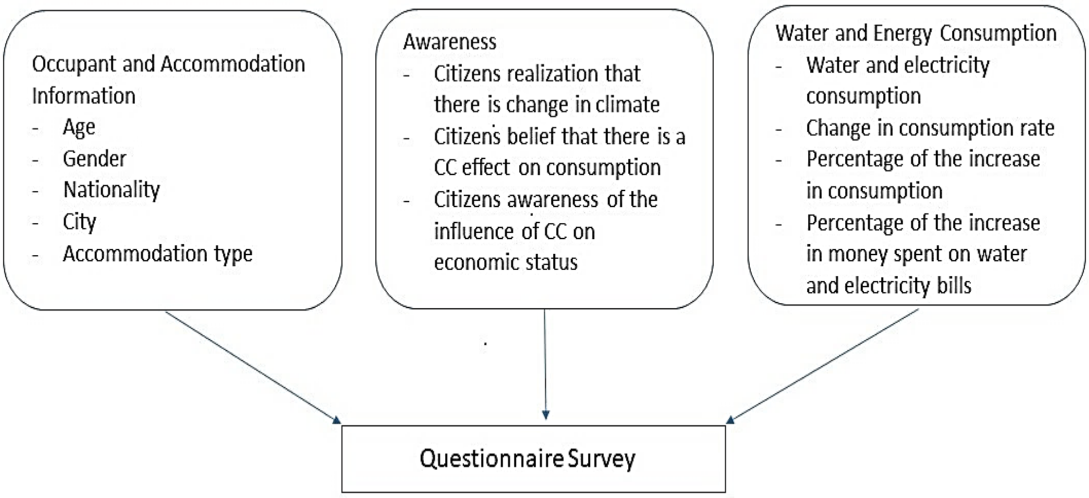


Figure 5.1: Three groups of survey content and coverage area

A pilot survey was conducted to ensure that the questions are clear and answerable (Appendix 2). Feedback from a volunteer was received and the survey was modified accordingly.

Table 5.1: Five categories and survey questions

Category	Survey Questions
Consumption behavior	Q2, Q3, Q4, Q5, Q6 Q7, Q12, Q13, Q14, Q15
Prices and Economic Influence	Q11, Q12, Q13, Q14, Q15
Lands and Building Prices	Q1, Q8, Q9, Q10
Climate Realization	Q16, Q17, Q18, Q19
Climate Awareness	Q20, Q21

Three hundred and twenty-one (321) surveys were collected in the three cities of the study area. Abu Dhabi city has the largest population, followed by Al-Ain, and then Al Dhafra (SCAD, 2017), reported that the total population of the Emirate of Abu Dhabi is 2,908,000 people, 1,807,000 (63%) live in Abu Dhabi city, and about 766,900 (26%) live in Al Ain region, leaving 334,000 (11%) in Al Dhafra region. The surveys were distributed according to the population percentages of the cities. Descriptive statistical methods and nonparametric tests were used to compare quantitative data at different levels of the sociodemographic variables.

5.4 Results

Of the 321 collected surveys, 58.3% (187) of the respondents were males and 41.7% (134) were females. The Emirati respondents comprised 54.5% of the total nationalities; 5.9% were from the GCC; 35.8% were non-Emirati Arab, 3.4% were Asians; and 0.3% were other nationalities. The youngest group of respondents ranged between the ages of 20 and 30 and comprised 24.9% of the total respondents, 29.9% were between 31 and 40, 31.5% between 41 and 50, 10.3% are between 51 and 60 and 1.9% are between 61 and 70. The results showed that a substantial portion of the respondents is below 30 years old, part of the questionnaires were distributed among UAE University students who ages are ranging between 20-30 years.

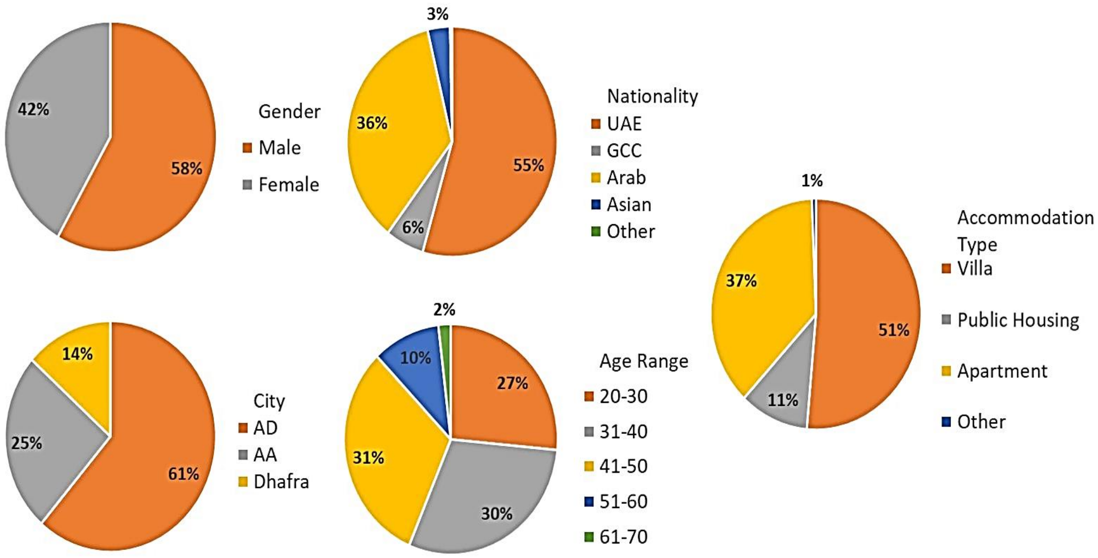


Figure 5.2: Demography and general information

The students were asked to answer the question with the assistant of their parents because they will not be able to compare today's climate and consumption of water and energy as well as costs of bills to the past twenty years. Yet it seems like the students wrote their names and ages instead of their parents'. For accommodation type, 51.4% were villas, 10.6% public housing, 37.4% apartments and 0.6% were other types. Figure 5.2 shows the pie charts of the survey demography and general information. To measure the internal consistency of the questionnaire groups, the reliability test (Cronbach's Alpha) in SPSS statistical software was used. The results show that the value is more than 70% for all questionnaire groups, which indicates that the data is reliable (see Table 5.2). About 47.6% of the respondents agreed that they are considering moving to another city with lower prices if prices continued to increase. Seventy-two percent (72%) of the respondents declared that they are consuming more water for showering than they used to 20 years ago and 57% said that they are using the AC at their houses for more hours per day than they used to 20 years ago.

Table 5.2: Cronbach's Alpha values of three questionnaire group

Questionnaire	Cronbach's Alpha
Questionnaire A	0.892
Questionnaire B	0.875
Questionnaire C	0.775

Fifty-six percent (56%) of the respondents think that climate change is controlling their water and energy consumption. Forty percent (40%) think that climate change is affecting land prices while 32% responded neutrally. Figure 5.3 shows a clustered bar chart illustrating the relationship between question 20 (see Appendix 1) and gender.

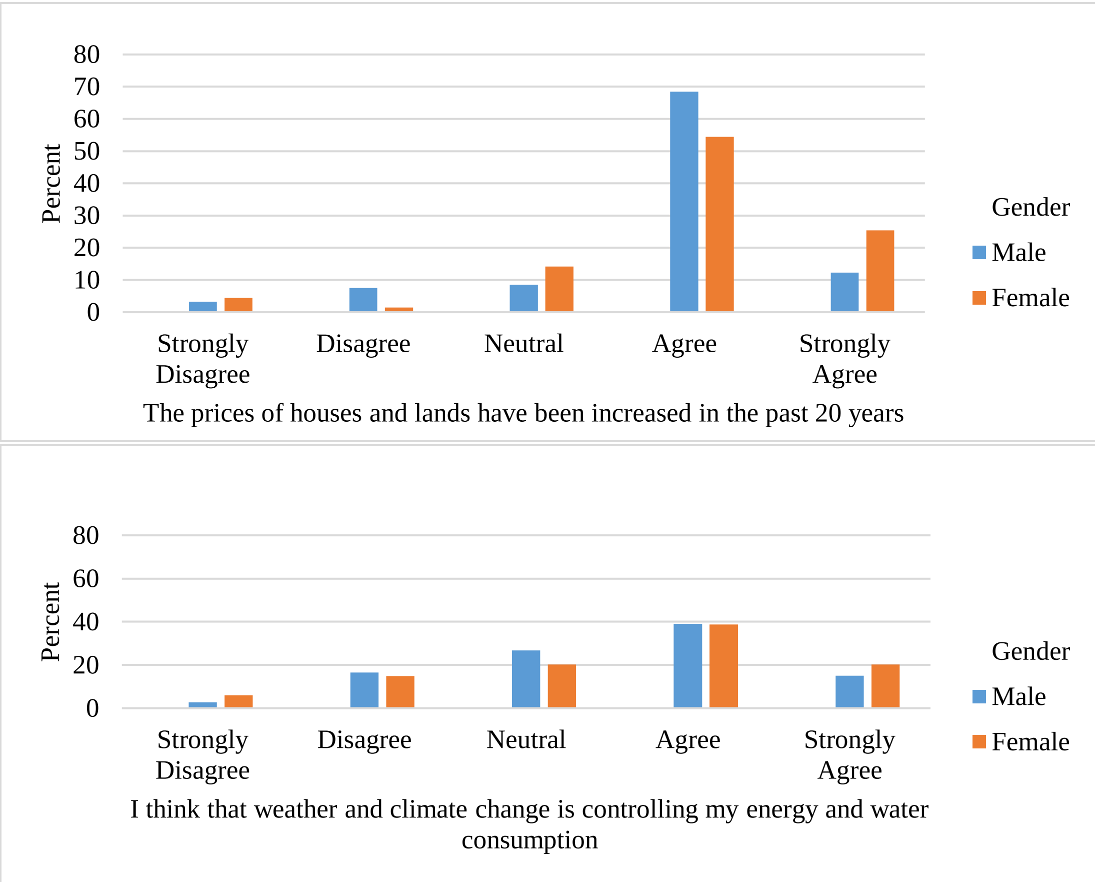
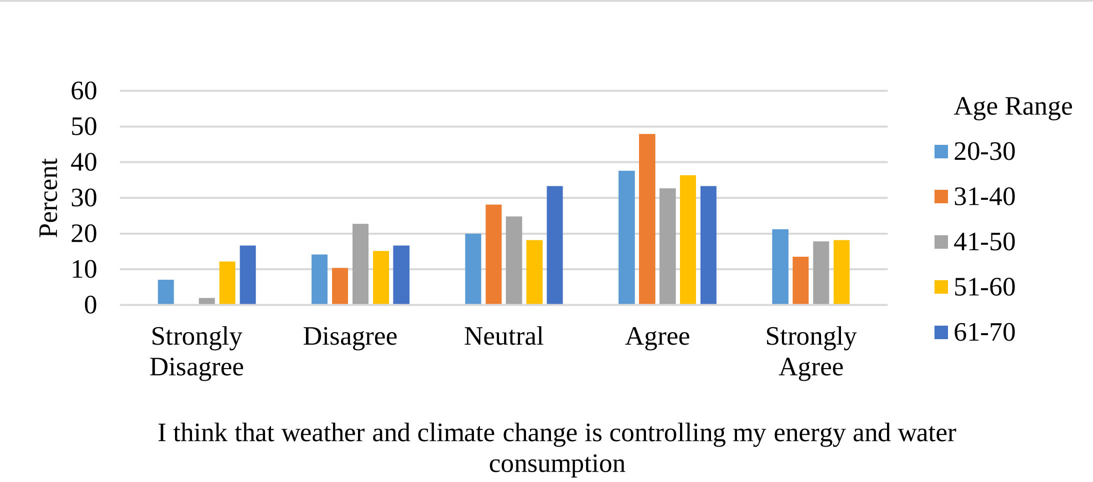


Figure 5.3: Gender vs prices and awareness

It was found that males are more likely to think that climate change is controlling their water and energy consumption. The second bar chart shows how the numbers of males and females responded to question 1; males are in agreement that the prices of houses and lands increased in the past 20 years. Comparing age groups with question 4 and question 20 showed that respondents aged between 30 and 40 are using AC for more hours per day than other respondents, and that they think that climate change is controlling their water and energy consumption (see Figure 5.4). It was found that respondents from Abu Dhabi consume the most water and energy compared to the past 20 years, followed by Al-Ain and then Al Dhafra (see Figure 5.5).



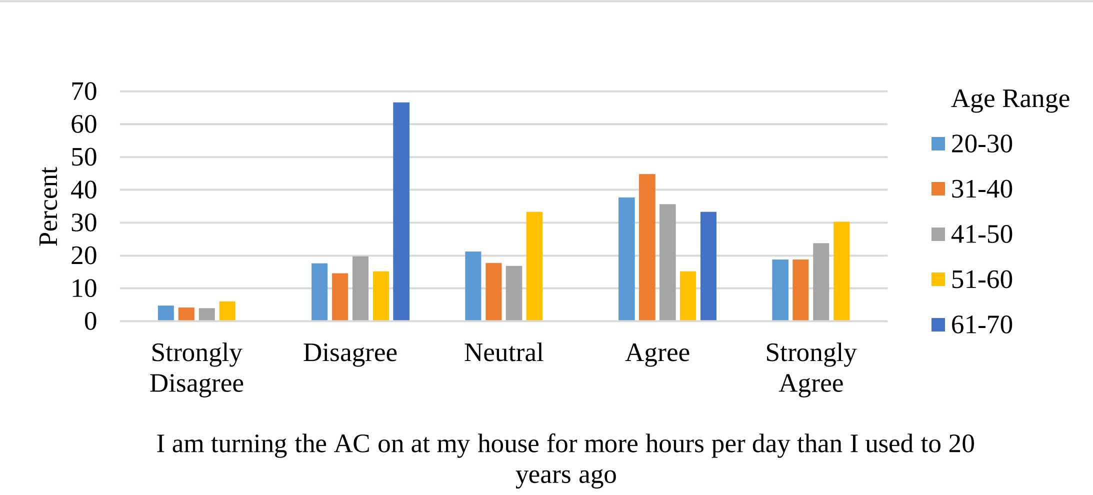


Figure 5.4: Age vs consumption and awareness

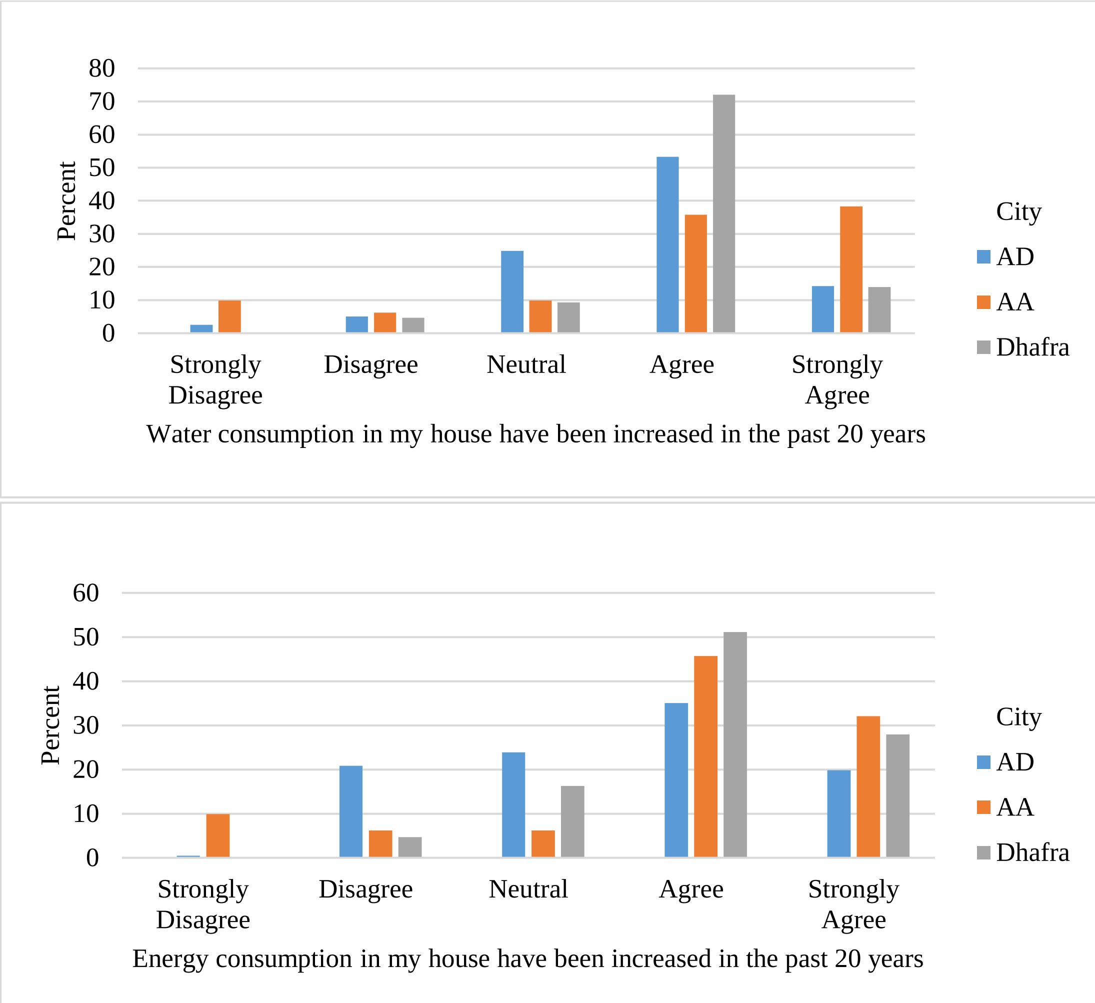


Figure 5.5: City vs consumption

Based on accommodation type, respondents living in villas consume more water and energy compared to other accommodation types (Figure 5.6). When asked about their consideration of moving to another city with lower accommodation costs if prices continued to increase, the majority of the respondents from the UAE disagreed or stayed neutral, while non-Emirati Arab respondents agreed that they would move to a different city.

