Influence of Climate Variables upon selected Infectious Diseases in Asir Region, Saudi Arabia

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Abstract

Although the incidence of some infectious diseases (Malaria, Cutaneous Leishmaniasis (CL), and Schistosomiasis) in the Asir Region, Saudi Arabia, has decreased over the last decade, they still cause significant health problems. This study tests the hypotheses that there are relationships between climate variables (maximum, mean and minimum temperature, rainfall and relative humidity) and these diseases in Asir Region. Monthly malaria, CL and schistosomiasis cases and climate variable data were obtained for the study area between 1995 and 2006, 1996 and 2007 and 1998 and 2009 respectively.

Multiple regressions on the number of cases of each disease were performed against the climate variables. The climate variables were lagged to account for time gaps between weather events and disease. Different relationships with climate may occur at different times of the year and so separate models were created for each season.

Within Asir, there are two separate malaria endemic areas in the lowlands: Tehama of Asir (TA) and Tehama of Qahtan (TQ). The results revealed that in these areas, rainfall in the current and previous month was positively associated ($P<0.05$ and $P<0.001$ respectively) with an increase in malaria cases during the summer. This may be due to increased breeding and survival of vectors after the rainfall. Temperature was not an important factor.

Temperature was the most important factor associated with CL cases in all Asir and in the highlands area during the summer and beginning of autumn. If the maximum temperature in the previous 2 to 4 months was elevated there were more cases ($P<0.001$). Rainfall also plays a role in CL transmission in the lowlands. There were more cases of CL if rainfall was elevated in the previous 1 to 3 months ($P<0.05$).

Temperature was an important factor associated with schistosomiasis throughout Asir during the summer and beginning of autumn. If the maximum temperature in the previous 3 to 4 months was elevated, there were more cases of schistosomiasis ($P<0.05$). Rainfall also plays an important role in schistosomiasis transmission in the highlands. There were more cases if rainfall in the previous 6 to 7 months ($P<0.005$) was elevated. This occurs during spring and summer seasons

Based on these findings and an understanding of how these diseases are affected by climate it should be possible to design an early warning system using the weather to predict each disease's incidence. Therefore, the results of this study have important implications for policies to improve public health in this region.

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List of Abbreviations

CBD	The Convention of Biological Diversity
CDC	Centres for Diseases Control and Prevention
CDSI	Central Department of Statistic & Information Saudi Arabia,
CFSPH	The Centre for Food Security and Public Health
CL	Cutaneous Leishmaniasis
CPRD	Costal Plain Red Sea
ECDC	European Centre for Diseases Prevention and Control
El Nino	If the change of temperature over the Pacific Ocean is positive
ENSO	El Nino southern oscillation
HIV/AIDS	Human Immunodeficiency virus/ Acquired Immune Deficiency Syndrome
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWGCCH	Interagency Working Group on Climate Change and Health
La Nina	If the temperature change over the Pacific Ocean is negative
MCL	Mucocutaneous Leishmaniasis
MEPS	Meteorological and Environmental Protection Section
MOH	Ministry of Health
MOWE	Ministry of Water and Electricity

NIAID	National Institute of Allergy and Infection Diseases
NIEHS	The National Institute of Environmental Health Sciences
NWS	National Weather Service
Schist	The Schistosomiasis diseases
SPSS	Statistical Package for the Social Sciences
TA	Tehama of Asir, Saudi Arabia
TQ	Tehama of Qahtan, Saudi Arabia
UNFCCC	United Nations Framework Convention on Climate Change
VCA	The Vector Control Administration, in Health Affairs Directorate in Asir Region.
VL	Visceral Leishmaniasis
WHO	World Health Organisation
WSH	Water Sanitation and Health

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Chapter 1

Introduction and Overview

Background

1.1 What are Infectious Diseases?

Infectious diseases, also known as communicable diseases, are diseases which can be passed from one person to another. It is also possible for such diseases to spread indirectly from animals to people (zoonotic diseases) or through unhygienic conditions (Patz et al., 2002; Ryan et al., 2010). These diseases may cause damage or injury to the host due to the presence of pathogenic microbial agents such as viruses, bacteria, fungi, protozoa and parasites (Ryan et al., 2010). Examples of these diseases include herpes, malaria, mumps, HIV/AIDS, influenza, chicken pox, leishmaniasis and schistosomiasis (CDC, 2010). Vector-borne diseases are type of infectious diseases which are transmitted from one person to another by an insect or other arthropod vectors that carry the pathogens**.** The vector is an agent such as a micro organism, animal or person which carries and transmits an infectious agent. Common vectors include domestic animals, mammals or arthropods which assist in transmitting the parasitic organisms to humans (Schmidt and Roberts, 1996). An example of a vector-borne disease is malaria where the mosquito acts as a vector. Water-borne diseases are those diseases where the micro-organisms spend part of their lifecycle in water. An example is schistosomiasis which is transmitted by worms through contact with contaminated water (WHO, 2010).

There are different classifications of infectious diseases. The transmission mode of these diseases can either be anthroponoses or zoonoses according to the pathogen natural reservoir. Anthroponoses are where the reservoir is human, whereas zoonoses occur when the reservoir is animal. Transmission can also be direct or indirect. Direct transmission is where transmission occurs directly from person to person or from animal to animal. In the latter case the animal then gives the illness to a person. Indirect transmission is where human to human or animal to animal transmission is dependent upon a vector (Patz et al., 2002; Ryan et al., 2010). Figure 1.1 shows these different types of transmission cycle for infectious diseases.

Infectious diseases are transmitted by a variety of different mechanisms including (Schmidt and Roberts, 1996; Ryan et al., 2010; ECDC, 2010):

1. Ingesting contaminated food or water. These are known as gastrointestinal diseases (e.g. salmonellosis, cholera).
2. Contact with bodily fluids, often through sexual activity blood transfusions and sharing needles. (e.g. HIV/ADIS, hepatitis B).

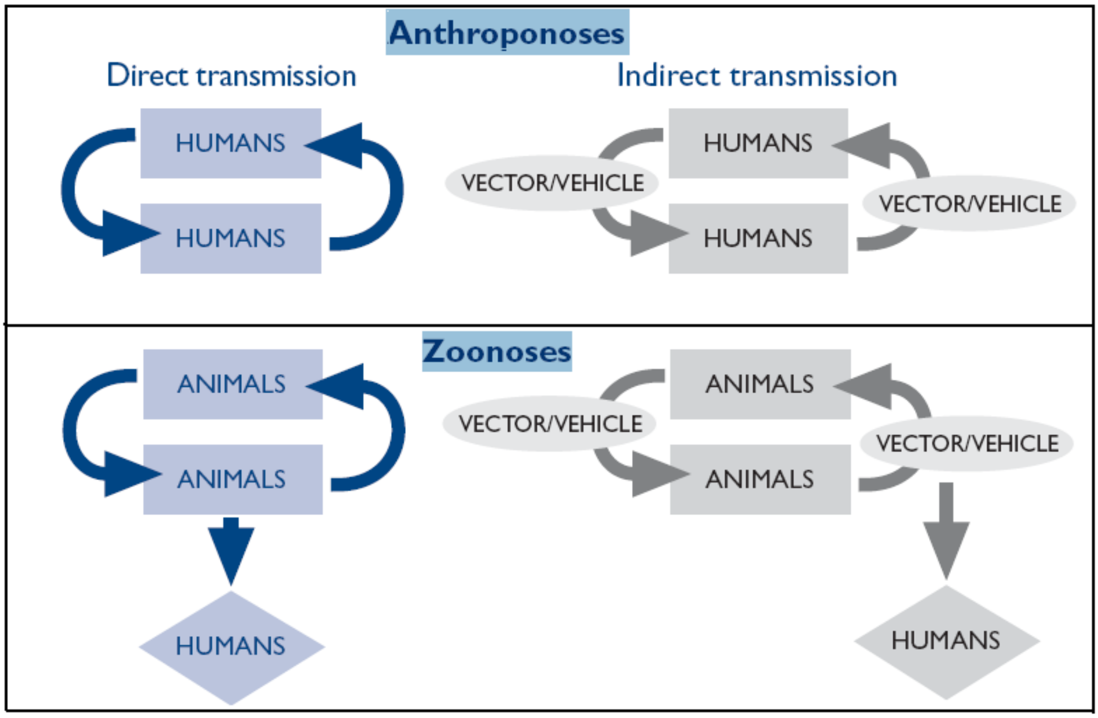

Figure1.1: Four main transmission cycles for infectious diseases. Adapted from Patz et al., (2002)

3. Aerosolized droplets spread by sneezing, coughing, talking and kissing (e.g. flu, meningitis).
4. Contact with a contaminated inanimate object such as clothes which can pass disease from one person to another (e.g. scabies).
5. Transmission of infectious diseases by mechanical vector. An example would be houseflies that pick up an infectious agent on the outside of its body and transmits it to an individual in a passive method (e.g. Typhoid, anthrax).
6. Transmission of infectious diseases by biological vectors such as mosquitoes and sandflies that deliver pathogens from one host to another (e.g. dengue fever and leishmaniasis).

1.2 The Global Importance of Infectious Diseases to Health

Throughout history, many types of these infectious diseases have killed millions of people. For example, an estimated 75 to 200 million people were killed by the Black Death during the 14^{th} century and this disease continues to kill about 3000 people each year (Philipkoski, 2008). Another example occurred in Mexico during the 15^{th} and 16^{th} centuries, when the introduction of smallpox, measles, and typhus led to disease pandemics which killed over 80% of the population (Dobson et al., 1996). Moreover, the first European influenza epidemic occurred during the 16^{th} century which is estimated to have killed 20% of the population. Tuberculosis killed an estimated quarter of the adult population of Europe during the 19th century. In 1918 the influenza pandemic killed up to 50 million people, and today this disease is responsible for about 0.5 million deaths worldwide each year (The Navy Department Library, 2005; WHO, 2010).

Infectious diseases still represent a major health problem today and the World Health Organization (2002) has estimated that currently there are more than 14.8 million deaths per year globally due to infectious diseases. This represents 25.9% of all deaths over the world (The World Health Report, 2004). Malaria is the most important vector-borne disease, and WHO estimates that 2.4 billion people live in malarious regions of the world (WHO/SDE/PHE, 1999). The exact number of deaths caused by malaria is unknown but it has been estimated at 1.5 - 3 million annually (De Savigny et al., 2004).

1.3 Climate Variables and Climate Change

Weather has been defined as "the short term changes in temperature, rainfall, wind speed, and some other atmospheric conditions" (WHO, 2003). Weather events usually occur on a daily time scale and these variables are associated with many health impacts (Harold et al., 2000). Climate is the total experience of weather over a longer time scale (conventionally 30 years) (IPCC, 2007). Atmospheric variables such as temperature, rainfall, wind, relative humidity and cloudiness are described as climate variables (McMichael et al., 2003). Climate variability occurs on many time scales, it usually occurs on a daily time scale and these variables are associated with many impacts on health. Climate variability occurs at other scales such as seasonal variability and also over longer periods. One important example of climate variability over longer time scales is the El Nino southern oscillation (ENSO). It is a global climate phenomenon, which affects temperature (a warming or cooling of at least 0.5 °C) over the tropical Pacific Ocean. Time periods are known as "El Nino" if the change of temperature over the Pacific Ocean is positive. If the temperature change is negative it is known as “La Nina”. These events occur every 3 to 5 years on average and lead to changing of the weather patterns across much of the planet (Lipp et al., 2002: NWS, 2005). El Nino creates an increase in rainfall across the east-central and eastern Pacific Ocean. It also causes extreme weather conditions such as floods and droughts in many regions of the world.

Human activities that burn fossil fuels such as oil increase the amount of greenhouse gases in the atmosphere. Although these gases also occur naturally, their recent increase may contribute to climate change (IPCC, 2007). During the 20th century the global surface temperature increased 0.74 ± 0.18°C (IPCC, 2007). Scientists predict that climate change will cause a mass extinction of several species of plants and animals, lead to the flooding of low-lying areas, and increase the frequency of extreme weather events (IUCN, 2009). The United Nations Framework Convention on Climate Change declared that climate change “contributes to the global burden of disease and premature death” (UNFCCC, 2007). There are four climatic zones in Asia; boreal, arid and semi-arid, tropical and temperate (UNFCCC, 2007). Martens et al., (1999) state that the principal impacts of climate change on health in Asia will be upon epidemics of vector-borne diseases.

1.4 The Influence of Climate Variables upon Infectious Diseases

The vectors of vector-borne diseases (a part of infectious diseases) such as mosquitoes and sandflies are sensitive to climate factors specifically temperature, rainfall and relative humidity (Hana et al., 2001; Cross et al., 1996). Therefore the weather will have an influence upon the transmission dynamics of these diseases. This will affect their spatial and temporal patterns. For example elevated temperatures in an area could increase the occurrence of vector-borne diseases such as malaria. Also Pampana, 1969 noted that the absolute temperature and its duration can affect the life cycle of malaria, but that this varies by parasite species.

There are many other examples. Air-borne infectious diseases can be affected by climate variables, although little is known about these types of diseases (Lipp et al., 2002). An example is influenza where Langford et al., (1995) found that the peak number of cases of flu and cold occur during winter in the Northern Hemisphere indicating that the transmission of the viruses is more active during winter season, thus increasing the cases. Food-borne diseases are also affected by climate variables. Lake et al., (2009) examined the correlation between temperature and food-borne infectious diseases. There were positive correlations ($P<0.01$) with each temperature lagged at the current week to 5 weeks. These were attributed to increased bacterial reproduction during warm weather as well as to changes in human behaviour (e.g. the popularity of barbecues during warm weather). Climate (e.g. heavy rainfall, flooding and increased temperature) is also recognized to be an important factor influencing the epidemiology of water borne disease (Hunter, 2003). Therefore water-borne diseases may increase due to changes in environmental conditions. Outbreaks in water-borne disease have been positively associated to extreme rainfall in the USA between 1948 and 1994 (Curriero, 2001).

There have been many previous studies which have indicated that climate variables have an impact on infectious diseases, particularly vector, air, food and water-borne diseases (Tulu, 1996; Woube, 1997; Ye et al., 2007; Alam et al., 2008; Lake et al., 2009; Oluleye and Akinbobola, 2010). Some have shown that the weather influences the abundance of vectors (Cross and Hyams, 1996; Amerasinghe et al., 1999; Abdoon and Alshahrani, 2003; Boussaa et al., 2005; Kasap et al., 2009) while others have found that vector abundance had an effect on the incidence of these type of diseases (Al-Amru, 2002; Al-Tawfiq et al., 2004; Al- Ibrahim et al., 2005).

1.5 Climate Change and its Potential Impact Health

Climate changes can affect human health directly as well as indirectly by changing ecological and biological processes (WHO et al., 2003; Cowie, 2007; Habib, 2011). These changes can cause death, injuries, illness, suffering and increases in the risk of infection diseases. In addition there may be adverse effects on the quality and quantity of food and water (Confalonieri et al., 2007). Postigo, (2007) has estimated that there are 150,000 deaths per year resulting from climate change and this number may increase to 300,000 by 2030. Recently, heavy rainfall events occurred in Jeddah, Saudi Arabia, in November 2009 and also in January 2011 which caused loss of life for hundreds of people and much damage to the infrastructure (Almazroui, 2001). These may have been associated with climate change.

The previous section has show that weather can affect the incidence of infectious disease. Therefore any change in climate may impact upon infectious diseases. These changes can influence the transmission patterns of many infectious diseases (Lindgren et al., 2010). In addition to the importance of climate change, other factors may influence the incidence of infectious diseases in the future. Examples include environmental influences such as agricultural development, deforestation and urbanization (Grasso et al., 2010). There are also socio demographic factors such as transportation, nutrition and human migration which may all have an impact (WHO, 2006).

A report in the United States, published by Environmental Health Perspectives and the National Institute of Environmental Health Sciences (NIEHS), has linked climate change to nine broad human health categories including infectious diseases such as vector-borne diseases and water-borne diseases (IWGCCH, 2010). The link between climate change and vector or water-borne disease incidence is presented in Figure 1.2. This figure shows that many factors, both direct and indirect, can influence water-borne diseases and vector-borne diseases, starting with climate change but noting other effects such as human behaviour, activities, host pathogen transmission, vector and vector habitat.

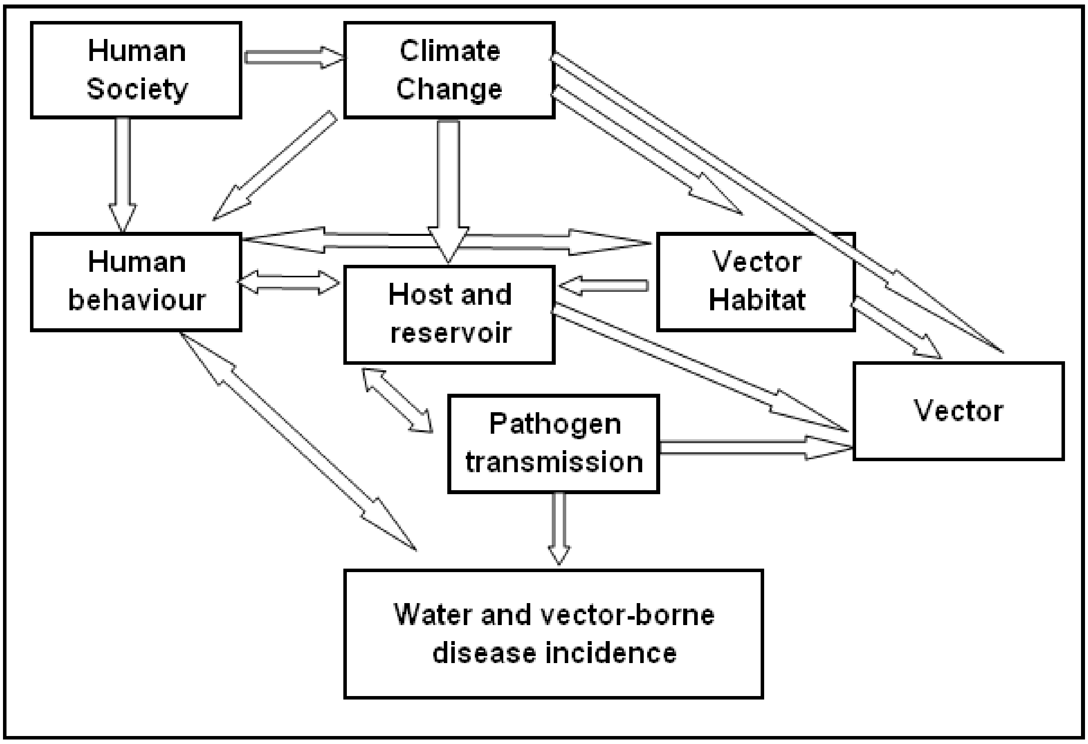

Figure 1.2: *The links between climate change and vector & water-borne diseases incidence. Adapted from ECDC, 2010*

Figure 1.3 shows another example of the impact of climate change with other factors upon health and presence of some infectious diseases.