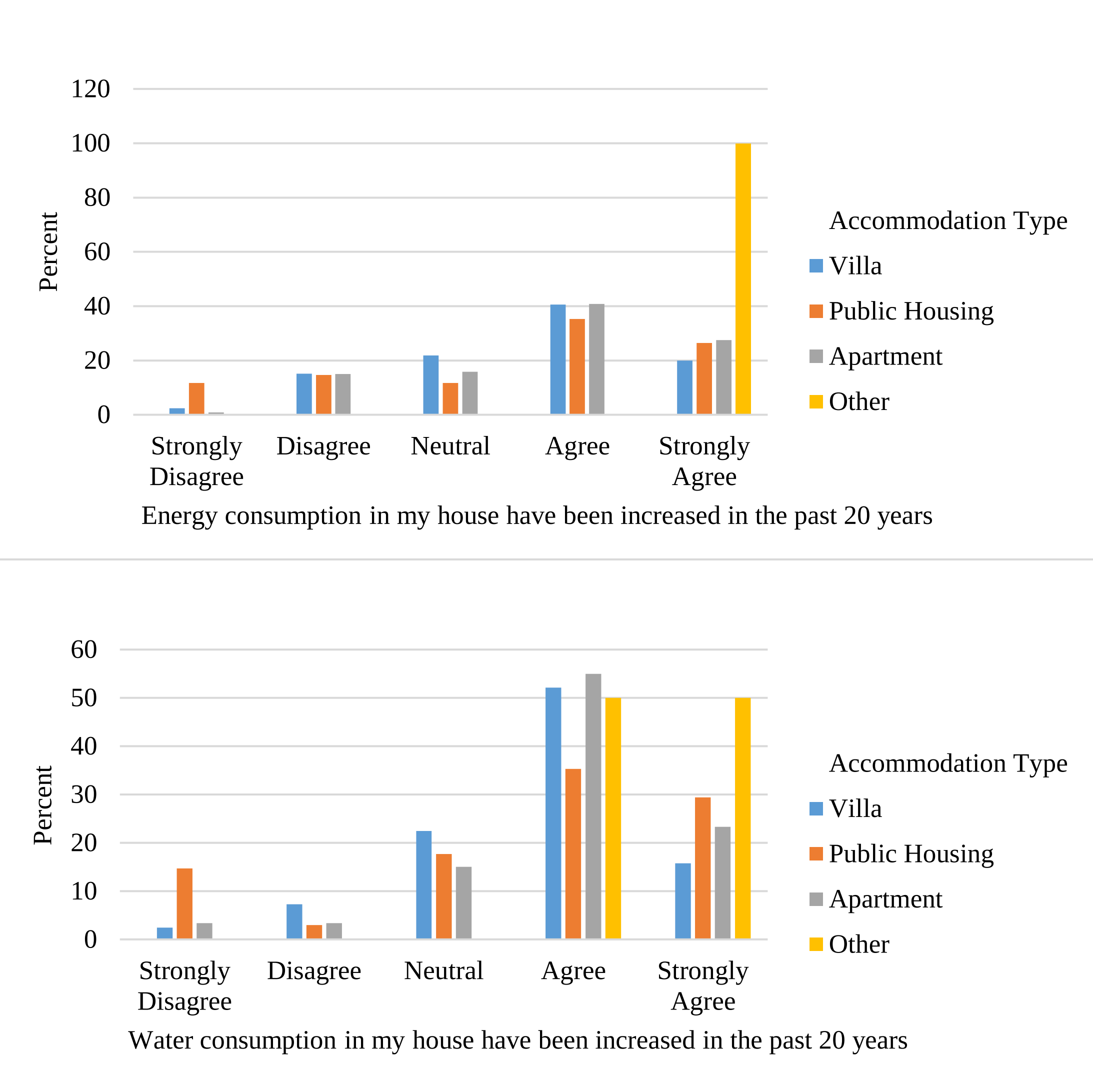


Figure 5.6: Accommodation type vs consumption and awareness

Most of the respondents agreed that water and electricity bills have increased in the past 20 years (see Figure 5.7). Due to the ordinal nature of the data, nonparametric techniques were used to analyze Likert-type data. These techniques included a Mann-Whitney test for a difference in scoring tendencies between two groups demographic variables (Gender). And a Kruskal-Wallis test for a difference in scoring tendencies of participants between demographic variables of more than two groups. Therefore, for gender 2-variables (Mann Whitney Test) in SPSS was used, while for nationality, living area, age and accommodation type K-variables (Kruskal-Wallis Test) was used.

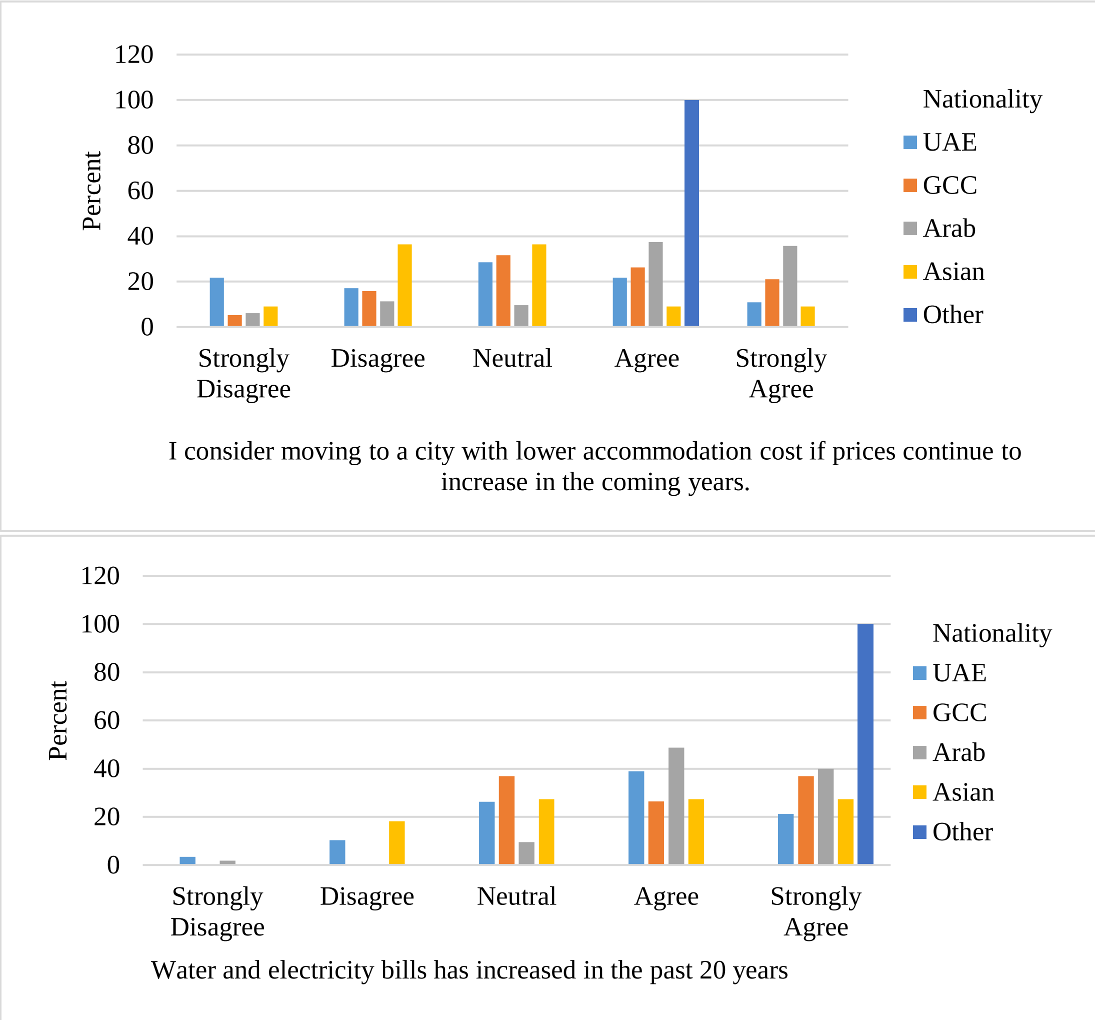


Figure 5.7: Nationality vs consumption and awareness

The value of the Asymptomatic significance is shown in Table 5.3. The data support that there is a significant difference between nationalities in terms of responses to question 3, ($P<0.05$), and this can be applied to the living area as well. Responses to question 4 and 5 "duration of using AC", varied significantly with the nationalities, living area and accommodation type. Significant difference in the responses to question 6 "water consumed for showering", was observed in "nationality and accommodation type".

There were significant differences found in responses to question 7 “utility bills” depending on the nationality, age and accommodation type. For questions 8 and 9 “size of lands and cost of building”, there were significant differences in responses to depending on gender and nationality in addition to age in the case of the response to question 9. Significant differences were also found in responses to question 10 “cost affecting the decision of building houses” depending on nationality and accommodation type.

Table 5.3: Values of Asymptomatic significance for twenty-one survey questions

Q#	Gender	Nationality	Living Area	Age	Accommodation
1	0.064	0.053	0.488	0.010*	0.098
2	0.302	0.043*	0.010*	0.117	0.122
3	0.106	0.002*	0.001*	0.076	0.097
4	0.973	0.000*	0.009*	0.428	0.001*
5	0.277	0.000*	0.005*	0.354	0.000*
6	0.920	0.001*	0.216	0.234	0.002*
7	0.139	0.000*	0.240	0.004*	0.013
8	0.026*	0.026*	0.248	0.119	0.360
9	0.021*	0.000*	0.063	0.002*	0.035*
10	0.413	0.000*	0.110	0.125	0.003*
11	0.001*	0.000*	0.000*	0.000*	0.000*
12	0.524	0.000*	0.644	0.036*	0.000*
13	0.245	0.000*	0.390	0.013*	0.000*
14	0.155	0.000*	0.073	0.020*	0.001*
15	0.034*	0.000*	0.076	0.067	0.000*
16	0.010*	0.230*	0.049	0.015*	0.608
17	0.746	0.001*	0.768	0.289	0.031*
18	0.036*	0.000*	0.292	0.004*	0.001*
19	0.035*	0.001*	0.125	0.221	0.342
20	0.502	0.000*	0.000*	0.307	0.134
21	0.001*	0.000*	0.000*	0.000*	0.000*

*Sig. at 0.01 level.

For question 11 “moving to another city”, there were significant differences based on all variables. Significant differences in responses to question 12 “increase in amount of energy consumed” were observed in the responses depending on the nationalities and accommodation type. Data also showed that there were significant differences in responses to questions 13 “increase in amount of water consumed” and 14 “increase in utility bills” depending on the nationality, age and accommodation type, and differences were based only on the nationalities and accommodation type in the case of question 15 “prices of houses”. For question 16 “is summer getting hotter”, there were significant differences depending on the gender and age, while for the question 17 “is summer getting longer” response, there were significant differences depending on the nationalities and accommodation type. Significant differences were also found in question 18 “winter is colder than 20 years ago” depending on the gender, nationality, age and accommodation type. Significant differences were also found in the responses to questions 19 “amount of rainfall” and 20 “climate is controlling water and energy consumption” depending on the gender and nationality, and depending on the nationality and living area respectively. Question 21 “climate has an impact of land prices”, varied significantly for all the variables.

Questions were analyzed by category groups (the average of each category) with respect to the survey variables, except for accommodation type that was only compared with the consumption behavior (see Figures 5.8 to 5.13). The results showed that for the consumption behavior category, females (55%) were more likely to agree that their water and energy consumption has increased in the past 20 years. Seventy-two percent (72%) of the respondents of Al Dhafra think that their consumption had increased. Among the different nationalities, non-Emirati Arab were more likely to agree that they are consuming more water and electricity (66%). Respondents between the ages 20 and 30 years think that they consume more water and electricity (58%). Within respondents in different accommodation types, people living in public housing and other types of accommodation think that they consume more water and electricity (see Figures 5.9 and 5.10).