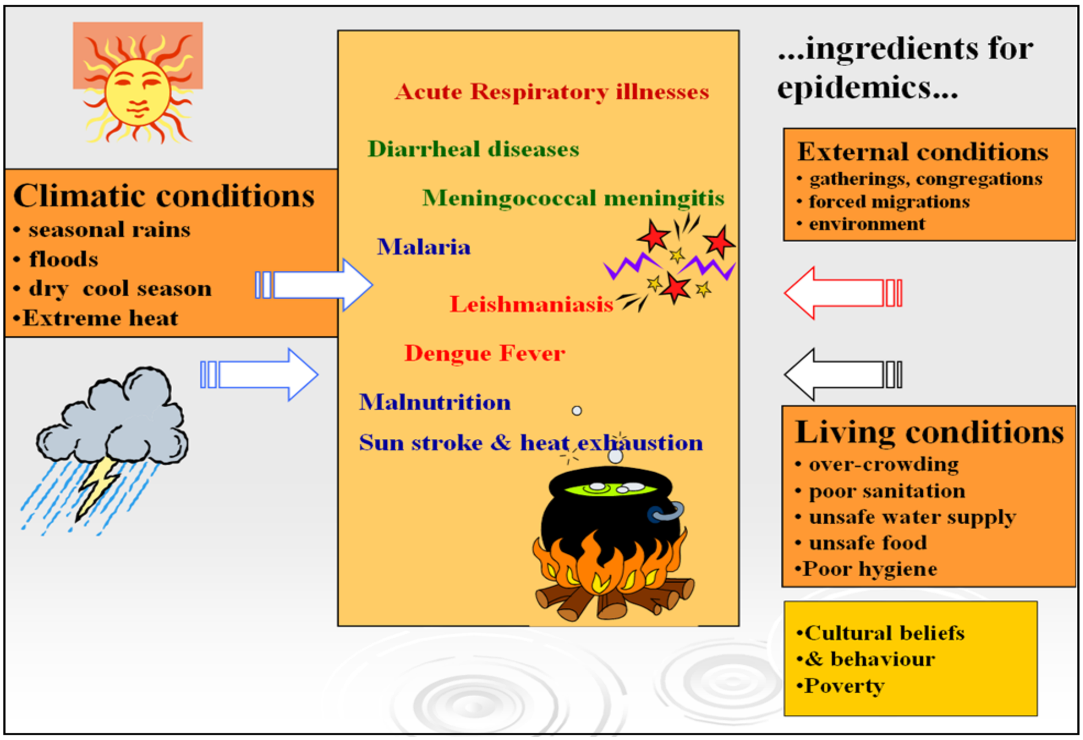

***Figure1.3**: Impact of climate change with some other factors upon health. Adapted from (MOH, Climate change, 2006)*

WHO, (2011) has listed a number of facts about climate change including some significant observations relating to health such as the changing patterns of infectious diseases in extreme high temperature. Sea levels can rise as a consequence of global warming and resultant flooding will increase the risks of infection from water and vector borne diseases. Shortages of fresh water or water of poor quality can occur in areas where rainfall amounts vary and this affects hygiene and health. This occurs especially where water has to be carried long distances as this increases the likelihood of contamination. Life threatening diseases transmitted through water via vectors such as mosquitoes are sensitive to climatic conditions as increased temperatures provide optimum conditions for mosquito breeding. As global temperatures rise, new geographical areas may provide these conditions. In the highlands of Kenya, for example, many people died of malaria in the summer of 1997. This was blamed on climate change as the population there had not previously been exposed to this disease.

There are many potential consequences of climate change and some examples and their impacts will be presented. Drought may affect the transmission of some mosquito-borne diseases. During droughts in an endemic area, the activity of mosquito is usually reduced. This may reduce case incidence but also the immunity of the population. When this drought breaks, increases in mosquito abundance may occur. This leads to a large increase in cases because of more vectors and weakened immunity in the population (Woodruff et al., 2002). Another example is heat waves which are related to increases in mortality in different areas across the world. In India several heat waves were reported during the last decade of the last century. These caused thousands of deaths (Mohanty et al., 2003). Furthermore, flood is a frequent disaster. This event is a result of interaction of rainfall, wind, sea level, surface runoff and natural topography (Confalonieri et al., 2007). In Venezuela more than 30,000 people lost their lives due to storms and floods during 1999 (Guha Sapir et al, 2004). More than 130 million people in China were affected by floods during 2003.

There is already evidence that climate change is affecting disease. Increases in malaria and leishmaniasis transmission and infectious diseases in general have been reported in Bolivia during the end of the last century. There was no responding from the related governmental agencies to adapt these increases (Confalonieri et al., 2007). However in Canada when increases in heat wave related to the number of deaths, due to the increases in air pollution, vector-borne diseases and allergic disorders, the relevant private and governmental agencies have tried to adapt. A number of different steps have been taken including monitoring for the emergence of the infectious diseases, measuring to reduce the heat island effect, upgrading water and wastewater treatment facilities, preparing plans for emergency management and early warning systems (Confalonieri et al., 2007; Riedel, 2004).

The effects of climate change on human health as well as the effects on the environment have been widely discussed. There is an almost universal scientific consensus on the many direct effects of climate change that will occur in the coming decades. There has been much research in these areas but the impact of climate changes on health and specifically on infectious diseases is an area where more research is needed.

1.6 Influence of Climate Variables upon Selected Infectious Diseases in the Asir Region, Saudi Arabia.

1.6.1 Overview

This study investigates the influence of climate variables on three related vector and water -borne diseases in the Asir region, Saudi Arabia. The diseases that have been chosen for the study are malaria, cutaneous leishmaniasis and schistosomiasis. These diseases are the most wide spread vector and water-borne diseases which have the highest impact on public health in Asir (Dr A. Abdoon 2007 pers. Comm.).

Each disease has been considered separately and has a complete chapter devoted to it. Asir is an interesting study area because it has a variety of different geographical regions from the low plains of the sea coast to mountainous areas over 3000m. Because of this, it has been possible to study three diseases in different climatic conditions within a single area in Saudi Arabia. The extent of each disease in a particular sector of the Asir Region is discussed in the individual chapters on each disease.

The hypothesis for this study is that climate variables, specifically temperature, rainfall and humidity, have an influence on these diseases within Asir Region.

1.6.2 Importance of the study

This study is important for three main reasons. First, it is innovative research as it is the first time that there has been a specific and rigorous investigation of the influence of climate variables upon diseases in Saudi Arabia. Other Saudi Arabian studies have mentioned the influence of climate briefly but have not dealt with it in detail or analyzed its influence rigorously. Secondly, it is a subject that fully justifies research because these diseases have a large impact on the lives of people in Saudi Arabia who become infected, with high costs to public health. Prevention of a disease is better than cure and it is hoped that using the results of this study it should be possible to design an early warning system from weather patterns to predict the incidence of each selected disease. Finally as the climate changes in Saudi Arabia associated with climate change, this research could help predict the impact of any changes upon the health of the population.

1.7 Structure of Thesis

The first chapter (Introduction) will give an overview of infectious diseases and their importance to health. Climate and climate change will then be described followed by their influence upon infectious diseases. The chapter will then consider this study and its importance in detail.

The study area (second chapter) will be presented. This introduces the country of study, Saudi Arabia, including information on topography, climate, demography, education and the health of the population. The second half of this chapter will examine Asir Region in more detail. This is the region in the South West of the Country which forms the study area for this thesis.

There are three main chapters; 3, 4 and 5 which will examine the influence of weather upon malaria, leishmaniasis and schistosomiasis respectively within the Asir Region. Due to the similar methods used for studying each disease these three chapters have a similar structure. Each one will start by providing an overview of the disease globally. Its transmission will then be described in detail followed by information on the symptoms and causes of the disease. Each chapter will then show how this illness may be prevented and treated. The influence of weather upon disease is the focus of this thesis and so we will then present a literature review of the illness and previous studies that have looked at its relationships with weather. This will conclude with a brief summary of the literature and how this information will be developed into the design for each study. The study area will then be introduced focusing specifically on the prevalence of the disease. This will be followed by a description of the data sources to be used in each chapter and a description of the methods to be employed. The results of the analysis will then be presented, specifically evidence of any relationships with weather. Each of these three chapters will conclude with a section discussing the results obtained.

The last chapter (6) will present the summary and conclusions of this study. This will include a discussion of its strengths and limitation. It will also discuss how research developed over the 3 chapters. Finally it will make recommendations for future research.

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Chapter 2

Study Area

2. Introduction

2.1 Saudi Arabia

2.1.1 Geography and Demography:

Saudi Arabia is located in the south west of the Asian continent and is the largest country in the Middle East. It occupies four-fifths of the Arabian Peninsula covering an area of 2.25 million km^2. According to the system of regions issued during 1992, this country has been divided into 13 administrative regions (Figure 2.1) (Central Department of Statistic & Information (CDSI), 2010). The population in 2010 was 27.14 million (18.7 million Saudis, 8.4 million non-Saudi) and the annual population growth rate between 2004 and 2010 was 3.2% (CDSI, 2010). Figure 2.2 shows the distribution of population by regions according to a demographic survey undertaken during 2007. This figure shows that Riyadh and Makkah regions have the highest population number followed by Eastern Region then Asir Region which has the fourth highest population in Saudi Arabia. The lowest population number is in Northern Border followed by Jouf region. The survey also shows that the population of males is higher than females in all regions with the greatest difference in the regions of Riyadh, Makkah and Eastern Province.

Saudi Arabia is bordered by 7 countries, Jordan on the northwest, Iraq on the north and northeast, Kuwait, Qatar, Bahrain, and the Arab Emirates on the east, Oman on the southeast and Yemen on the south. It is also bordered by two seas the Arabian Gulf to the North East and the Red Sea on the west (Garout, 2000). The west coastal plain which lies along the Red Sea is 1,100 km long. The most significant mountains chain are the Sarawat Mountains (rising to 3000 meters in the south and gradually falling to 1000 meters in the north) located to the east of the west coastal plain. From these mountains there are many valleys which slope westward to the sea and eastward into the hills and the desert (CDSI, 2010).

As the country has a large area it can be divided into several different geographical areas including (Garout, 2000; CDCI, 2010):

- Najd: located in the middle of Saudi Arabia including some plateaus, hills and oases, e.g. Riyadh City (Capital City) and Beraidah City.

- Hejaz: spreads along the western coast, and includes many cities such as Makkah, Madinah and Jeddah.
- Asir Region: Located in the south west of Saudi Arabia, with three altitudes; Highlands (2000 – 3000m) which from part of the Sarawat Mounties range (e.g. Abha City), Tehama which lies on the coastal plain with foothills (e.g. Muhail City) and the east plateaus (e.g. Bishah City).
- Eastern Region which includes Al Hasa oases (e.g. Al Hasa City), coastal plains on the Arabian Gulf (e.g. Dammam City) and a large part of the Empty Quarter desert (Alrub Alkhali).
- Northern Region: contains some oases and part of the Nufoud desert.

Figure 2.1: *Map of Saudi Arabia with its administrative regions (CDSI, 2008)*

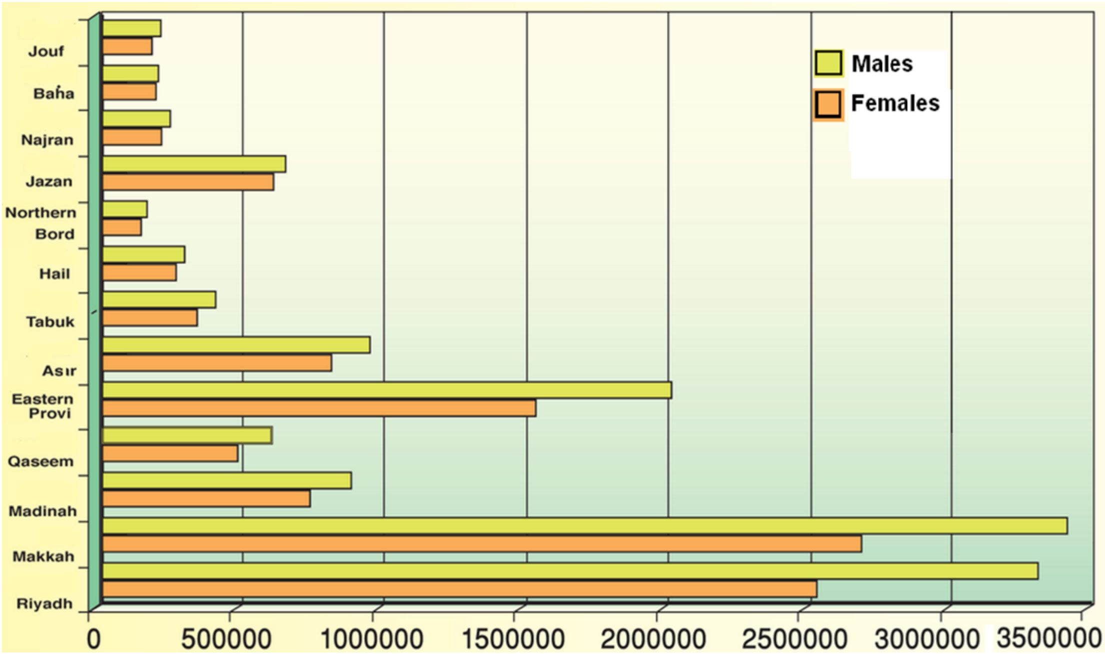


***Figure 2.2**: Population distribution by regions by demographic survey 2007 (CDSI, 2008)*

Table 2.1 illustrates a comparison of demographic indicators among selected neighbouring countries of Saudi Arabia during 2006. This figure shows that Saudi Arabia has the largest area compared to the neighbouring countries, and has the second highest population. It also has the second lowest population density. More than 85% of people in Saudi Arabia live in urban areas.

***Table 2.1:** Comparison of demographic indicators among selected neighbouring countries of Saudi Arabia during 2004 (WHO, 2007; CDSI, 2006)*

	KSA	UAE	Qatar	Bahrain	Kuwait	Iraq	Yemen	Oman
Area (000) km^2	2250	83.6	11.58	0.72	17.82	435.1	555	309.5
Pop. (Million)	23.7	4.1	0.84	0.74	3.10	28.00	20.90	2.60
Density person/km2	10.5	49.1	72.4	1031.9	171.2	64.3	37.6	8.3
Pop. <15 (%)	32.9	19.5	22.5	27.3	21.8	43.3	45	32.4
Population +65 (%)	2.8	2.9	1.2	2.5	1.6	2.8	2.9	2.2
Urban Pop. %	85	82	100	100	100	67	26	71
Crude birth rate ‰	24.9	15.7	16.8	20.9	17.8	38	24.2	39.2
Crude death rate ‰	4	1.5	2.1	3.1	1.7	10	2.5	11.4

Pop.: population

Tables 2.2 and 2.3 demonstrate some selected demographic and health economic indicators for Saudi Arabia between 2007 and 2010. They indicated that advances in health services, industry, education, commerce, agriculture and construction have turned the country into one of the fastest developing countries in the world (CDCI, 2010).

Table 2.2: *Demographic and health economic indicators of Saudi Arabia between 2007 and 2008. Adapted from (MOH, 2008; CDSI, 2008)*

Estimated population	24,807,273
Crude birth rate /1000 pop	24.1
Pop. Growth Rate	2.23%
Population Under 5 years	11.56%
Population under 15 years	32.26%
Population 15 - 64 years	64.95%
Population from 65 & above	2.79%
Total Fertility rate	3.04
Life expectancy at birth Male Female	73.4 72.4 74.5
GDP per capita	$ 19206
MOH Budget (of Governmental Budget)	5.6%
MOH Expenditure per capita	$ 271

Table 2.3: *Key indicators of Saudi Arabia (CDSI, 2010)*

Population 2010 (people)	27,136,977
Population density (person / sq km) 2010	14
GDP growth at (CDSI), 2010 constant prices 2009	0.6
The contribution of the private sector in GDP at constant prices 2009	48%
Per capita GDP at current prices in 2009 (SAR)	52,853
Export growth in 2009	-37.44%
Import growth in 2009	-9.08%
The contribution of exports to GDP at current prices in 2009	54%
Unemployment Rate (2009)	5.4%
General index for the cost of living 2009	122.4
Change in the index of cost of living (inflation) for the year 2009%	5.06
Growth rate of GDP per employed person (2008)	19.3
The proportion of the working population to population (2009 m)	32.1
Gross enrolment rate in primary education (2009 m)%	99
Rate and infant mortality (per thousand live births) 2009	14

2.1.2 Climate

The climate of Saudi Arabia is arid and semiarid with extremes of high temperature during summer. It is cool during the winter in Najd and some parts of the Eastern Region. However temperatures are more moderate in South Western and Northern regions during the summer and cooler in the winter. Frost and snow may occur in the Northern region. In contrast, the temperature during the summer season is high in most of the country (>400C). The humidity is high along the coastal areas (MEPS, 2007; CDSI, 2010). Average annual rainfall for Riyadh, Jeddah and Jazan is 100mm, 54mm and 500mm respectively (MOH, Workshop, 2006).

2.1.3 Education

The government of Saudi Arabia gives a high priority to education which is almost free and the literacy rate is growing steadily. In 2007, 86.3% of the total population was literate compared to only 40% during 1950. Table 2.4 shows the literacy rate, unemployed rate and the percentage of the population living in traditional houses for each administrative region of Saudi Arabia. Literacy rate, unemployed rate and percentage of traditional houses are considered indicators of the living standards. The region of Riyadh has the best living standards with high literacy, low unemployment and a low percentage of traditional homes. This is followed by the Eastern Region. The lowest living standards were in Jazan Region, although the highest unemployment rate was in Albahah, followed by Hail. Asir Region comes in the middle of living standards in Saudi Arabia.