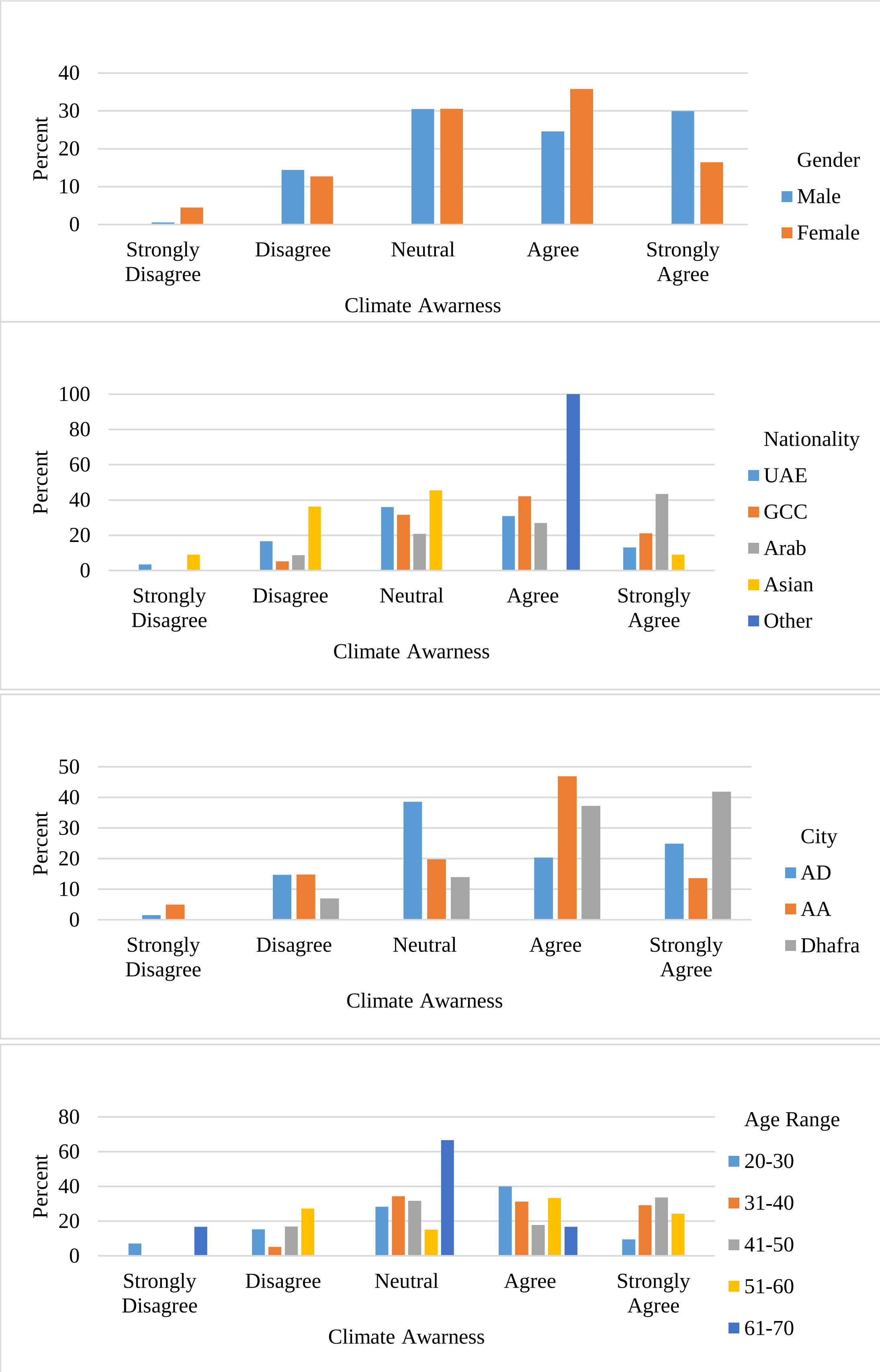


Figure 5.8: Climate awareness

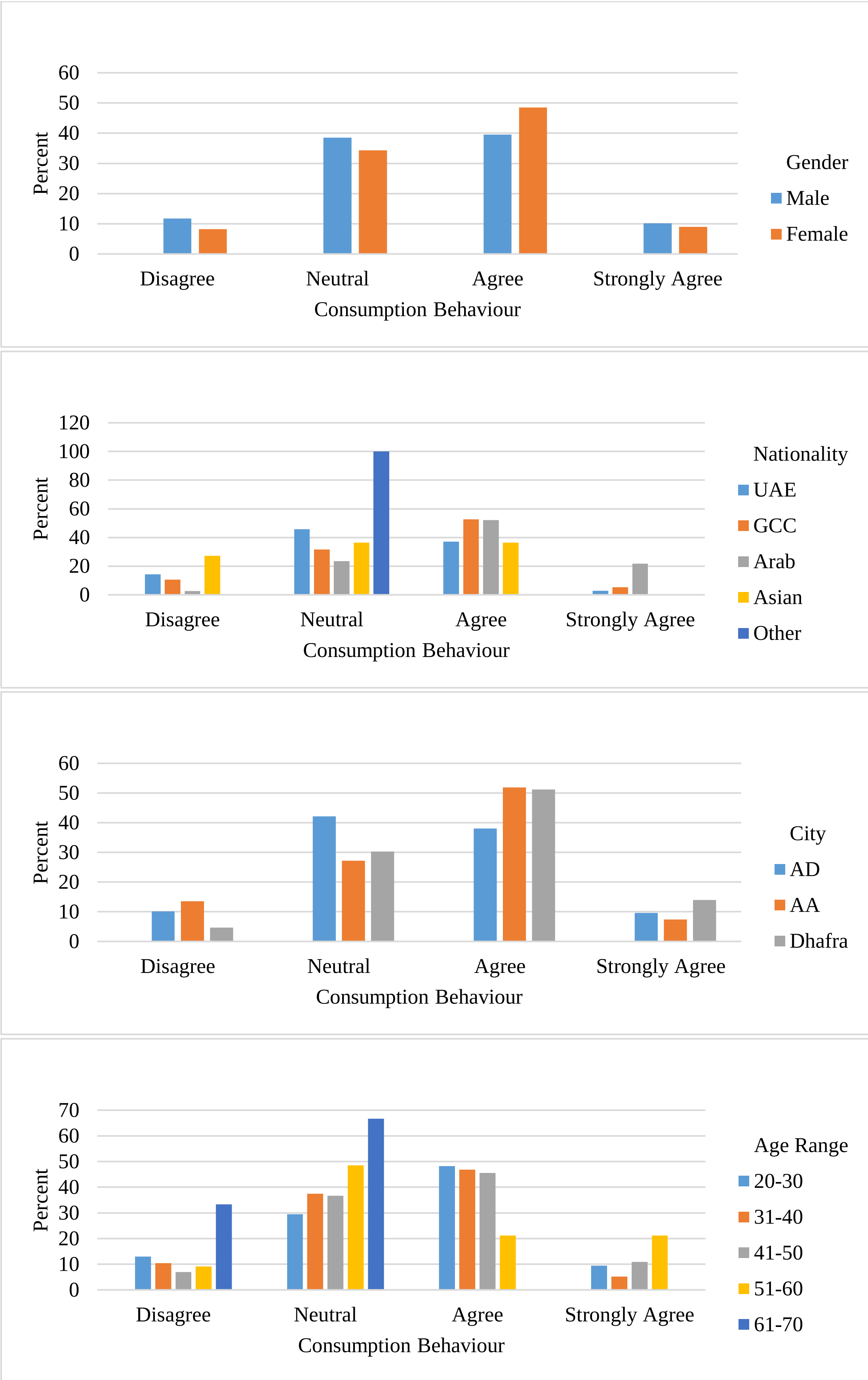


Figure 5.9: Consumption behavior

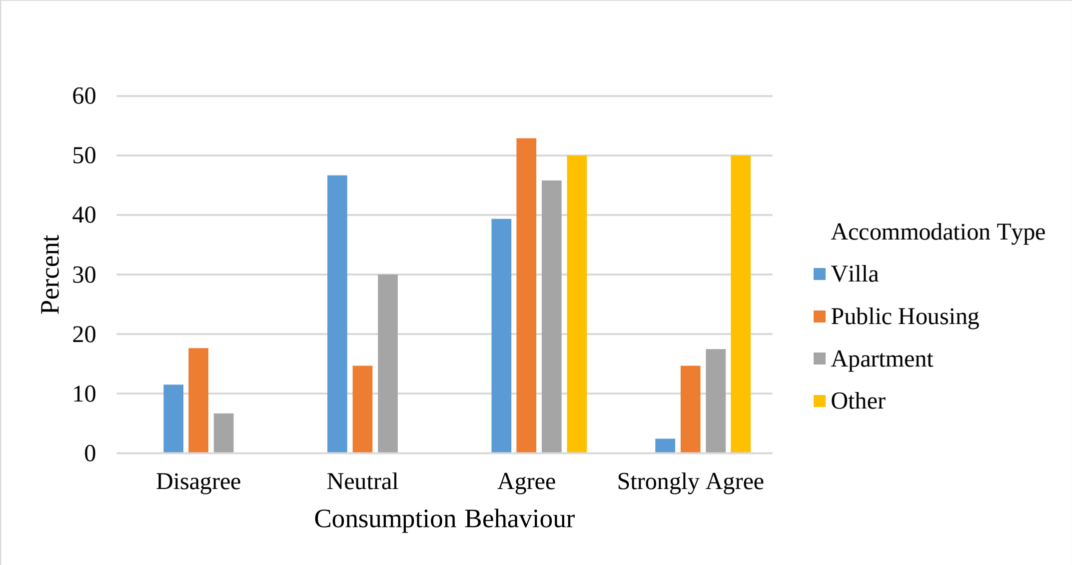


Figure 5.10: Consumption behavior and accommodation type

In the prices and economic influence category, it was found that 41% of males agreed that prices have increased and that there was an economic influence (Figure 5.13). Fifty-five percent (55%) of the respondents in Al Dhafra think that there is an economic influence. About 65% of the non Emirati-Arab respondents agreed that there are prices rising and economic influence and 50% of the respondents between the ages of 51 and 60 think that prices have increased and that there was an economic influence. In the lands and building prices category, the results showed that 80% of females think that prices of lands and buildings have increased compared to the past 20 years. Seventy-six percent (76%) of respondents in Al Dhafra agree that there's been an increase, along with 65% of respondents in Abu Dhabi and 63% of respondents in Al-Ain (Figure 5.12). Among nationalities, 98% of other nationalities and 93% of non-Emirati Arab think that there's been an increase. Within age ranges, 88% of respondents between 51 and 60 think that there has been an increase.

In climate realization category, about 74% of the females think that climate is changing, while 70% of the males are aware of climate change (Figure 5.11). The highest percentage is in Al Dhafra (83%), followed by Al-Ain (75%), and then Abu Dhabi (67%). Non-Emirati Arab tend to be more aware of the occurrence of climate change (84%) and respondents between ages of 41 and 50 had the highest percentage (73%). The last category is climate awareness. It was found that males are more aware of climate change, (53%), and geographically, respondents in Al Dhafra are more aware of climate change (80%). Other nationalities (98%) and non-Emirati Arab (72%) have the highest percentages. Respondents between 51 and 60 years are more aware of climate change.

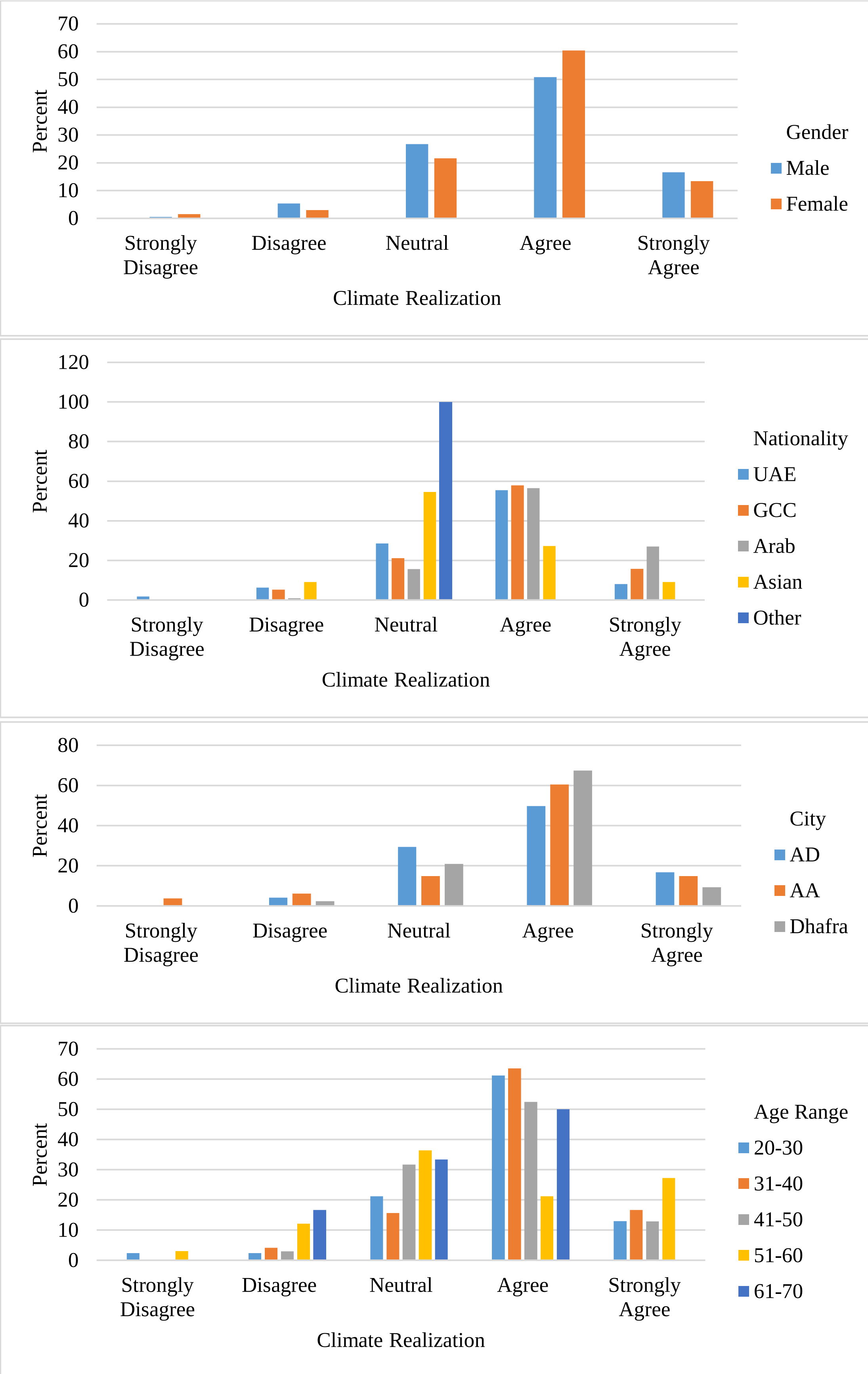


Figure 5.11: Climate realization

Figure 5.12: Lands and building prices

Figure 5.13: Prices and economic influence

5.5 Discussion

The rapid economic change, the altered life-styles and the social and cultural changes has influenced our behavior in different aspects. The results of this study, showed that 58% of the Emiratis agreed that their consumption of energy has increased, while 79% of non-Emirati Arab and 66% of Gulf Cooperation Council (GCC) nationals said that their energy consumption has increased in the past 20 years. Additionally, 41% of the Emiratis used AC more hours while 79% of non-Emirati Arab and 74% of GCC nationals responded that they used the AC for more hours per day than they used to 20 years ago. According to SCAD (2017), Electricity consumption per capita in Abu Dhabi in 2010 was 18.7 and 20.8 in 2017. In a study on Abu Dhabi city by AlNaqbi et al. (2012), they found that the behavior of expatriates is greener than that of Emirati nationals.

The water and electricity tariffs vary in UAE, based on AADC (2017), Emiratis pay 2.09 AED per 1000 liter for water while expats pay 7.84 AED per 1000 liter. For electricity, Emiratis pay 6.7 fils/kWh while expats pay 26.8 fils/kWh. This could explain the variation in energy and water consumption between Emirates and other nationalities in Abu Dhabi. Whitmarsh et al. (2011), found that 25.2% of a sample agreed that ”climate change is just a natural fluctuation in Earths temperatures”, and 22.4% agreed that ”they were uncertain about whether climate change is actually occurring”. Many neutral answers were received which can be explained to mean that the respondent was unaware of climate change or did not believe that it is having a real influence on the planet or on the daily life.

Among 733 respondents to a survey in the UK by Pandve et al. (2011), 91.68% of respondents commented that the global climate is changing. This study showed that, within the 321 respondents, 88% of the Emiratis believe that weather and climate change is affecting their energy and water consumption. Lorenzoni and Pidgeon (2006), reported that climate change is only the third most important environmental issue that most people in Europe worry about and it is considered secondary in its importance compared to other environmental, personal, and social issues. Respondents over the age of 40 tend to be more conscious and aware of climate change, because they experienced the climate from 20 years ago and the changes through this period are thus most noticeable to them. Males tend to agree that there is an economic influence, due to the increase in prices; the reason for this is that males generally bear the financial responsibility for their families, so they are more exposed to prices and tend to be directly concerned with their economic status.

They also pay monthly bills for water and electricity and any increase in prices would be noticeable to them. Younger respondents agreed that they consume more water and electricity; the consumption behavior of younger groups can be less responsible due to their age. Based on the study findings, question 3 (Energy consumption in my house has increased in the past 20 years), there was a significant difference between nationalities and living area. This is normal due to the different backgrounds, cultures and behaviors of different nationalities. Living area (Abu Dhabi, Al-Ain and Al Dhafra) have changed in terms of building design and populations in the past 20 years, so it is expected that consumption will vary when compared to different variables.

Respondents living in public housing agreed that they are consuming more energy compared to the past 20 years. This can be attributed to the construction materials used in old public housing, which was not based on new environmental codes and regulations. In addition, older cooling systems can cause more energy consumption. Lorenzoni and Pidgeon (2006) found that, generally, individuals have a limited understanding of human contributions to changing climate. This corresponds with the findings of Eiser et al. (2002) that state that there is a lack of a directly experienced link between the causes of climate change and their consequences.