Table 2.4 *Literacy rate of each region of Saudi Arabia with unemployed rate and traditional houses during 2007(CDSI, 2010)*

	Al-Riyadh	Makkah	Al-Madinah	Al-Qaseem	Eastern Region	Asir	Tabouk
Literacy rate %	90.1	86.3	86.1	85.0	89.9	82.5	87.1
Unemployed %	1.5	2.5	3.2	3.1	1.8	4.5	2.2
Traditional houses %	12.2	31.8	31.9	28.0	17.0	40.7	30.4

Continue table 2.4

	Hail	Northern Borders	Jazan	Najran	Al-Baha	Al-Jouf	Total
Literacy rate %	79.5	82.2	76.5	80.9	80.2	86.0	86.3
Unemployed %	4.7	3.0	4.9	3.2	5.6	2.3	2.7
Traditional houses %	51.2	19.8	73.4	40.3	41.0	25.5	27.8

2.1.4 Drinking Water Services

Saudi Arabia draws its water from four main sources (Ministry of Water and Electricity (MOWE), 2005):

- Surface water, such as dams, springs and wells (<30meters depth) which is to be found mostly in the west and south-west of the country (7%).
- Ground water which is held in aquifers. Some are naturally replenished while others are non-renewable (23%).
- Desalinated seawater, a source of water production in which this country is now a world leader. There are 29 desalination plants providing drinking water to major urban and industrial centres through a network of water pipes (Figure 2.3). During 2004 desalination met around 70% of the Kingdom's drinking water requirements.
- Reclaimed wastewater (<1%).

In terms of how this water is distributed to households, Figure 2.4 shows the different sources of water supply in Saudi Arabia during 2004. The figure shows that most of the households (>70%) use public piped water followed by those who use catchment tanks (~24%). Less than 5% use wells and less than 1% use other sources (MOWE, 2005).

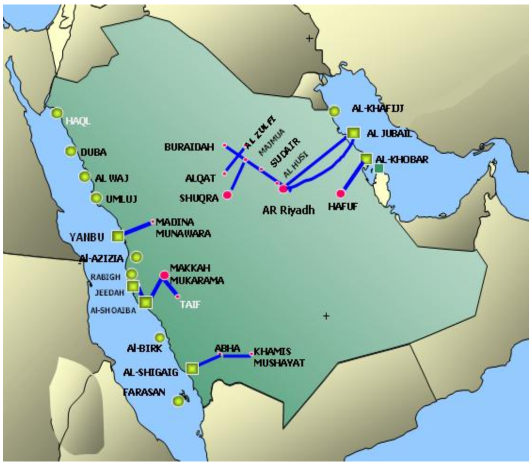


Figure 2.3 Projects locations of water desalinated& distribution locations in SA (MOWE, 2005)

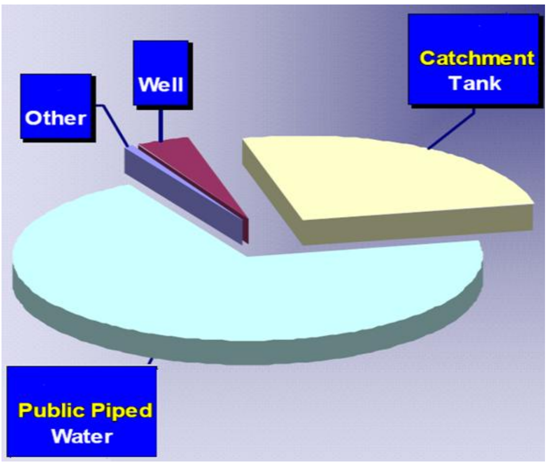


Figure 2.4: The different sources of households of water supply in SA (MOWE, 2005)

2.1.5 Health service

All parts and sectors in Saudi Arabia provide health care services under the supervision of the Ministry of Health with some other governmental health sectors such as the National Guard health services, health services of the Ministry of Defense & Aviation and Security Force health services. These sectors have their own hospitals that provide health care for their employees and their dependents (Garout, 2000). In addition, there is a private sector, and this service is increasingly being used by business companies to provide medical care for their employees.

The Ministry of Health has three main assistant agencies; curative preventive, prevention medicine and an assistant agency for planning and research with many other programs and services. The Primary Health Care Centers (PHCC) are the first health care point for the community. The Ministry of Health has made considerable efforts to develop these centers. In 2008 there were more than 1986 centers covering each part of the country (MOH, 2009; CDSI, 2010). PHCCs provide basic health care services including maternity and child health and immunization programs. More than 60% of these centers have laboratory facilities, 25% have an X-ray service and 45% have dental services. The second level of health care is hospitals, which are widely distributed throughout each main part of the country. In 2007 there were 393 hospitals with 58.8% (231) under the supervision of the MOH with 31720 beds (MOH, 2008; CDSI, 2010). Table 2.5 shows the health resources indicators for Saudi Arabia during 2008.

Table 2.5 *The Health resources rate for Saudi Arabia during 2008 (Rate per 10,000 Pop) (CDSI, 2010)*

Physicians	21.5
Dentists	2.8
Pharmacists	6.4
Nurses	40.8
Allied health Personnel	20.8
Hospitals beds,	21.72
Primary health care centers	0.8
Governmental hospital beds	17.14
Private hospital beds	4.58

- **Infectious Diseases**

In order to eliminate infectious diseases the MOH is continuously upgrading its prevention and control programs. As a result of these efforts during the last decades, they have eliminated several diseases such as diphtheria and poliomyelitis. The number of cases of the remaining diseases such as tetanus and measles have been reduced. This is due to the control and surveillance of the epidemiological control units spread over the whole of the country (MOH, 2008). There has been a reduction in the incidence of some vaccination target diseases such as whooping cough and mumps, due to the high immunization coverage achieved over the last decade.

Despite advances in the health services, the control of infectious diseases remains a challenge. For example, a massive spray against Rift Valley Fever lasting for more than six months started in Asir and Jazan during 2000. This action was carried out by many related governmental agencies using airplanes, cars and manpower (Dr A. Abdoon 2007 pers. Comm.).

Figure 2.5 shows the reporting system for infectious diseases in MOH, Saudi Arabia. The first level for the weekly notification in each region of this country is the primary health care centres, clinics, hospitals and any related health center. Monthly report is sent by the related department into the health directorate, primary health care department & preventive medicine division for each administrative region. Each health directorate of a region sends these reports to the infectious diseases department in the Ministry of Health.

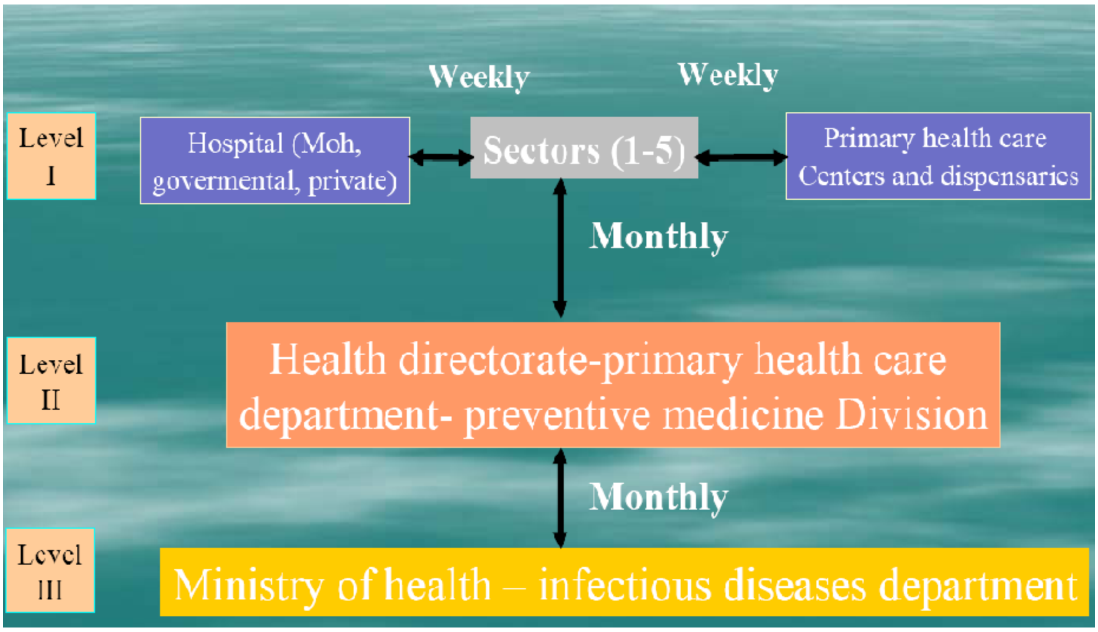


Figure 2.5: *Reporting System for infectious diseases in MOH, Saudi Arabia (Epidemiology Field, MOH, 2007)*

Table 2.6 presents the reported cases of notifiable infectious diseases in the country during 2008 (MOH, 2009).

***Table 2.6**: Reported Cases of notifiable infectious diseases by Region, Saudi Arabia during 2008 (MOH, 2009)*

Cholera	7	Malaria	1497
Diphtheria	0	Leishmaniasis	2321
Whooping cough	30	Schistosomiasis	699
Tetanus neonatorum	13	Rift valley fever	0
Tetanus, other forms	4	Plague	0
Poliomyelitis	0	Yellow fever	0
Measles	158	Guillian - Barre syndrome	121
Mumps	31	Dengue fever	913
Rubella	15	Rabies	0
Chickenpox	60007	Echinococcus hydatid disease	6
Brucellosis	3447	Salmonellosis	1292
Meningococcal	7	Shigellosis	188
Pneumococcal	25	Amoebic dysentery	3311
Haemophilus influenza.	4	Typhoid & paratyphoid	269
Meningococcal, other forms	270	Unspecified hepatitis	255
Tuberculosis (TB)	3900	Hepatitis A	1678
Pulmonary TB	2635	Hepatitis B	5066
Extra – pulmonary TB	1265	Hepatitis C	2733

2.1.6 Zoogeographical areas of Saudi Arabia

Saudi Arabia lies at the crossroads of three of the world's major zoogeographical realms, the Palaearctic zone, the Afro-tropical and the Indo-Malayan and is itself at the centre of the Eremian zone (or Saharo - Sindian) desert region which is the vast desert belt extending from Morocco to western China (CBD, 2007). Asir and Jazan Regions are located in the Afro-tropical zone as some countries in the east of Africa. This could provide suitable climate conditions for some vectors of vector-borne diseases such as malaria and leishmaniasis (Abdoon and Alshahrani, 2003).