The results of this study showed a group of respondents who choose to have a neutral answer to questions that are related to climate change awareness. The reason could be attributed to their limited understanding, or a cognitive disconnect between climate change, what it can lead to, and how that will influence their lives.

5.6 Conclusions

In hot regions, energy consumption for cooling is relatively high due to high temperatures and humidity levels. With the increasing climate temperature since the 1960s and the predictions of similar future trend, the consumption of water and electricity will definitely be affected. Within the 321 respondents of this study, 72% of them declared that they are consuming more water for showering than they used to do 20 years ago and 57% of them said that they are using AC at their houses for more hours per day than they used to do 20 years ago. It also was found that about 47.6% of the respondents agree that they are considering moving to another city with lower prices if the prices continued to increase. Most of the respondents agreed that utility bills have increased in the past 20 years. Respondents in Al Dhafra are more aware of climate change (80%). Younger respondents agreed that they consume more water and electricity, the consumption behavior in younger groups can be less responsible due to age.

Going back to the research questions, the energy consumption is influenced by the climate change in Abu Dhabi. While the residents of Abu Dhabi are not clearly aware of how climate change impacts their energy and water consumption, the general conclusion is that climate has an influence on energy and water consumption and climate awareness campaigns are needed to help citizens understand the influence of climate change on their lives.

Chapter 6: The Impact of Climate Change on Agricultural and Livestock Production and Groundwater Characteristics in Abu Dhabi, UAE

6.1 Overview

Agriculture is located at the crossing point between ecosystems and society, where changes in the global environmental conditions affect agricultural activities. The total agricultural area in Abu Dhabi Emirate in 2017 was 749,868 donums. This study had two main objectives; first, to understand how agricultural and livestock production have changed and how these changes are relevant to socioeconomic statuses; second, to assess climate change's impact on agricultural and livestock production through groundwater characteristics. Three hundred and one (301) surveys were distributed and collected throughout the three main regions in the Abu Dhabi Emirate (Abu Dhabi City, Al-Ain City, and Al Dhafrah). The results indicated that approximately 68% of the respondents in Al-Ain agreed that it is currently much easier and more profitable to manage a farm than it was 20 years ago. Further, 39% of the farmers agreed that both production quality and quantity have improved over the past 20 years (Figure 6.5). About 51% of Emirati nationals agreed that production has changed over time. The farmers aged between 51-60 years also agreed that there has been a change in production over time. Half of the farm owners agreed that production has changed, while a majority of the workers provided neutral responses on this topic. While a number of both owners and workers agreed that both production and income levels changed, more respondents disagreed than agreed that these changes had occurred. Finally, the farmers aged between 51-60 years agreed more that the groundwater levels and quality had changed over the past 20 years.

6.2 Introduction

Agriculture is located at the crossing point between ecosystems and society (Olesen and Bindi, 2002). Changes in the global environmental conditions affect agricultural activities, but these activities contribute nearly 20% of the greenhouse gas emissions (methane and nitrous oxide in particular) (Rosenzweig and Hillel, 2000). Climate is the main determinant of agricultural productivity, and agriculture's processes of food and fiber production heavily burden the environment (Ibrahim et al., 2015). It is expected that climate change will affect agriculture in various ways across the globe (Parry et al., 1999). Those effects are highly dependent on the current climatic and soil conditions, the pathways of change, and a region's ability (based on infrastructure and resources) to survive the change (Olesen and Bindi, 2002). Based on Stocker et al. (2013) Summary for Policymakers in an Intergovernmental Panel on Climate Change Report, anthropogenic influences have been altering the global water cycle since 1960. Anthropogenic influences have magnified moisture content in the atmosphere, which led to global-level changes in the precipitation patterns over land. Currently, cultivated ecosystems have replaced natural vegetation in many areas of the world for the purposes of growing crops. Unfortunately, many of these cultivated areas have been abandoned for cultural, economic, and sustainability reasons (McGuire et al., 2001).

Past experiments have demonstrated that increasing temperatures will generally be beneficial for many field-grown vegetationetable crops, as this crop production can continue to expand northwards. Temperature increases in certain areas will allow for longer harvesting seasons, leading to continuous market supplies for longer periods throughout the year (Olesen and Bindi, 2002). According to the

Statistics Centre Abu Dhabi (SCAD)'s 2018 yearbook, horticultural crops covered approximately 5,118 donums of the total cultivated areas in Abu Dhabi Emirate in 2017 (SCAD, 2018). The main effects of the climatic warming that is projected for the protected crops would be changes in the greenhouses' heating and cooling requirements (Olesen and Bindi, 2002). As time passes, scientists are becoming more confident that an increase in greenhouse gases will lead to a rise in global temperatures (Houghton et al., 1996). Developing countries have thus become more concerned about climate change's economic impact on agriculture (Watson et al., 1996). Developing countries largely rely on climate-dependent agriculture; this dependence, in conjunction with poverty rates and rapid population growth, makes developing countries highly vulnerable to climate change (Porter et al., 2014).

Climate change will definitely influence crop and livestock production, hydrologic balances, and several other agricultural system components. Nevertheless, the human responses to these biophysical effects are complex and undefined (Ibrahim et al., 2015; Al-Maamary et al., 2017). Livestock production, like any other production process, releases carbon gases as a result of the energy and fertilizer used in the production process. Cultivated soil, land use change, and the animals themselves can also release carbon gases (Steinfeld et al., 2006; Gerber et al., 2010). The Ministry of Economy (MOE) reported that the amount of rainfall in the northern and eastern parts of the United Arab Emirates UAE increased from 31 mm in 2001 to 145.5 mm in 2006 (MOE, 2007). For these regions, it is possible that heavy rainfall periods will occur every 10 years (Rizk et al., 1997). In the Arab Gulf states, there is still a dilemma in regard to specifying the water stress levels. However, both virtual water trading and desalination can lessen the many surrounding water stress issues that might occur (Al-Maamary et al., 2017).

The majority of studies have only focused on the local impacts of climate change on the rainfall that feeds agriculture (Al Shidi et al., 2016). However, climate change's impacts on human societies will vary according to numerous factors, such as the amount of low-lying or arid land they inhabit and/or their degree of dependence on agriculture or aquatic resources (Bruce et al., 1996). Water vitally links climate change and agriculture. Water is the base upon which agriculture rests, yet climate change induced temperatures are expected to cause a wider variability in rainfall and temperatures (Sanderson and Curtis, 2016).

In the UAE, there has been both a reduction in groundwater resources and an increase in demand for water, leading to stressful situations and limited natural water resources (Murad, 2010). Groundwater aquifers depend on precipitation, and precipitation is then highly dependent on the climate. Groundwater is the main freshwater source in the Arabian Gulf Countries' hydrological cycles, and this source (especially during droughts) provides water for daily human consumption, agriculture, industry, and other sectors (Kløve et al., 2014). Based on the above information, this study's research questions are the following: (1) Have agricultural and livestock production changed over the past 20 years in UAE? (2) Has climate change influenced the agricultural and livestock production in UAE? The research objectives of this study are twofold. First, this study aims to understand how agricultural and livestock production have changed and how these changes are relevant to socioeconomic statuses. Second, this study attempts to assess climate change's impact on agricultural and livestock production by analyzing groundwater characteristics.

6.3 Methodology

6.3.1 Study Area

Abu Dhabi is the capital and the largest UAE emirate by area (67,340 km^2), accounting for approximately 87% of the country's total land area (excluding islands). This emirate's topography is dominated by a low-lying sandy terrain dotted with sand dunes, a number of which exceed 300 m in height (in certain southern areas). Eastern Abu Dhabi borders the western fringes of the Al-Hajar Mountains. The mountain with the highest elevation in Abu Dhabi is Hafeet Mountain, which is located south of Al-Ain city and reaches approximately 1,300 m in height. The emirate is located in the tropical dry region. The climate is arid, and the region experiences high temperatures throughout the year with very hot summers. Abu Dhabi has warm winters and only occasionally experiences low temperatures. There are variations in regard to air temperatures among the coastal strip in Abu Dhabi City, the desert interior in Al Dhafra and Al-Ain City, and the areas of higher elevation. These areas together comprise the emirate's topography.

The total agricultural area in Abu Dhabi Emirate in 2017 was 749,868 donums. Al-Ain City had the largest area of plant holdings with approximately 452.503 donums, Al Dhafra had the second-largest area with 207.686 donums, and Abu Dhabi had the third-largest area with 89.679 donums. Based on the SCAD's 2018 statistical yearbook, the total amount of field crop production in 2017 was 234,230 tons, with 16,381 tons in the Abu Dhabi region, 163,056 tons in the Al-Ain Region, and 54,793 tons in the Al Dhafra Region.

6.3.2 Data and Method

Figure 6.1 displays the content and coverage area included in the study's survey. The survey content includes general information, production, costs, and income.

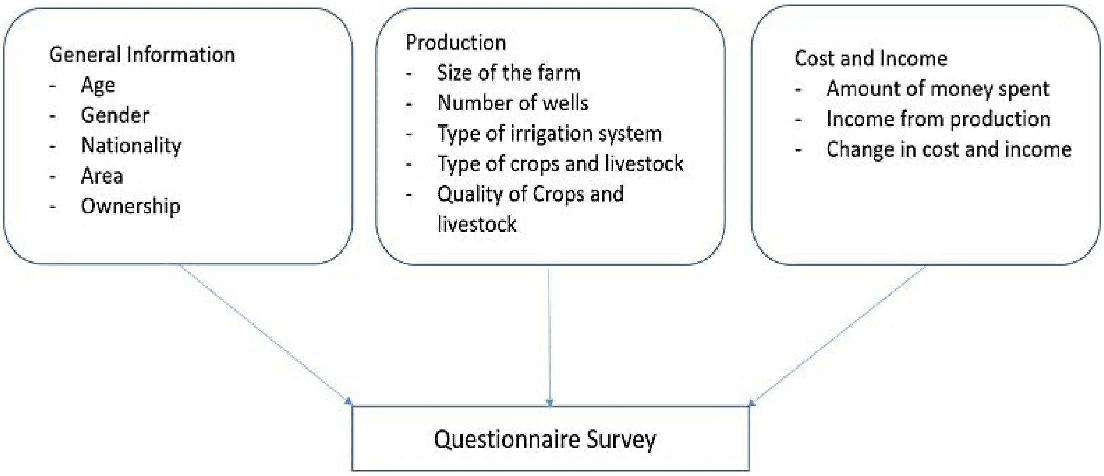


Figure 6.1: Survey content and coverage areas

The survey includes 38 questions that are grouped into three sectionsquestionnaires A, B, and C (Appendix 3). Table 6.1 shows the categories and questions that are included in each questionnaire. A number of survey questions (e.g., Q1, Q2, Q3, and Q6) are relevant to more than one category (e.g., production and cost of production and income). A pilot survey was conducted to ensure that the questions are clear and answerable (Appendix 4).

A principal component analysis (PCA) was applied to convert the possibly correlated variables into a set of values of linearly uncorrelated variables. However, this analysis did not show a realistic connection between the variables within the set of values. A pilot study was performed to assure that the questions were clear and answerable. A feedback was received from a volunteer who are a colleague that owns a farm, and the survey was modified accordingly. Three hundred and one (301) questionnaires were collected in the three cities of the study area.

Table 6.1: Four categories and survey questions

Category	Survey questions
Production (quantity and quality)	Q1, Q2, Q6 to Q19, Q24, Q29, Q32, Q34, Q35, Q37, Q38
Wells and groundwater	Q4, Q5, Q23, Q24, Q25, Q26
Income and cost of production	Q1 to Q3, Q6 to Q22, Q24, Q28, Q30, Q31, Q33, Q36-Q38
Change in production over time	Q20, Q26, Q27, Q28, Q30 to Q36

Questionnaires were distributed according to the regions' production percentages. Descriptive statistical methods were used, and nonparametric tests were used to compare the quantitative data at different levels of the sociodemographic variables.

6.4 Results

Of the 301 collected surveys, 300 of the respondents were male and one was female. The respondents included 162 Emiratis who own farms, 19 Arabs who work on farms, and 1120 Asians who also work on farms. In Al-Ain, 171 surveys were collected, 80 in Al Dhafrah, and 50 in Abu Dhabi. Approximately 50% of the respondents were aged between 31 to 40-years-old. Figure 6.2 displays the pie charts that represent the survey's demographic and general information. Respondents aged between 21 to 30 can give guessing answers linked to the earliest time they owned or worked in the farm and not twenty years ago. The percentage of this sample is not more than 5%. Cronbach's Alpha reliability test was conducted to measure the internal consistency of the questionnaire groupings. The results indicate that the Cronbach's

Alpha values were more than 80% for questionnaires B and C, while it was 56% for Questionnaire A. The acceptable values is more than 70% yet for Questionnaire A, the questions are general and will not affect the results. These results might have occurred because the questions are nominal, but the data still considered to be reliable (see Table 6.2). The survey includes five farm sizes, ranging between 10,000 sqft as small size farms to the big size farms, which are more than 1,000,000 sqft. Above 80% of the farms in Al-Ain are larger than 1,000,000 sqft. In Al Dhafrah, 60% of the farms are between 10,000 to 50,000 sqft in size, while 22% of the farms in Abu Dhabi are between 55,000 to 100,000 sqft in size.

Table 6.2: Value of Cronbach's Alpha of each questionnaire group

Questionnaire	Cronbach's Alpha
Questionnaire A	0.562
Questionnaire B	0.913
Questionnaire C	0.835

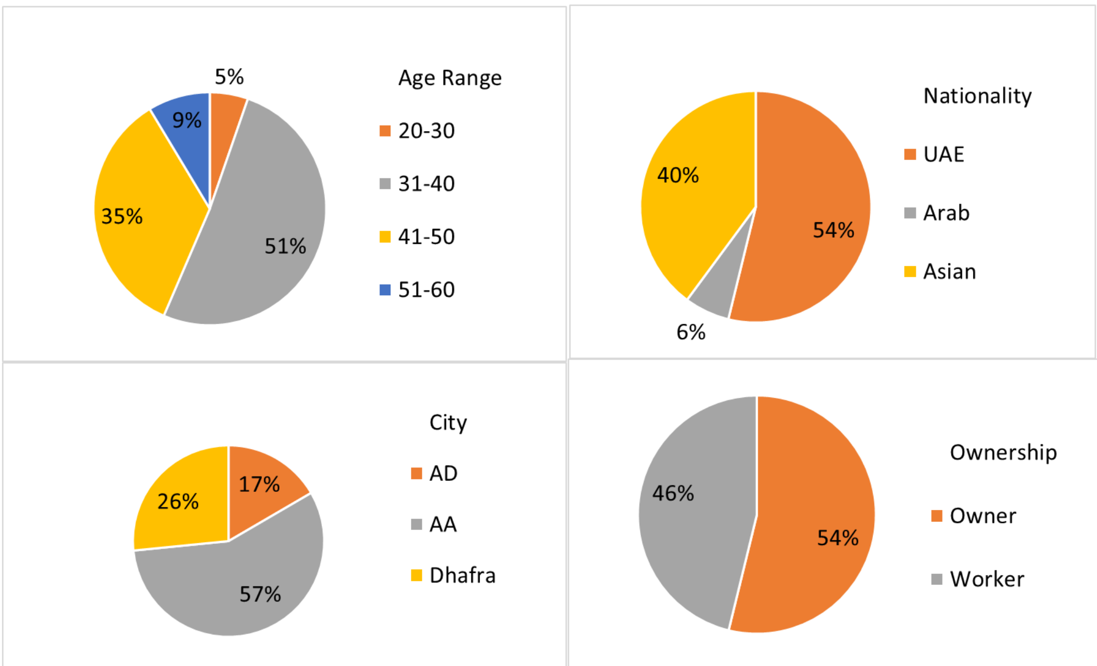


Figure 6.2: Demographic and general information collected from the survey

Nearly 60% of the farmers in Al-Ain use sprinklers for their irrigation systems, followed by the the Aflaj irrigation system (an old irrigation system used mainly for date palm planting) and the drip system. The majority of Abu Dhabi farmers use drip. See Figure 6.3. Cows comprise the largest number of livestock in Al-Ain (67%). In AI Dhafrah and Abu Dhabi, the largest number of livestock is camels (31%) and goats (24%), respectively. Since the category for other is undefined, it was excluded from the analysis.as irrigation system (25%), while 34% of farmers use the Aflaj system in Al Dhafrah.

Approximately 68% of the respondents in Al-Ain agreed that managing a farm nowadays is much easier and more profitable than it was 20 years ago. In Al Dhafrah, 29% of the respondents agreed with the profitability statement, while the majority of the Abu Dhabi respondents disagreed. In regard to the question that gauged whether farmers spent more money raising livestock over the past 20 years, the majority (60%) of Al-Ain respondents either disagreed or responded neutrally. Nearly 70% of the respondents in Abu Dhabi, and 34% of the respondents in AI Dhafrah, disagreed that raising livestock has been more expensive. More than 50% of the farm owners (UAE nationals) strongly agreed that their crop sales have increased over the past 20 years, while the majority of workers (Arabs and Asians) either disagreed or responded neutrally (see Figure 6.4). Approximately 65% of the farmers living in Al-Ain strongly agreed that the groundwater’s salinity has increased over the past 20 years.

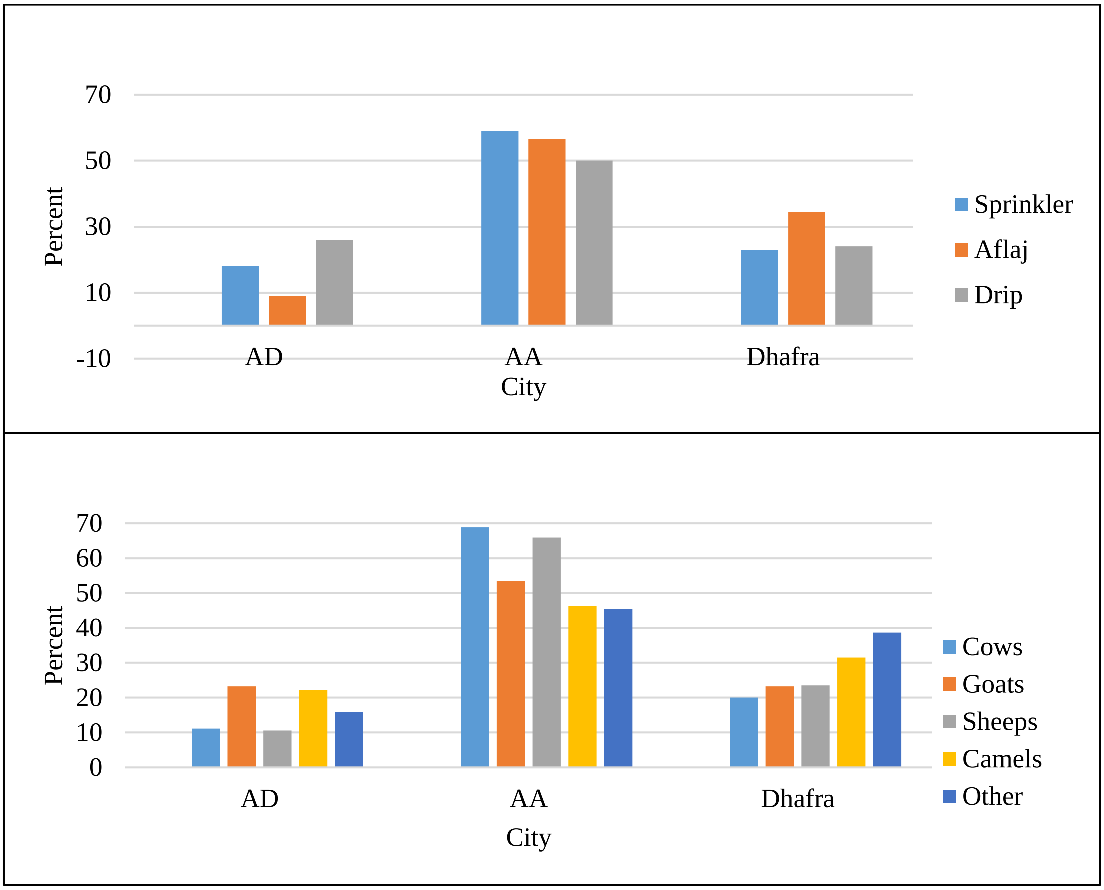


Figure 6.3: Irrigation systems and livestock production

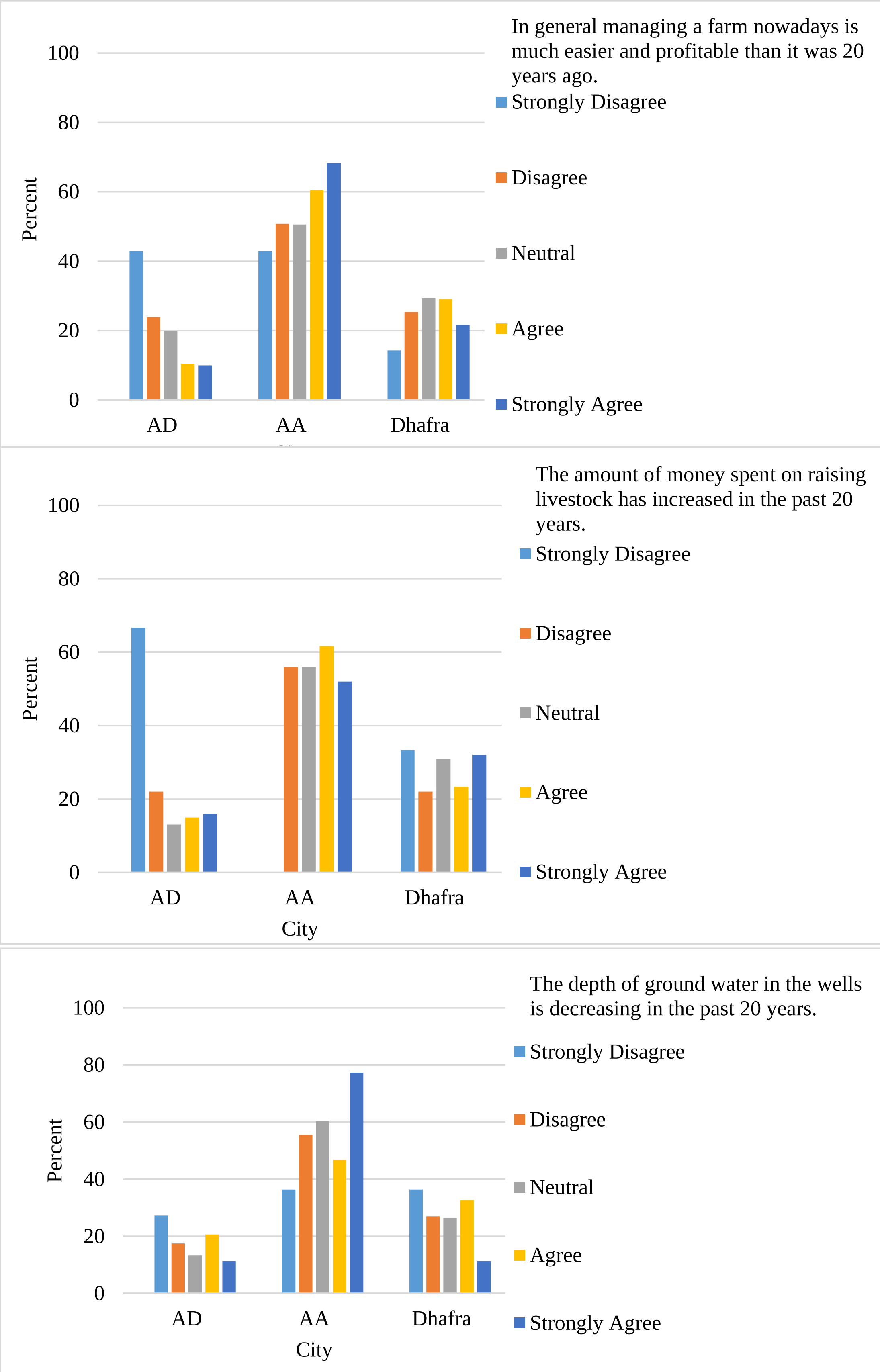
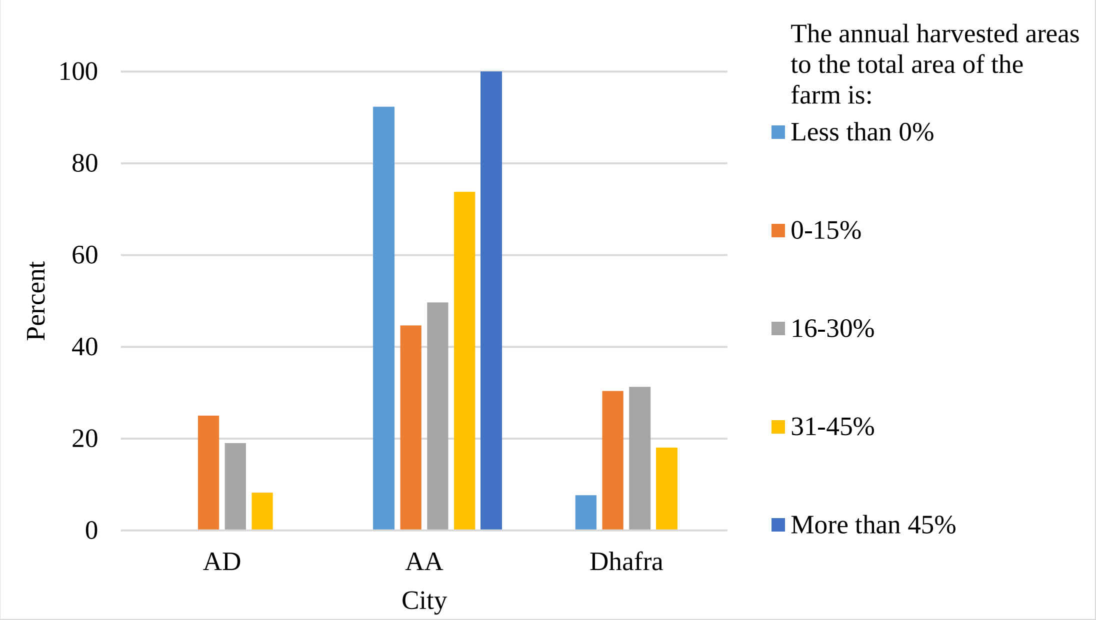
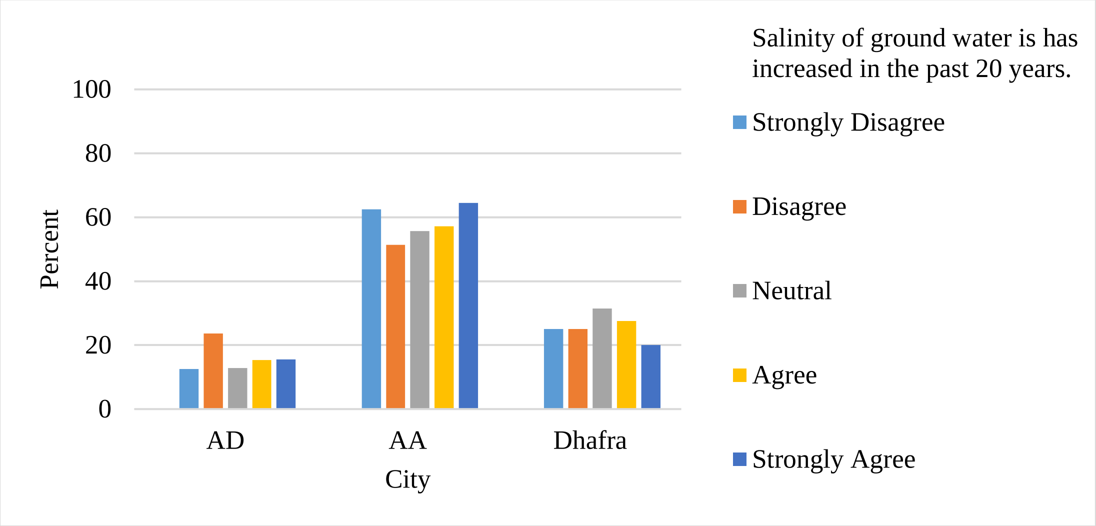


Figure 6.4: Survey responses in the different cities





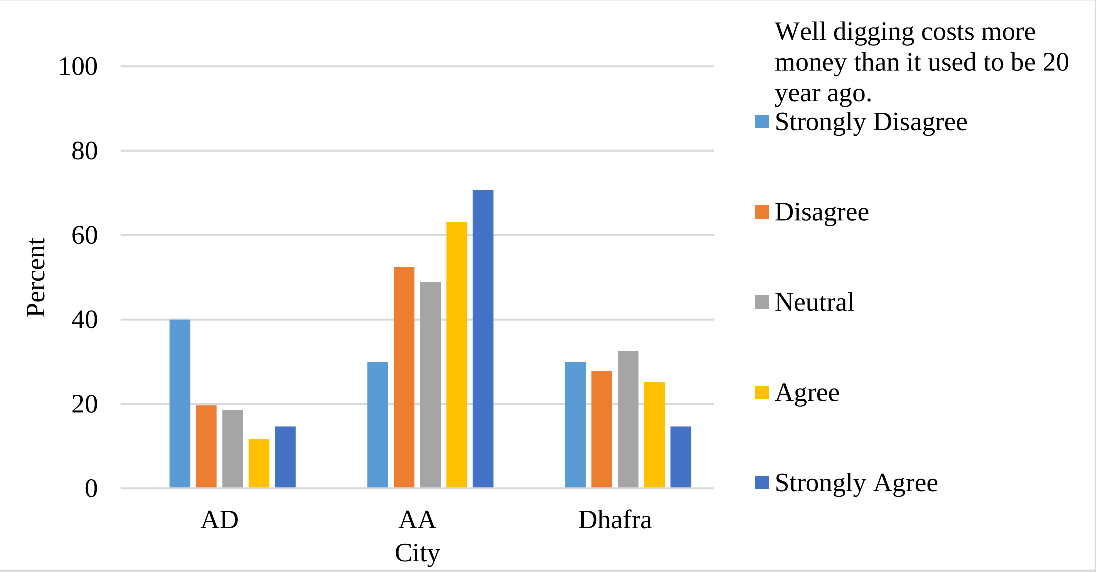


Figure 6.4: Survey responses in the different cities (Continued)

In Al Dhafrah, 28% of the farmers agreed with the groundwater salinity statement, while 24% of the respondents in Abu Dhabi disagreed. The respondents in Abu Dhabi and Al Dhafrah strongly disagreed that the depth of groundwater in the wells has decreased over the past 20 years, while 73% of the farmers in Al-Ain strongly agreed. The survey questions were analyzed with each category's average with respect to the survey variables. Gender was excluded because there was only one female farmer respondent. The results showed that, for the production category, 39% of the farmers agreed more that production quality and quantity has increased in the past 20 years (Figure 6.5). In Al-Ain, 46% of the respondents remarked that their production had increased. The farm owners agreed more that their production increasing (47%) in comparison to the workers. In regard to ages, approximately half (50%) of the respondents aged between 20-30 and 51-60 years reported that their production is increasing.

For the change in production over time category, it was found that 41% of the farmers in Al-Ain, 30% in Abu Dhabi, and 33% in AI Dhafrah agreed that there has been a change in production over time (Figure 6.6). The majority of the UAE nationals (51%) agreed that there has been a change in production over time, with 42% of Arabs and 28% of Asians also agreeing with this statement. The farmers aged between 51-60 years agreed that there has been a change in production over time. Approximately 50% of the farm owners agreed that there has been change in production, while the majority of the workers responded neutrally on this topic.