2.1.7 Distribution of Malaria, Leishmaniasis and Schistosomiasis in Saudi Arabia

The focus of the current study will be on malaria, leishmaniasis and schistosomiasis. The distribution of these illnesses varies from one region to another. It even varies within regions and from one year to another.

Malaria transmission is confined to the southwest of Saudi Arabia (Jazan, Asir, and A1-Baha Regions) but also occurs in some isolated rural areas in Makah and Madinah Regions. Environmental conditions play an important role in the distribution of malaria, as they affect the mosquito species to be found in an area, its life cycle, the life span of the plasmodium and the density of mosquitoes. These conditions may vary from year to year. Malaria transmission is also affected by the control measures taken against it. Figure 2.6 shows the distribution of malaria across Saudi Arabia, the pathogenic mosquitoes in each area and the endemicity of malaria in each area (MOH, 2006; Al-Saghayer S. and Alattas M, 2006). The distribution in the map shows that the regions of Asir and Jizan are higher endemic areas followed by Makkah and Albahah Regions. The low endemic areas are in Najran, Madinah, and Tabuk Regions. The other Saudi Arabian regions do not report indigenous cases.

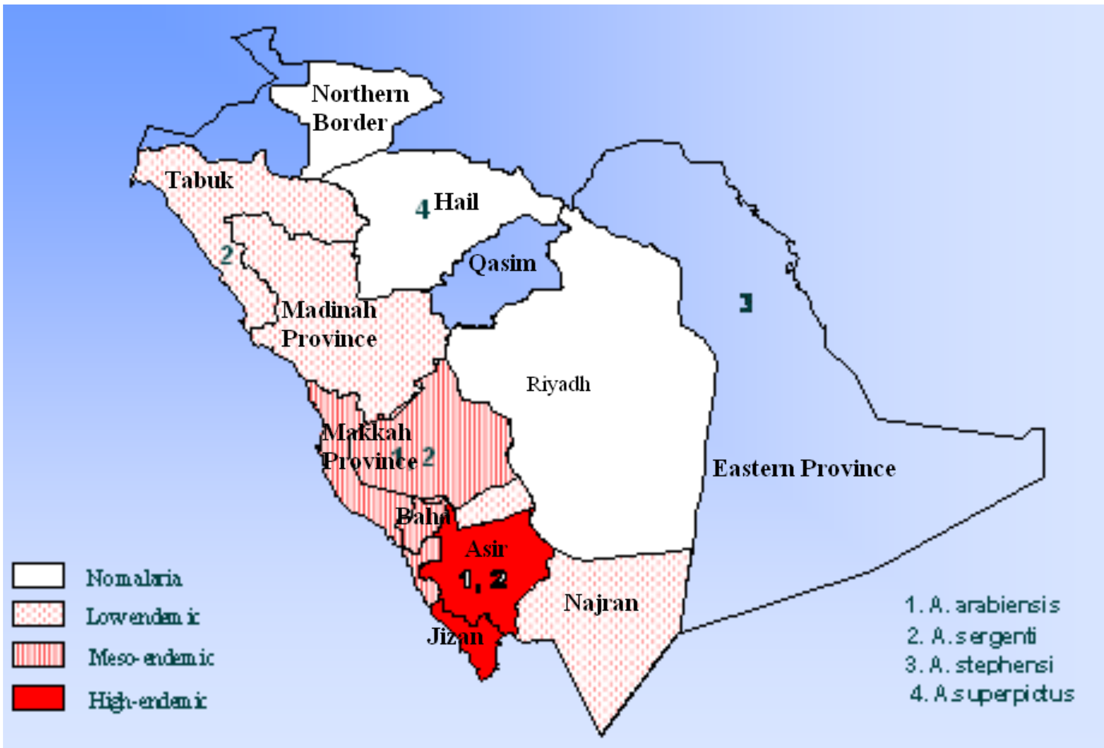


***Figure 2.6**: Malaria distribution in Saudi Arabia and prevelace of the vector (The main vector in the high- endemic foothills area is arabiensis, and sergenti in the coastal plain) Adapted from (Al-Saghayer S. and Alattas M, 2006)*

There are two types of leishmaniasis in Saudi Arabia; cutaneous leishmaniasis (CL) and visceral leishmaniasis (VL). CL and VL have differing distributions across Saudi Arabia. According to MOH, (2008) CL occurs in most Saudi Arabian regions except the Northern region, AlJouf, Qurayat, Hafr-Albaten and Qunfedah Regions. The peak of CL occurs during winter, and the lowest incidence occurs during the end of spring and the beginning of summer (MOH, 2008). VL has a different distribution and during 2008 90.6% of cases occurred in Jazan, 6.3% in Asir and most other cases (3.1%) were reported in Qaseem (MOH, 2008).

The geographical distribution of schistosomiasis in Saudi Arabia varies depending on the type of the disease. During 2008, urinary schistosomiasis was recorded only in Jazan and Asir. Intestinal schistosomiasis was recorded in Taif, Albahah, and Asir. However, combined schistosomiasis was recorded only in Asir, as environmental predisposing factors are present in this region (MOH, 2008). The geographical distribution of the intermediate host of schistosomiasis is different from the distribution of cases of the disease. The host (snail) of urinary schistosomiasis is endemic in Makkah, Madinah, Jazan, Asir and Lith regions. The host of Intestinal schistosomiasis is endemic in Taif, Albahah, Asir, Najran, Makkah, Madinah, Hail, Jeddah and Jazan regions. Both types of host are present in Jazan, Makkah, Asir and Madinah (MOH, 2008). Figures 2.7 and 2.8 demonstrate the distribution of endemicity of schistosomiasis in the regions of Saudi Arabia in 2009. The distribution in the map shows that the regions of Asir Jizan and Albahah have low incidence of schistosomiasis followed by Makkah Region which has irregular incidence. There were no cases recorded in the regions of Najran, Riyadh, Madinah Tabuk, Hail and Al-Jouf. The rest of Saudi Arabia regions are free incidence. The diagram in Figure 2.8 shows that Asir and Taif regions have the highest schistosomiasis cases followed by Jazan, with lowest cases in Alqunfidah regions. It is worth mentioning that all of these regions are located in southern Saudi Arabia, with the exception of Taif region which is close to these regions.

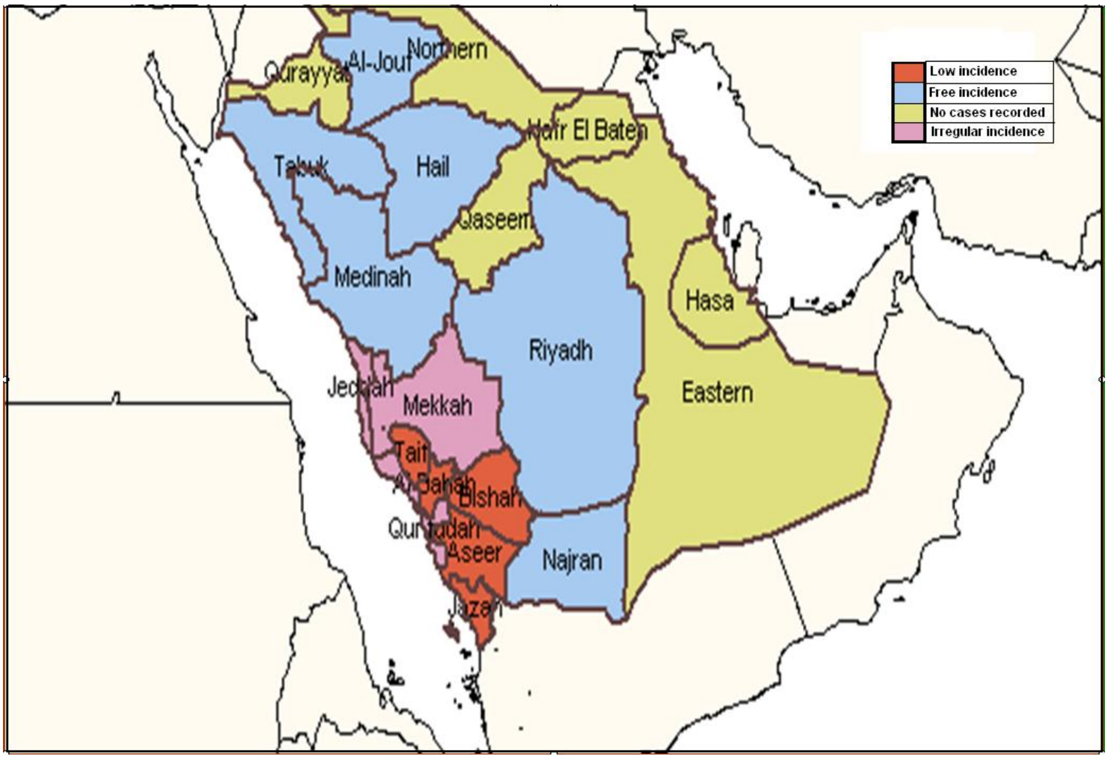


Figure 2.7: *distribution of endemicity of schistosomiasis in Saudi Arabia during* 2009 *(Dr M. Alzahrani 2010 pers. Comm.)*