For the cost of production and income category, both the owners and workers agreed that there has been a change in both production and income (Figure 6.7). However, there were more workers who disagreed (50%) than workers who agreed

(35%) with this statement. In Al-Ain, 40% of farmers agreed that there have been changes in both income and production costs, while only 34% and 30% of the farmers in Al Dhafra and Abu Dhabi agreed, respectively. For the wells and groundwater category, farmers aged between 51-60 years agreed more compared to other group ages, that there have been changes in the groundwater level over the past 20 years (Figure 6.8).

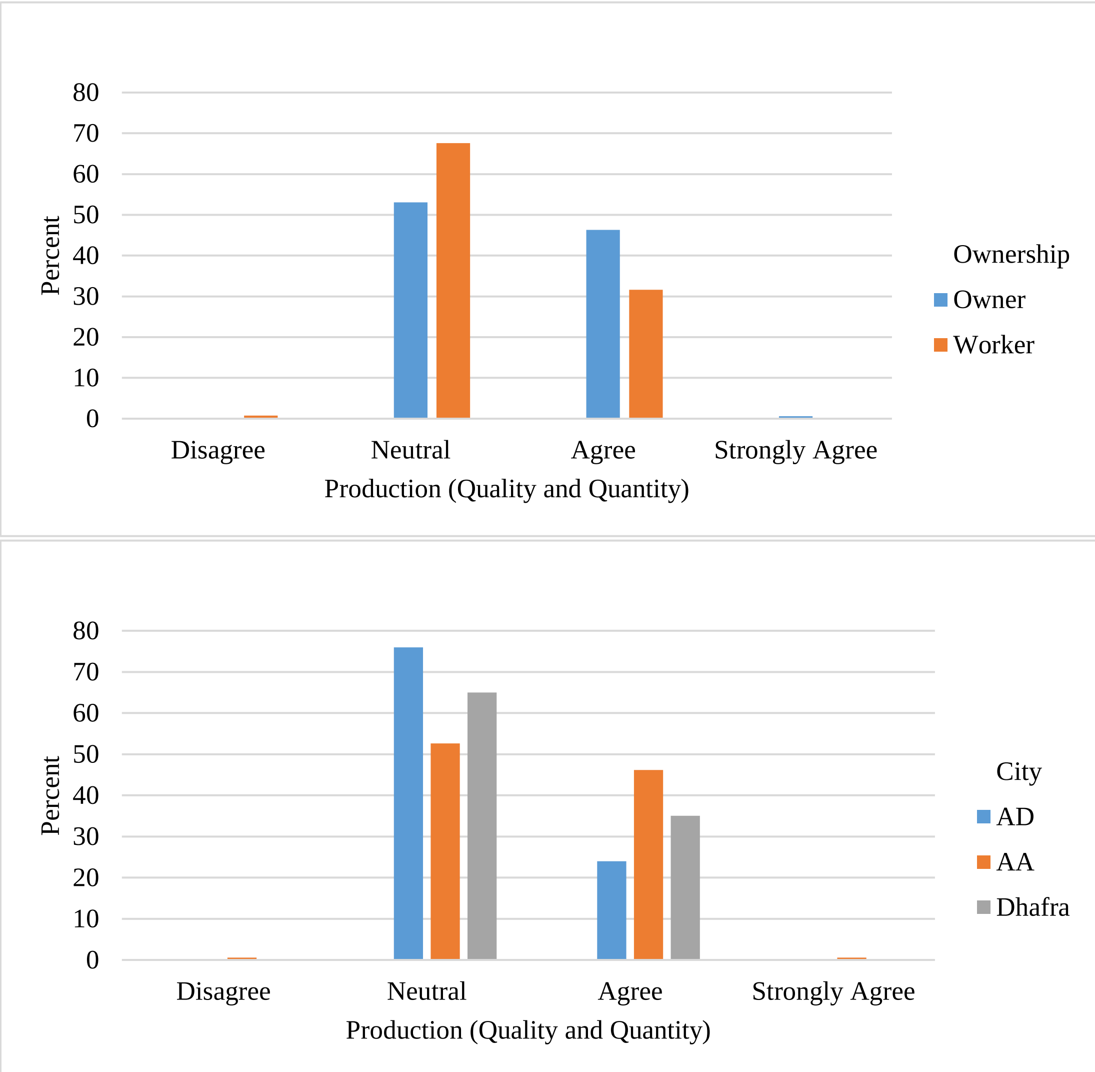
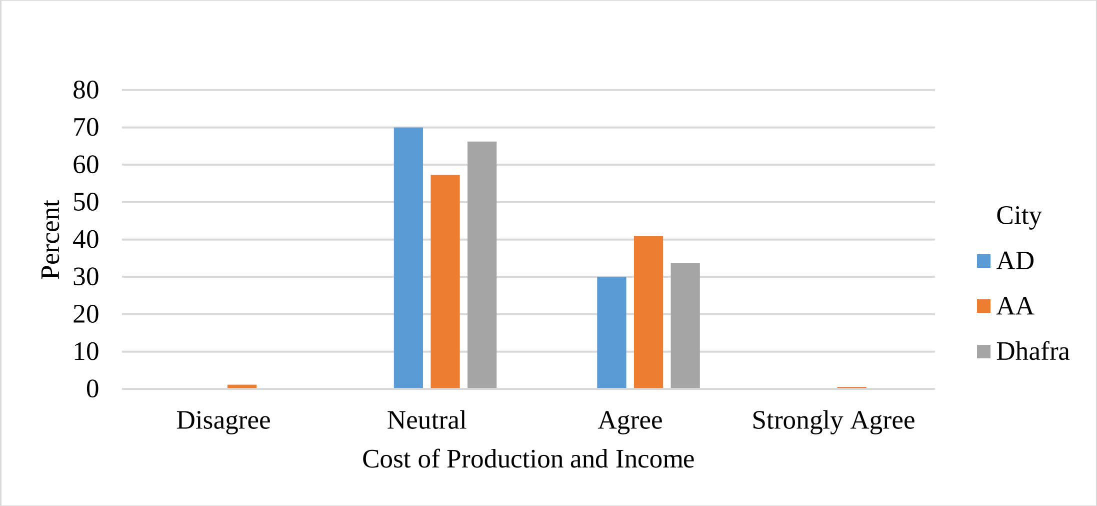


Figure 6.5: Survey responses on production quality and quantity questions



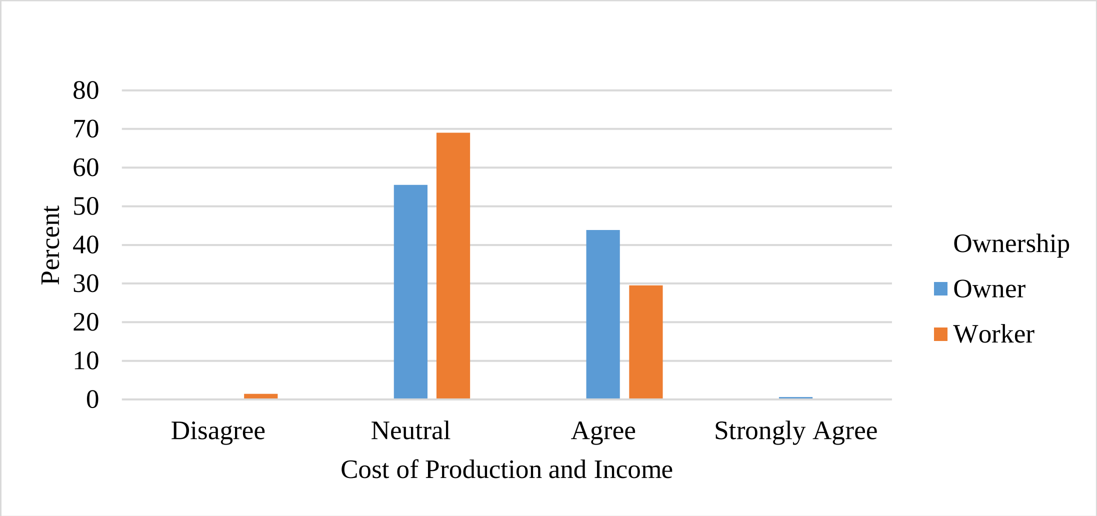


Figure 6.6: Survey responses on change in production over time questions

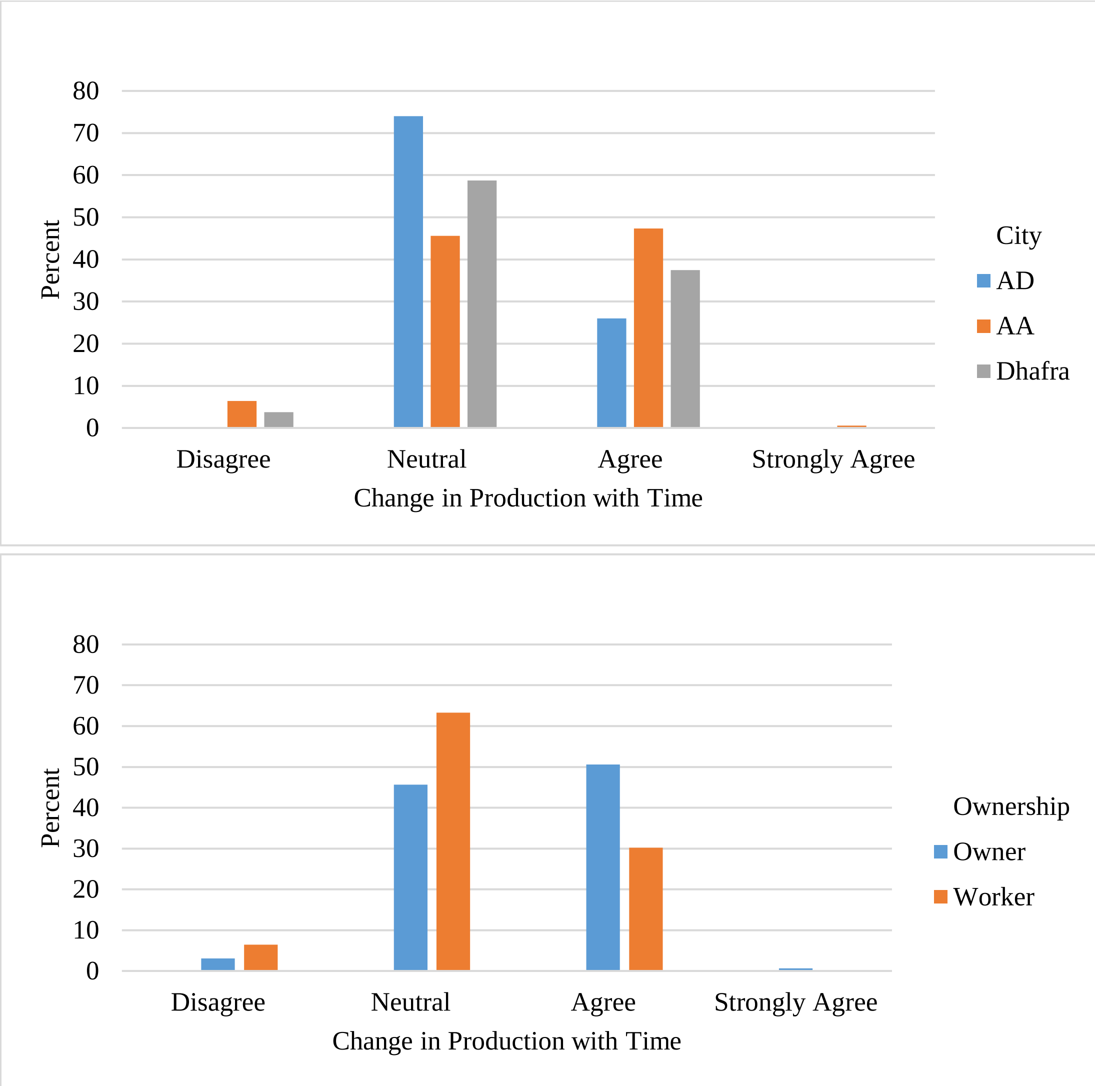


Figure 6.7: Responses on cost of production and income questions

Approximately 32% of the workers disagreed that there has been a change in the groundwater quantity, while 18% of the owners agreed. The majority of the respondents were neutral in their responses to this set of questions (Figure 6.8).

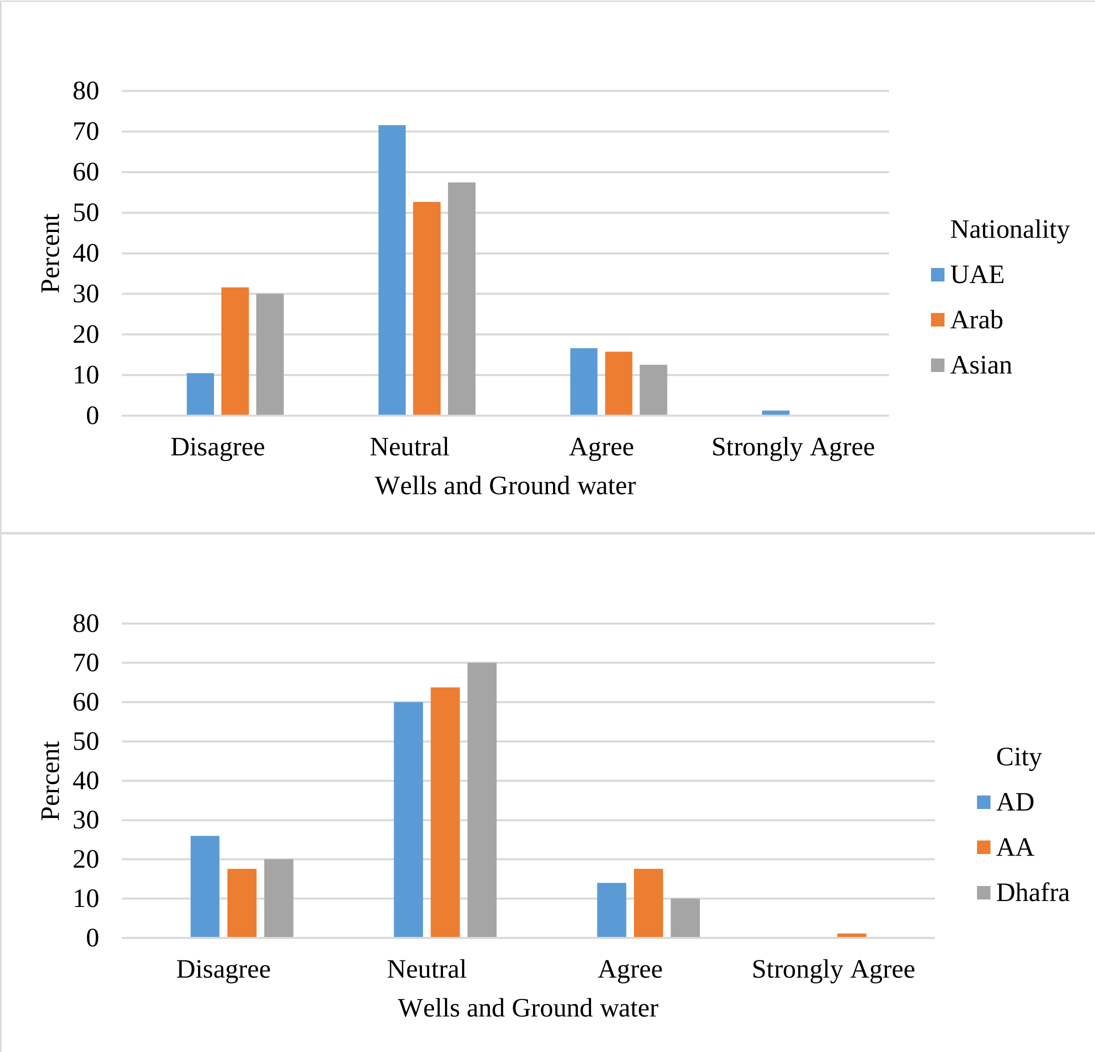


Figure 6.8: Survey responses on wells and groundwater questions

The farmers in Abu Dhabi disagreed that there has been a change in the groundwater quantity (26%), and 20% of the Al Dhafrah farmers disagreed. In this case, the percentage of farmers who disagreed was equal to the percentage of farmers who agreed with the groundwater quantity statement (both 18%) in the mentioned cities. Given that the Likert-type data is ordinal, nonparametric techniques were used to analyze the data. A Mann-Whitney test was conducted to analyze the difference in scoring tendencies between two groups' demographic variables. Additionally, a Kruskal-Wallis test was applied to analyze the difference in the participants' scoring tendencies for the demographic variables of more than two groups.

Table 6.3: Values of Asymptomatic significance for thirty-eight survey questions

Q#	Gender	Ownership	Nationality	City	Age
1	0.284	0.912	0.542	0.234	0.050
2	0.357	0.006*	0.024*	0.599	0.000*
3	0.479	0.045*	0.091	0.531	0.903
4	0.173	0.165	0.306	0.489	0.015*
5	0.117	0.629	0.636	0.612	0.005*
6	0.415	0.375	0.660	0.066	0.161
7	0.952	0.043*	0.109	0.518	0.209
8	0.988	0.343	0.029*	0.085	0.044*
9	0.085	0.146	0.175	0.00*	0.135
10	0.143	0.034*	0.089	0.00*	0.131
11	0.607	0.012*	0.042*	0.611	0.783
12	0.100	0.001*	0.002*	0.862	0.444
13	0.105	0.298	0.238	0.617	0.347
14	0.571	0.144	0.397	0.359	0.056
15	0.440	0.379	0.414	0.787	0.444
16	0.126	0.671	0.671	0.023*	0.944
17	0.164	0.911	0.451	0.180	0.771
18	0.145	0.056	0.061	0.661	0.974
19	0.653	0.208	0.171	0.594	0.653
20	0.448	0.018*	0.02*	0.369	0.349
21	0.191	0.254	0.183	0.697	0.682
22	0.607	0.005*	0.031*	0.915	0.023*
23	0.471	0.131	0.144	0.434	0.451
24	0.188	0.023*	0.074	0.015*	0.109
25	0.241	0.000*	0.001*	0.554	0.019*
26	0.209	0.708	0.694	0.002*	0.963
27	0.476	0.810	0.954	0.001*	0.033*
28	0.288	0.047*	0.039*	0.000*	0.585
29	0.932	0.000*	0.000*	0.000*	0.206
30	0.179	0.109	0.232	0.083	0.138
31	0.146	0.021*	0.046*	0.328	0.346
32	0.144	0.008*	0.016*	0.256	0.652
33	0.651	0.001*	0.002*	0.007*	0.608
34	0.327	0.000*	0.000*	0.199	0.392
35	1.000	0.001*	0.002*	0.029	0.042*
36	0.302	0.001*	0.001*	0.009*	0.098
37	0.304	0.001*	0.002*	0.001*	0.701
38	0.400	0.000*	0.002*	0.024*	0.320

*Sig. at 0.01 level

For gender and ownership, two variables (Mann Whitney Test) was used and K variables (Kruskul-Wallis Test) was used for nationality, city, and age. The Asymptomatic Significance values are shown in Table 6.3. Data indicate that there is a significant difference ($P<0.05$) between nationality and age for question 8 (vegetable crops were planted in the farm). For question 11 (all the produced crops were sold in the market), there is a significant difference between ownership and nationality. There was also a significant difference between ownership and nationality for questions 12, 20, 28 and questions 31-38. For question 22 (the total amount of farm expenses has increased over the last 20 years), there is a significant difference between ownership and nationality and age.

6.5 Discussion

It is known that climate change will not influence all farms equally (Claessens et al., 2012). While some farms will be greatly impacted by climate change, others will not be impacted at all. The results indicated that approximately 68% of the respondents in Al-Ain agreed that managing a farm nowadays is much easier and more profitable than it was 20 years ago. In Al Dhafrah, 29% of the respondents agreed with this statement, while the majority of the Abu Dhabi respondents disagreed. These results indicate that the farms in Al-Ain are not influenced by climate change, or, that climate change’s influence is more manageable in Al-Ain than it is in Abu Dhabi (where the majority of the farmers were unable to easily manage their farms). Differing governmental policies do not factor in here, as both Al-Ain and Abu Dhabi are governed by the same regulations and codes.

In addition, farmers in both Al-Ain and Abu-Dhabi receive similar services and aid amounts from the government. Instead, it is possible that climate-related factors are the drivers of the farms' managing processes. Scanlon et al. (2005) reported that, in the next 50 years, the area of agricultural lands will increase by 20%. This supports the current study results, which indicate that 80% of the Al-Ain farmers strongly agreed that their production has increased over the past 20 years. However, only 28% and 18% of the respondents in AI Dhafrah and Abu Dhabi City agreed, respectively. SCAD (2018) reported that the estimated number of livestock in 2017 was 613,841 in Abu Dhabi, 2,335,268 in Al-Ain, and 595,891 in Al Dhafrah. When questioned about whether the amount of money they spent raising livestock had increased over the past 20 years, the majority of Al-Ain respondents either disagreed or responded neutrally (more than 60%), nearly 70% of respondents in Abu Dhabi disagreed, and 34% of the respondents in Al Dhafrah disagreed. The farmers in the three cities of the study area, are managing the livestock properly, and it is clear that they are not facing financial or other possible issues in raising them.

The total value of field crop production was 325,654 AED in Abu Dhabi Emirate, comprised of 74.8% in Al-Ain, 17.3% in Al Dhafrah, and 8.0% in Abu Dhabi City (SCAD, 2018). More than 50% of the farm owners (UAE nationals) strongly agreed that their crop-selling income has increased over the past 20 years, while the majority of workers (Arabs and Asians) either disagreed or responded neutrally. The farm owners handle the financial matters related to their farms; the income flows directly to the owners' accounts, while the workers receive their salaries without knowledge of the farm's total profit. Mertz et al. (2009) found that farmers in agricultural countries have been able to develop their own strategies for continuously managing the unpredictable climate, pest attacks, and changing policies. Al-Ain, as the city of oasis, is known for its agricultural and livestock production, as its people are highly experienced in farming and irrigating techniques and in managing the different cultivation tools. Aldababseh et al. (2018) reported that the central and eastern part of Abu Dhabi Emirate has the highest capability which is approving that present agricultural farms were developed on highly capable land. This might explain why the Al-Ain farmers had more positive responses about the question that states; "managing a farm nowadays is easier and much profitable than it used to be 20 years ago", compared to the respondents in Abu Dhabi city. For the production quality and quantity category, 50% of the respondents aged between 51-60 years reported that their production is increasing. These respondents likely provided better and more reliable answers, as they have had experience with farming over the last 20 years. For the change in production over time category, it was found that 41%, 30%, and 33% of the farmers in Al-Ain, Abu Dhabi, and Al Dhafrah, respectively, noted that production has changed over time. Al-Ain's higher positive percentage for this category is likely also explained by the same reasons listed above. The UAE nationals (51%), Arabs (42%), and Asians (28%) also agreed that there has been a change in production over time. The farmers aged between 51-60 years also agreed that there has been a change in production over time. Approximately half (50%) of the farm owners agreed that production has changed over time, while the majority of workers responded neutrally on this topic. In general, the workers tended to respond neutrally to the questions, which might have been because they were not aware of the issues or because they did not properly understand the questions (due to language differences [for the Asian respondents] or low educational levels [for the Asian or Arab respondents]).

For the cost of production and income category, both owners and workers agreed that income and production costs have changed; however, more workers disagreed (50%) than agreed (35%) with this statement. Approximately 40% of the farmers in Al-Ain, 34% in AI Dhafra, and 30% in Abu Dhabi agreed that income and production costs have changed. The expenses and incomes are both increasing, which has occurred in various businesses due to increases in oil prices, demand for goods, etc. The farm owners thus sell their crops and livestock at higher prices, which could subsequently translate into higher income. Although the total loans given to the farmers in agricultural sector in Al-Ain was decreased to 166,000 AED, where it was 21,752,000 AED in 2010 and to 147,000 AED in 2017 compared to 4,967,000 AED in Abu Dhabi and Al Dhafrah in 2010 (SCAD, 2018).

Many farms have been abandoned over the past 20 years due to the new policies and regulations, yet the surveyed farmers are productive farmers. A study conducted on water consumption rates in the different KSA sectors found that modern irrigation (localized and sprinkler irrigation) covers about 66% of the total irrigated area in the KSA, with the remaining proportion (34%) using surface irrigation (IMF, 2013). The results showed that almost 60% of the farmers in Al-Ain use sprinklers for their irrigation systems, followed by the Aflaj and drip systems. The majority of Abu Dhabi farmers use drip irrigation systems (25%), while 34% of the farmers in Al Dhafrah use the Aflaj system. A number of scientists have proposed that climate change might influence the physical characteristics of aquifers (Shah, 2009). The results indicated that farmers aged between 51-60 years agreed more so than did younger farmers, that the groundwater quantities and quality have changed over the past 20 years. This result is important because this age range has the most experience with farming. The majority of the respondents provided neutral responses on this set of questions. It is unclear whether the respondents were not aware of the groundwater’s status or if they did not understand the questions due to language differences or other factors. The farmers in Abu Dhabi (26%) and Al Dhafrah (20%) disagreed that the groundwater levels had changed.

Alauddin and Sarker (2014) found that the majority of farm households in Bangladesh had observed that both groundwater and surface water were less available during the summers than they used to be. In this study there is no focus on a specific season, yet, Alauddin and Sarket's study is applicable to the study region, as the region is dry and hot for most of the year. Groundwater wells are the most important that tool farmers have used to survive droughts. Consequently, well digging tends to peak during drought years, and this is expected to continue and even increase with the amplified hydro-climatic variability (Shah, 2009). Approximately 70% of the farmers in Al-Ain strongly agreed that well digging currently costs more money than it used to cost 20 years ago. In Abu Dhabi and Al Dhafrah, 16% and 24% of the farmers agreed that the digging costs had increased, respectively. This cost increase could be due to increases in machinery costs and/or water depths.

6.6 Conclusions

Of the 301 respondents, 64% of the local farmers agreed that the total farm expenses had increased over the past 20 years. In addition, the local farmers strongly agreed that their crop-selling income had also increased over the past 20 years. Approximately 32% of the farmers aged between 51-60 years agreed more compared to the younger groups that the groundwater levels and quality had changed over the past 20 years. The farmers in Al-Ain agreed that the groundwater's salinity had increased over the past 20 years. Generally, 68% of the Al-Ain respondents reported that managing a farm nowadays is much easier than it was 20 years ago.

In addressing the research questions, it is possible to determine that there has been a change in agricultural and livestock production over the past 20 years, and that this change varies (in both amount and nature) across the different regions of Abu

Dhabi Emirate. The assumption was that climate change has influenced agriculture and livestock production, and the survey was built on this assumption in order to assess how climate change has affected farm production and groundwater characteristics. Climate change's negative influence was not clearly indicated in the findings. The responses indicated that both agricultural and livestock production have recently increased. In addition, the responses suggest that the groundwater characteristics have not been clearly influenced by climate change. This research's findings open the door for future researchers to further explore the region in regard to climate change's influence on agricultural and livestock production through other factors including groundwater.

Chapter 7: Summary

The purpose of this research was to assess the impact of climate change on land use change in Abu Dhabi Emirate from environmental and socio-economic perspectives.

The impact of climate change on the UAE land use/ land cover was assessed using Landsat images for the area from 1997 to 2017. A change in the land cover was detected from the change in the areas of classes. A change in temperature was detected as well. The temperature increase that is connected to climate change can affect the land use land cover and vice versa. When temperature increase in an area that is known as camel grazing area that can lead to area abandoning. These open areas that are usually away from the crowded city faced urbanization crawling which made the camel owners move their camel to some quieter areas.

Urbanization crawling led to cooling the land surface temperatures because of the effect of the vegetation that comes with the urbanization across the roads and near the residential areas. In this research it was not very clear if there is an effect of climate change on land surface temperatures.

The impact of climate change on water and energy consumption in Abu Dhabi Emirate was studied from the socio-economic perception of the questionnaire participants. The lifestyle and the availability of the sources of water and energy in UAE can influence people's consumption and not only the rise of temperatures during the past 20 years. The results of the research showed that there is a lack of awareness about the impact of climate change.

In this research, there was no clear connection between the effect of climate change and the agricultural and livestock production in Abu Dhabi Emirate. Ground water characteristics can give an indication on the impact of climate change and can be linked to the production. Although the level of ground water and its quality was negative, the agricultural and livestock production seemed to be unaffected. Using different approaches in studying the agricultural and livestock production and how climate change can influence is recommended.

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Al-Blooshi, L., Issa, S. and Ksiksi, T., 2020. Assessing the Environmental Impact of Climate Change on Desert Ecosystems: A Review. Advances in Ecological and Environmental Research, 5(2), 27-52.

Al Blooshi, L. S., Ksiksi, T. S., Gargoum, A. S. and Aboelenein, M., 2020. Climate Change and Environmental Awareness: A Study of Energy Consumption among the Residents of Abu Dhabi, UAE. Perspectives on Global Development and Technology, 18(6), 564-582.

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Appendices

Appendix 1: Questionnaire 1 - Energy and water consumption

جامعة الإمارات العربية المتحدة
United Arab Emirates University

UAEU College of Science

Survey - An Assessment of the Impact of Climate Change on Land Use in the Emirate of Abu Dhabi

An Environmental and Socio-economic Perspective

This survey is targeting citizens of the emirate of Abu Dhabi. The information is going to be used in a PhD study about the assessment of the impact of climate change on the land use n the emirate of AD on an environmental and socio-economic perspective. No personal information is needed and all the results will be used for scientific research. Please note that you may withdraw at any time from the study. Your participation is voluntary. All information that you provide will be confidential and anonymous. There is minimal risk in participating in this study since all data collected will be anonymous.
I agree to voluntarily participate in the study.

Agree ☐

General Information

Gender	**Male**	**Female**			
Nationality	**UAE**	**GCC**	**Arab**	**Asian**	**Other**
Living area/town	**Abu Dhabi (-------------)**	**Al Ain (-------------)**		**Al-Dharfa (-------------)**	
Age	**20-30**	**31-40**	**41-50**	**51-60**	**61-70**
Accommodation type	**Villa**	**Public housing**	**Apartment**	**Other**	

Questionnaire - A

	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree
1. The prices of houses and lands have been increased in the past 20 years.	☐	☐	☐	☐	☐
2. Water consumption in my house have been increased in the past 20 years.	☐	☐	☐	☐	☐
3. Energy consumption in my house have been increased in the past 20 years.	☐	☐	☐	☐	☐
4. I am turning the AC on at my house for more hours per day than I used to 20 years ago.	☐	☐	☐	☐	☐
5. I am turning the AC on at my house for more months per year than I used to 20 years ago.	☐	☐	☐	☐	☐
6. I am consuming more water for showering than I used to 20 years ago.	☐	☐	☐	☐	☐
7. Water and electricity bills has increased in the past 20 years.	☐	☐	☐	☐	☐
8. Size of lands has decreased in the past 20 years.	☐	☐	☐	☐	☐
9. The cost of building a new house has increased in the past 20 years due to changes in the construction specifications.	☐	☐	☐	☐	☐

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10. Because of the increased cost many citizens decide to delay or not to build their houses.	☐	☐	☐	☐	☐
11. I consider moving to a city with lower accommodation cost if prices continue to increase	☐	☐	☐	☐	☐

Questionnaire - B

12. The amount of energy I consume has increased been increased in the past 20 years by:	Less than 0%	0-15%	16-30%	31-45%	More than 45%
13. The amount of water I consume has increased been increased in the past 20 years by:	Less than 0%	0-15%	16-30%	31-45%	More than 45%
14. The amount of money I spend for water and electricity has increased been increased in the past 20 years by:	Less than 0%	0-15%	16-30%	31-45%	More than 45%
16. The prices of houses (including renting prices) and lands have been increased in the past 20 years by:	Less than 0%	0-15%	16-30%	31-45%	More than 45%

Questionnaire - C

	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree
17. I think that summers are more hotter than they used to be 20 years ago.	☐	☐	☐	☐	☐
18. I think that summers are more longer than they used to be 20 years ago.	☐	☐	☐	☐	☐
19. I think that winters are more colder than they used to be 20 years ago.	☐	☐	☐	☐	☐
20. I think that precipitation rates are much lower than they used to be 20 years ago.	☐	☐	☐	☐	☐
21. I think that weather and climate change is controlling my energy and water consumption.	☐	☐	☐	☐	☐
22. I think that climate change has an impact on the land prices increase.	☐	☐	☐	☐	☐

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Appendix 2: Pilot questionnaire - Energy and water consumption

جامعة الإمارات العربيـة المتحدة
United Arab Emirates University

UAEU College of Science

يستهدف هذا الاستبيان سكان إمارة أبو ظبي. سيتم استخدام المعلومات في دراسة لبحث دكتوراه بعنوان تقييم تأثير التغير المناخي على اســتخدام الأراضـــي في إمارة أبو ظبي من منظور بيني واجتماعي – اقتصادي. المعلومات الشخصية غير مطلوبة وسيتم استخدام النتائج لأغراض البحث العلمي.