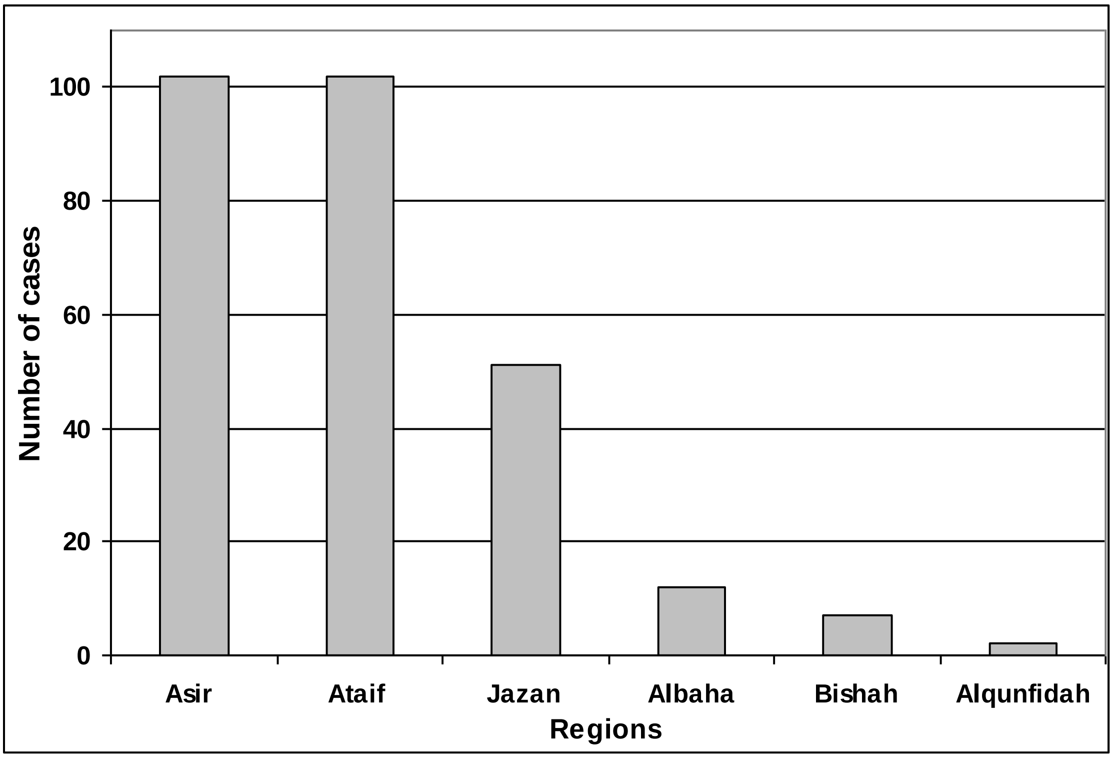
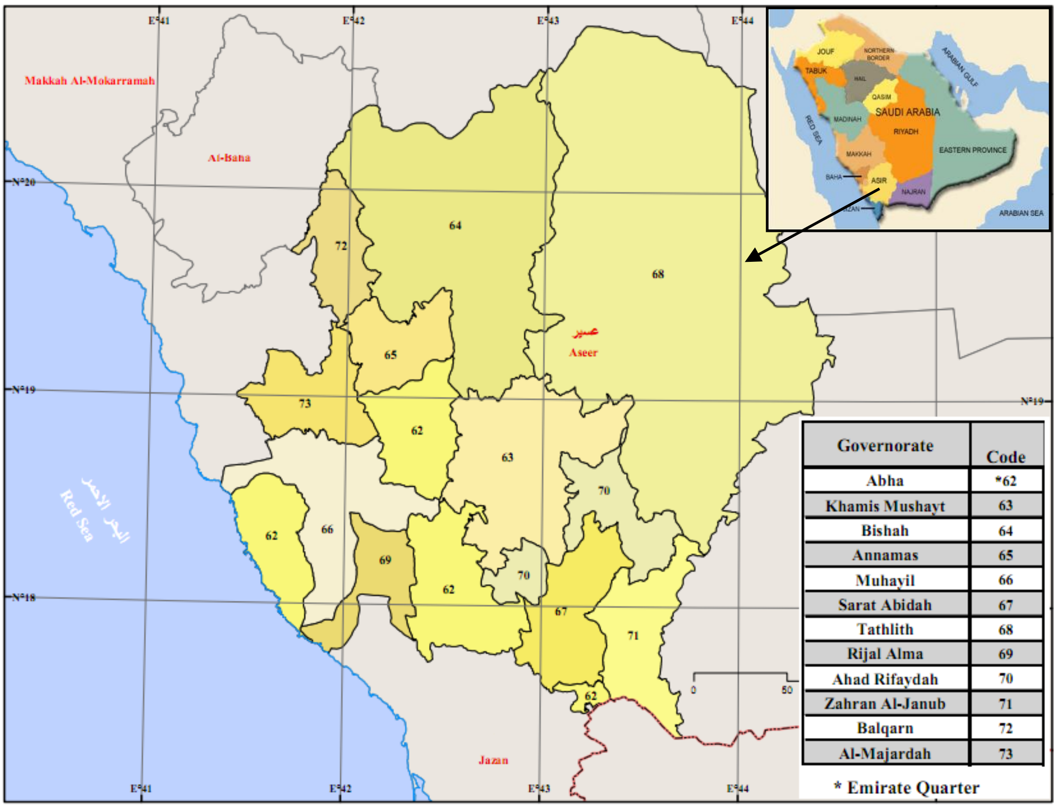


Figure 2.8: *The schistosomiasis endemic regions in Saudi Arabia during 2009*

2.2 Asir Region

2.2.1 Geography and Demography:

The Asir region is located in the south west of Saudi Arabia. It is a large administrative region, with its capital at Abha. It is divided into the emirate quarter and eleven governorates (Central Department and Information 2004; 2010) as illustrated in Figures 2.9 and 2.10. It has a varied terrain ranging from highlands, high mountains (2000 to ~3000m above sea level) and the lowlands (Tehama) parallel to the Red Sea (Gaafar et al., 1997). It also includes a large area of the desert to the north and east as far as the cities of Bishah and Tathlith. The mountain range has the highest rainfall in Saudi Arabia (MEPS, 2007; Subyani, 2000). The highest place in Saudi Arabia is in this region (Alsoudah, >3000m).



Central Department of Statistics & Information

Figure 2.9: *Map of Asir Region with its emirate quarter and governorates (CDSI, 2005)*

Figure 2.10: *Topography of Asir Region.*

There were more than 20 cities, 915 community centers and 7760 villages in this region in 2008. The main cities are Abha, Khamise, Bishah and Muhail. The population of Asir Region during 2010 was more than 1.9 million. Table 2.7 shows the distribution of population of the emirate quarters and governorates of this region (CDSI, 2010). The population of the sectors of Abha, Khamise and Bishah are more than 56% of the total population. Khamise has the highest population followed by Abha. The lowest population is in the Animas sector.

Table 2.7: *The population distribution of the emirate quarter and governorates of Asir region (CDSI 2010)*

Abha	366551
Khamise	512599
Bishah	205346
Animas	54119
Muhail	228979
Sarat-Abidah	67120
Tathlith	59188
Rejal-Alma	65406
Ahad-Rifadah	113043
Dhahran-Aljanoub	63119
Balgarn	74391
Majaredah	103531
Total	1913392

2.2.2 Climate in Asir

The topography of Asir has a large influence upon its climate. Therefore Asir can be divided climatically into three areas:

1. Asir Sarawat Mountains (Highlands): A series of high mountains extending from the north of Asir Region to the south (2000 -~3000m above sea level). The annual average temperature for this area is 17.7^{0}C, average rainfall is 500mm (the highest rainfall in Saudi Arabia), and the annual average relative humidity is 53.1%.
2. Asir Plateau (a part of Highlands Group): In the NE of Asir with an elevation range of between 1000 and 2000m, decreasing to the east. The annual average temperature for this sector is 19.5^{0}C, with 250mm annual rainfall and an annual average relative humidity of 44.4%.
3. Tehama (Lowlands): This area can be divided into two sections
   - Foothills (300 - 900m) - Red Sea Costal Plain (0 - 200m).

This area receives an annual rainfall of 350mm, and temperature ranges between 25^{0}C and 49^{0}C during summer. The relative humidity varies from 55% in summer to 70% in winter.

2.2.3 Drinking Water Services

Sources of water in this region are wells, dams and springs in addition to desalinated water. Desalinated water arrived in Abha for the first time in 1988 and the amount of water produced in 2007 was 47.68 million tons. Water is distributed throughout the region by a network of pipes which were initially installed in Abha during 1995. This network distribution of drinking water in Asir now covers four cities, Abha, Khamise, Ahad-Rifadah and Muhail. Within each city the proportion of homes on network supply is 70%, 30%, 50% and 30% respectively. This region suffers from a shortage of drinking water and most people who live in the countryside depend on water from wells or dams which may have health consequences. In addition, in this region the shortage of drinking water increases during summer with the beginning of the tourism season (General Directorate of Water and Electricity in Asir, 2008).