معلومات عامة

الجنس		ذكر		أنثى		
الجنسية	إمارات	دول الخليج	عربي	آسيوي		أخرى
المدينة		أبوظبي (------------)		العين (------------)		الغربية (------------)
العمر	20-30	31-40	41-50	51-60		61-70
نوع السكن	فيلا	مسكن شعبي	شقة	أخرى		

القسم الأول: A

	1=لا أوافق بشدة	2=لا أوافق	3=محايد	4=أوافق	5=أوافق بشدة
1. ارتفعت أســعار المنازل والأراضـــي خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
2. زاد اســــتهلاك الميــاه في منزلي خلال العشرين عاما الماضية.	☐	☐	☐	☐	✓
3. زاد اســتهلاك الطاقة (الكهرباء) في منزلي خلال العشرين عاما الماضية.	☐	☐	☐	☐	✓
4. أقوم بتشـــغيـل أجهزة التكييف في منزلي لساعات أطول خلال اليوم مقارنة بالعشرين عاما الماضية.	☐	☐	☐	☐	✓
5. أقوم بتشـــغيـل أجهزة التكييف في منزلي لأشـهر أطول خلال العام مقارنة بالعشـرين عاما الماضية.	☐	☐	☐	☐	✓
6. أقوم بـاســتهلاك كميـات أكبر من الميـاه لأغراض الاســتحمام مقارنة بالعشـــرين عاما الماضية.	☐	☐	☐	☐	✓
7. ارتفعت قيمة فواتير المياه والكهرباء خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
8. انخفضـت مسـاحات الأراضـي المخصـصـة خلال العشرين عاما الماضية.	☐	☐	☐	☐	✓
9. ارتفعت أسعار بناء المساكن خلال العشرين عاما الماضية نتيجة تغيير مواصفات البناء.	☐	☐	☐	✓	☐

Appendix 3: Questionnaire 2 – Agricultural and livestock production

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10. بسبب ارتفاع أسعار بناء المساكن قام الكثير من المواطنين بتأخير أو صرف النظر عن بناء مساكنهم.	☐	☑	☐	☐	☐
11. إنني أضع في اعتباري الانتقال إلى مدينة أخرى تكون أسعار السكن فيها أقل في حال استمرت الأسعار بالارتفاع.	☑	☐	☐	☐	☐

القسم الثاني:

12.زاد استهلاكي للطاقة (الكهرباء) خلال العشرين عاما الماضية بنسبة:	أقل من ٪0	٪15-0	٪30-16	٪45-31	أكثر من ٪45 ✓
13.زاد استهلاكي للمياه خلال العشرين عاما الماضية بنسبة:	أقل من ٪0	٪15-0	٪30-16	٪45-31	أكثر من ٪45 ✓
14. تبلغ نسبة الزيادة في المبالغ التي أدفعها لسداد فواتير الماء والكهرباء خلال العشرين عاما الماضية ما يقارب:	أقل من ٪0	٪15-0	٪30-16	٪45-31	أكثر من ٪45 ✓
15.تبلغ نسبة الزيادة في أسعار المساكن (شاملا أسعار الإيجارات) والأراضي خلال العشرين عاما الماضية ما يقارب:	أقل من ٪0	٪15-0	٪30-16 ✓	٪45-31	أكثر من ٪45

القسم الثالث:

	1=لا أوافق بشدة	2=لا أوافق	3=محايد	4=أوافق	5=أوافق بشدة
16.أعتقد بأن فصل الصيف أكثر حرارة عما كان عليه خلال العشرين عاما الماضية.	☐	☐	☐	☐	☑
17. أعتقد بأن فصل الصيف أطول مدة عما كان عليه خلال العشرين عاما الماضية.	☐	☐	☐	☐	☑
18. أعتقد بأن فصل الشتاء أكثر برودة عما كان عليه خلال العشرين عاما الماضية.	☑	☐	☐	☐	☐
19. أعتقد بأن كمية الأمطار أقل بكثير عما كانت عليه خلال العشرين عاما الماضية.	☐	☐	☐	☐	☑
20. أعتقد أن التغير المناخي يتحكم باستهلاكي للمياه والطاقة.	☐	☐	☐	☐	☑
21. أعتقد أن التغير المناخي له تأثير على ارتفاع أسعار الأراضي.	☐	☐	☑	☐	☐

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Survey - An Assessment of the Impact of Climate Change on Land Use in the Emirate of Abu Dhabi

An Environmental and Socio-economic Perspective

This survey is targeting citizens of the emirate of Abu Dhabi. The information is going to be used in a PhD study about the assessment of the impact of climate change on the land use n the emirate of AD on an environmental and socio-economic perspective. No personal information is needed and all the results will be used for scientific research. Please note that you may withdraw at any time from the study. Your participation is voluntary. All information that you provide will be confidential and anonymous. There is minimal risk in participating in this study since all data collected will be anonymous.
I agree to voluntarily participate in the study.

Agree ☐

General Information

Gender	Male	Female			
Nationality	UAE	GCC	Arab	Asian	Other
Living area/town	Abu Dhabi (--------------)	Al Ain (--------------)		Al-Dharfa (--------------)	
Age	20-30	31-40	41-50	51-60	61-70
I am	Owner of a farm	Worker in a farm			

Questionnaire - A

1. What is the estimated area of your farm in square foot?

10,000 – 50,000	55,000-100,000	105,000-500	510,000-1,000,000	More than 1,000,000

2. What is the number of workers in the farm?

2-3	4-6	7-9	10-12	More than 12

3. What irrigation system do you use in the farm?

Sprinkler	Aflaj	Drip		

4. What is the total number of wells in the farm?

1-3	4-6	7-9	10-12	More than 12

5. What is the number of operating wells in the farm?

1-3	4-6	7-9	10-12	More than 12

6. What are the types of livestock you are raising in your farm?

Cows	Sheep	Goats	Camels	Others

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Questionnaire - B

	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree
7. I plant palm trees in the farm.	☐	☐	☐	☐	☐
8. I plant vegetable crops in the farm.	☐	☐	☐	☐	☐
9. I plant fruits crops in the farm.	☐	☐	☐	☐	☐
10. I plant forage plants in the farm.	☐	☐	☐	☐	☐
11. I sell all the crops I produce in the market.	☐	☐	☐	☐	☐
12. Number of palm trees in the farm has been increased in the last 20 years.	☐	☐	☐	☐	☐
13. Quality of palm trees and dates produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
14. Amount of vegetables crops produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
15. Quality of vegetables crops produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
16. Amount of fruits crops produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
17. Quality of fruits crops produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
18. Amount of forage plants produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
19. Quality of forage plants produced has been increased in the last 20 years.	☐	☐	☐	☐	☐
20. Total production of the farm has been increased in the past 20 years.	☐	☐	☐	☐	☐
21. The income from selling crops produced in my farm has increased in the past 20 years.	☐	☐	☐	☐	☐
22. The total amount of the farm expenses has been increased in the last 20 years.	☐	☐	☐	☐	☐
23. The depth of ground water in the wells is decreasing in the past 20 years.	☐	☐	☐	☐	☐
24. Well digging costs more money than it used to be 20 year ago.	☐	☐	☐	☐	☐
25. Salinity of ground water is has increased in the past 20 years.	☐	☐	☐	☐	☐
26. The amount of water consumed for irrigation in my farm has been increased in the past 20 years.	☐	☐	☐	☐	☐

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27. The amount of energy consumption in my farm has been increased in the past 20 years.	☐	☐	☐	☐	☐
28. The amount money spent for energy in my farm has been increased in the past 20 years.	☐	☐	☐	☐	☐
29. I am raising livestock in my farm.	☐	☐	☐	☐	☐
30. The income from selling livestock has increased in the past 20 years	☐	☐	☐	☐	☐
31. The amount of money spent on raising livestock has increased in the past 20 years.	☐	☐	☐	☐	☐
32. Livestock need more care nowadays than it was in the last 20 years	☐	☐	☐	☐	☐
33. In general managing a farm nowadays is much easier and profitable than it was 20 years ago.	☐	☐	☐	☐	☐

Questionnaire - C

34. Total production of the farm has been increased in the past 20 years by	Less than 0%	0-15%	16-30%	31-45%	More than 45%
35. The annual harvested areas to the total area of the farm is:	Less than 0%	0-15%	16-30%	31-45%	More than 45%
36. In percentage, the amount of increased income is:	Less than 0%	0-20%	21-40%	41-60%	More than 60%
37. In percentage, the amount of increased expenses is ranged between:	Less than 0%	0-20%	21-40%	41-60%	More than 60%
38. The percentage of increase income from raising live stock is:	Less than 0%	0-20%	21-40%	41-60%	More than 60%

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Appendix 4: Pilot questionnaire - Agricultural and livestock production

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يستهدف هذا الاستبيان سكان إمارة أبو ظبي. سيتم استخدام المعلومات في دراسة لبحث دكتوراه بعنوان تقييم تأثير التغير المناخي على استخدام الأراضي في إمارة أبو ظبي من منظور بيئي واجتماعي – اقتصادي. المعلومات الشخصية غير مطلوبة وسيتم استخدام النتائج لأغراض البحث العلمي.

معلومات عامة A

الجنس: ذكر — أنثى

الجنسية: إمارات — دول الخليج — عربي — آسيوي — أخرى

المدينة: أبوظبي (-------------) — العين (-------------) — الغربية (-------------)

العمر: 30-20 — 40-31 — 50-41 — 60-51 — 70-61

أنا: مالك مزعه — عامل في مزرعة

القسم الأول:

1. كم تبلغ المساحة المقدرة لمزرعتك بالقدم المربع؟

10,000-50,000 — 55,000- — 105,000-500,000 — 510,000- — أكثر من

2. كم عدد العاملين في المزرعة؟

2-3 — 4-6 — 7-9 — 10-12 — أكثر من 12

3. ما هو نظام الري المستخدم في المزرعة؟

رشاشات — أفلاج — تنقيط

4. كم عدد الآبار الموجودة في المزرعة؟

1-3 — 4-6 — 7-9 — 10-12 — أكثر من 12

5. كم عدد الآبار التي يتم استخدامها للري في المزرعة؟

1-3 — 4-6 — 7-9 — 10-12 — أكثر من 12

6. ما هي أنواع الماشية التي يتم تربيتها في مزرعتك؟ لا يوجد

أبقار — ماعز — خرفان — جمال — أخرى

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القسم الثاني:

	1=لا أوافق بشدة	2=لا أوافق	3=محايد	4=أوافق	5=أوافق بشدة
7. أنا أقوم بزراعة أشجار النخيل في مزرعتي.	☐	☐	☐	☐	☑
8. أنا أقوم بزراعة محاصيل الخضروات في مزرعتي.	☐	☐	☐	☑	☐
9. أنا أقوم بزراعة محاصيل الفواكه في مزرعتي.	☑	☐	☐	☐	☐
10. أنا أقوم بزراعة الأعلاف في مزرعتي.	☑	☐	☐	☐	☐
11. أنا أقوم بتسويق المنتوجات الزراعية في الأسواق.	☐	☐	☐	☑	☐
12. عدد أشجار النخيل في المزرعة زاد خلال العشرين عاما الماضية.	☐	☐	☐	☑	☐
13. جودة المحاصيل من أشجار النخيل في المزرعة تحسنت خلال العشرين عاما الماضية.	☐	☐	☐	☑	☐
14. كمية المحاصيل من الخضروات في المزرعة زادت خلال العشرين عاما الماضية.	☐	☑	☐	☐	☐
15. جودة المحاصيل من الخضروات في المزرعة تحسنت خلال العشرين عاما الماضية.	☐	☐	☑	☐	☐
16. كمية المحاصيل من الفواكه في المزرعة زادت خلال العشرين عاما الماضية.	☑	☐	☐	☐	☐
17. جودة المحاصيل من الفواكه في المزرعة تحسنت خلال العشرين عاما الماضية.	☑	☐	☐	☐	☐
18. كمية المحاصيل من الأعلاف في المزرعة زادت خلال العشرين عاما الماضية.	☑	☐	☐	☐	☐
19. جودة المحاصيل من الأعلاف في المزرعة تحسنت خلال العشرين عاما الماضية.	☑	☐	☐	☐	☐
20. إجمالي الإنتاج في المزرعة زاد خلال العشرين عاما الماضية.	☐	☐	☐	☑	☐
21. عائد الدخل من تسويق إنتاج المزرعة زاد خلال العشرين عاما الماضية.	☐	☐	☐	☑	☐
22. إجمالي التكاليف لعملية الإنتاج في المزرعة زاد خلال العشرين عاما الماضية.	☐	☐	☑	☐	☐

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23. انخفض عمق المياه الجوفية في الآبار خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
24. تكلفة حفر الآبار زادت خلال العشرين عاما الماضية.	☐	☐	✓	☐	☐
25. ملوحة المياه الجوفية زادت خلال العشرين عاما الماضية.	☐	☐	☐	☐	✓
26. كمية المياه المستهلكة للري في مزرعتي زادت خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
27. كمية الطاقة (الكهرباء) المستهلكة في مزرعتي زادت خلال العشرين عاما الماضية.	☐	☐	✓	☐	☐
28. قيمة المال المدفوع لسداد فواتير المياه والكهرباء في مزرعتي زادت خلال العشرين عاما الماضية.	☐	☐	✓	☐	☐
29. أنا أقوم بتربية المواشي في مزرعتي.	✓	☐	☐	☐	☐
30. العائد من بيع المواشي ارتفع خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
31. قيمة المال المدفوع لتربية المواشي زادت خلال العشرين عاما الماضية.	☐	☐	☐	✓	☐
32. تحتاج تربية المواشي حاليا عناية أكبر مما كانت عليه قبل عشرين عاما.	☐	☐	☐	☐	✓
33. عموما إدارة المزارع حاليا أسهل وتعود بفائدة مالية أكبر عما كانت عليه قبل عشرين عاما.	✓	☐	☐	☐	☐

لايوجد مياه

في العزبة

القسم الثالث:

34. إجمالي إنتاج المزرعة زاد خلال العشرين عاما الماضية بنسبة:	أقل من 0٪	(0-15٪)	16-30٪	31-45٪	أكثر من 45٪
35. نسبة المساحة المحصودة سنويا من المزرعة مقارنة بمساحة المزرعة الكلية تساوي:	أقل من 0٪	0-15٪	(16-30٪)	31-45٪	أكثر من 45٪
36. تبلغ نسبة الزيادة في الدخل من إنتاج المحاصيل الزراعية في المزرعة:	أقل من 0٪	0-15٪	(16-30٪)	31-45٪	أكثر من 45٪
37. تبلغ نسبة الزيادة في تكاليف الإنتاج في المزرعة:	أقل من 0٪	(0-15٪)	16-30٪	31-45٪	أكثر من 45٪
38. تبلغ نسبة الزيادة في الدخل من تربية المواشي في المزرعة:	(أقل من 0٪)	(0-15٪)	16-30٪	31-45٪	أكثر من 45٪

العزبة

لايوجد

في العزبة