2.2.4 Environmental Problems

The region of Asir covers a large area and it has a border with Yemen where there are a lot of infectious diseases. These include vector-borne diseases such as malaria and leishmaniasis. It also has a border with Jazan region which suffers from the same problems. Therefore, it is influenced by conditions in neighbouring regions. Asir has many man-made dams (56) and lakes which form after rainfall. Both these may encourage the presence of mosquitoes or the parasites of schistosomiasis or other harmful insects. Some parts of Asir, such as the foothills are hot and humid during summer, and this weather may encourage some types of insects to multiply. Furthermore, the rural areas and most of the countryside areas in the region use cesspools which may contribute to the contamination of underground water and the environment (General Directorate of Water and Electricity in Asir, 2008; Dr A. Abdoon 2007 pers. Comm.; MOH, 2008).

2.2.5 Health Services

The Health Affairs Directorate in Asir represents the MOH in this region. This directorate provides the health care services in the region including curative medicine and preventive medicine. During 2007, there were 290 primary health care centers, 22 hospitals (18 public & 4 private) and one main referral hospital (Asir Central Hospital) in Abha as the capital city of this region. In addition, there are many assistant preventive medicine departments related to public health and environmental health.

Table 2.8 demonstrates the number of reported cases of some infectious diseases in Asir during 2008. This table shows that the highest number of cases of the infectious diseases in this region is from chickenpox followed by brucellosis, hepatitis B and amoebic dysentery. Other diseases exist in Asir including climate-sensitive diseases such as leishmaniasis and schistosomiasis. Sixteen infectious diseases had no cases in Asir during 2008.

***Table 2.8**: Reported cases of notifiable infectious diseases in Asir during 2008 (MOH, 2009)*

Cholera	0	Malaria	31
Diphtheria	0	CL Leishmaniasis	130
Whooping cough	1	Schistosomiasis	115
Tetanus neonatorum	0	Rift valley fever	0
Tetanus, other forms	0	Plague	0
Poliomyelitis	0	Yellow fever	0
Measles	1	Guillian - Barre syndrome	11
Mumps	0	Dengue fever	0
Rubella	1	Rabies	0
Chickenpox	4300	Echinococcus hydatid disease	0
Brucellosis	563	Salmonellosis	9
Meningococcal	0	Shigellosis	0
Pneumococcal	0	Amoebic dysentery	135
Haemophilus infi.	0	Typhoid & paratyphoid	30
Meningococcal, other forms	9	Unspecified hepatitis	13
Tuberculosis (TB)	125	Hepatitis A	93
Pulmonary TB	84	Hepatitis B	296
Extra – pulmonary TB	41	Hepatitis C	105

Table 2.9 shows comparisons among the main sectors of Asir Region 2004 for the rate of climate-sensitive borne diseases such as malaria, leishmaniasis and schistosomiasis. This table also illustrates the health infrastructure for each sector including the number of hospitals and primary health care centers.

Table 2.9: *Comparison of some health infrastructures and selected infectious diseases among some sectors of Asir Region 2004 (Department of preventive medicine, Health Affairs Directorate in Asir, MOH, 2006)*

Sector	Altitude L	Schist R	Malaria R	Parasite R	CL. R	Hospitals No.	PHCCs No.	Pop. that PHCCs cover	Pop. per every PHCC	No. of patients in month	% patients per pop. in month
Abha & its sectors	2500	0.0	0.0	14.7	0.2	3	44	152971	3477	43782	28.62
Khamise	1800	0.1	0.0	23.3	1.4	1	15	177700	11847	45601	25.66
Ahad-Rifadah	1700	0.0	0.0	60.6	0.0	1	9	64669	7185	16182	25.02
Al Madhah	1600	0.0	0.0	47.4	0.0	0	17	33950	1997	14898	43.88
Tathlith	975	0.0	0.0	17.5	0.4	1	18	50435	2802	26282	52.11
Sarat-Abeeda	2400	1.0	0.0	42.5	3.1	1	15	47716	3181	17106	35.85
Dhahran Al Janoub	2020	1.8	1.5	72.4	2.4	1	21	45308	2158	19658	43.39
Tanoma	2600	2.3	0.0	28.9	1.7	2	15	35182	2345	16588	47.15
Sabt-Alalaya	2200	6.6	0.0	175.4	0.7	2	18	59038	3280	20743	35.13
Muhail	450	3.2	0.7	6.39	0.0	1	22	120474	5476	38625	32.06
Al Majaredah	450	0.4	0.9	18.71	0.3	1	19	66814	3517	24601	36.82
Rejal	700	0.0	5.6	21.7	2.0	1	19	39180	2062	10995	28.06
Alberek	20	0.0	0.0	0	1.1	1	7	18200	2600	4291	23.58
Al Gahma	20	0.0	0.7	14.6	0.0	1	4	13619	3405	5352	39.30
Marabah	600	-	1 N	-	-	-	-	-	-	-	-
Al Farshah	450	-	51 N	-	-	-	-	-	-	-	-
Ballesmer	2250	-	-	-	-	1	9	10665	1185	2287	21.00
Central Laboratory	2200	11 N	32 N	279 N	68 N	-	-	-	-	-	-
Bishah	1020	-	6 N	-	-	3	35	-	-	-	-
Total	-	-	-	-	-	21	287	935921	-	306991	-

R: No. of cases /10000 population. N: No. of cases. L: above sea level. Schist: Schistosomiasis. PHCC: Primary health care. Pop: population. –: No information available

2.2.6 Distribution and Endemicity of Malaria, Leishmaniasis and Schistosomiasis in the Asir Region

According to the Vector Control Administration in Asir, environmental factors such as climate variables and topography play an important role in determining the distribution of many infectious diseases, in particular, vector and water-borne diseases. However the methods of control are different depending on the type of disease. Control methods may also vary between seasons and from one place to another. This fact is appreciated by the health decision makers in the Ministry of Health and in this sector.

This study will focus on and discuss the impact of climate variables upon three diseases (malaria, leishmaniasis and schistosomiasis). Each disease will be examined separately.

Chapter 3

Influence of Climate Variables upon Malaria Cases in Asir Region, Saudi Arabia

3.1 Introduction

Malaria is one of the major health problems facing tropical and subtropical areas of the world. It is the most important vector-borne disease, and WHO estimates that 2400 million people live in malarious regions of the world (WHO/SDE/PHE, 1999). It is responsible for an estimated 300–500 million clinical attacks globally (Keiser et al., 2004). The exact number of deaths caused by malaria is unknown but has been estimated at 1.5 - 3 million annually (De Savigny et al., 2004). Malaria transmission is sensitive to weather and climate conditions, so a changing climate is likely to change transmission dynamics in many regions (e.g. increased temperature or abnormal rainfall). Indeed, it is perceived as the vector-borne disease most likely to be affected by global climate change (WHO/WMO/UNEP, 1996; Mc Michael et al., 1996; Hana et al., 2001).

This chapter will start by providing an overview of malaria transmission and its life cycle involving two hosts; a human and a mosquito, and goes on to describe the symptoms and causes of malaria and how this illness may be prevented and treated. We will then present the literature review of malaria and previous studies that have looked at relationships with climate variables. The study area will then be introduced followed by a description of the data sources used and the method employed. This data will then be analyzed statistically to look at any relationships with climate variables. Finally we will present the results followed by discussion and conclusion.

3.2 Malaria Transmission

Malaria is a vector borne disease caused by protozoan parasites of the genus Plasmodium. It is caused by any of four species: *P. falciparum, P. vivax, P. ovale,* and *P. malaria.* These parasites are transmitted from person to person by the bite of an infective female anopheles mosquito (WHO, 2005). P. falciparum is responsible for 90% of deaths but only about 15% of infections. However, P. vivax is the most common cause of infection, and responsible for about 80% of all malaria cases (Mendis et al., 2001).

About 30 (out of 400) species of anopheles mosquitoes in the world are malaria vectors of major importance. However, throughout the world different species are responsible for malaria and these species vary in their ability to transmit the parasite. For example, Funestus, Gambia and Arabians, are highly efficient vectors which are spread throughout sub-Saharan Africa, whereas Stephensi and Minimus predominate in Asian countries are less efficient parasite transmitters (WHO, 2005).

3.3 Life Cycle of Malaria

The US Centre for Disease Control and Prevention (CDC, 2010) describes the life cycle of the malaria parasite and this is presented in Figure 3.1. The life cycle of malaria parasite consists of two host stages involving human and mosquitoes. In the initial stage, female mosquito (anopheles) injects and inoculates sporozoites into the human host during a blood meal. The sporozoites travel through the blood into the liver cells (hepatocytes) where they mature into schizonts which further ruptures into merozoites. In plasmodium vivax and ovale, the maturation into schizonts may not be achieved spontenously and can remain in the liver as dormant stage (hypnozoites) for a long while and may cause a relapse by re-infecting the blood. The schizoites containing mature merozoites in the liver cells undergo asexual multiplication in the red blood cells (erythrocytes). While in the erythrocytes, the merozoites grow into a ring-shaped form called trophozoite. Some merozoites then differentiate into male or female sexual forms called gametocytes (The only forms found in the blood). The gametocytes are then ingested by anopheles mosquito during blood meal where they fertilize each other, forming motile zygotes called ookinetes in the mosquitoe’s mid-gut. The ookinetes develop further into oocytes which mature and rapture into sporozoites. The sporozoites then migrate into mosquito’s salivary gland where they stay until they are inoculated into a human host for further development of the life cycle of the parasite (CDC, 2010; NIAID, 2010).

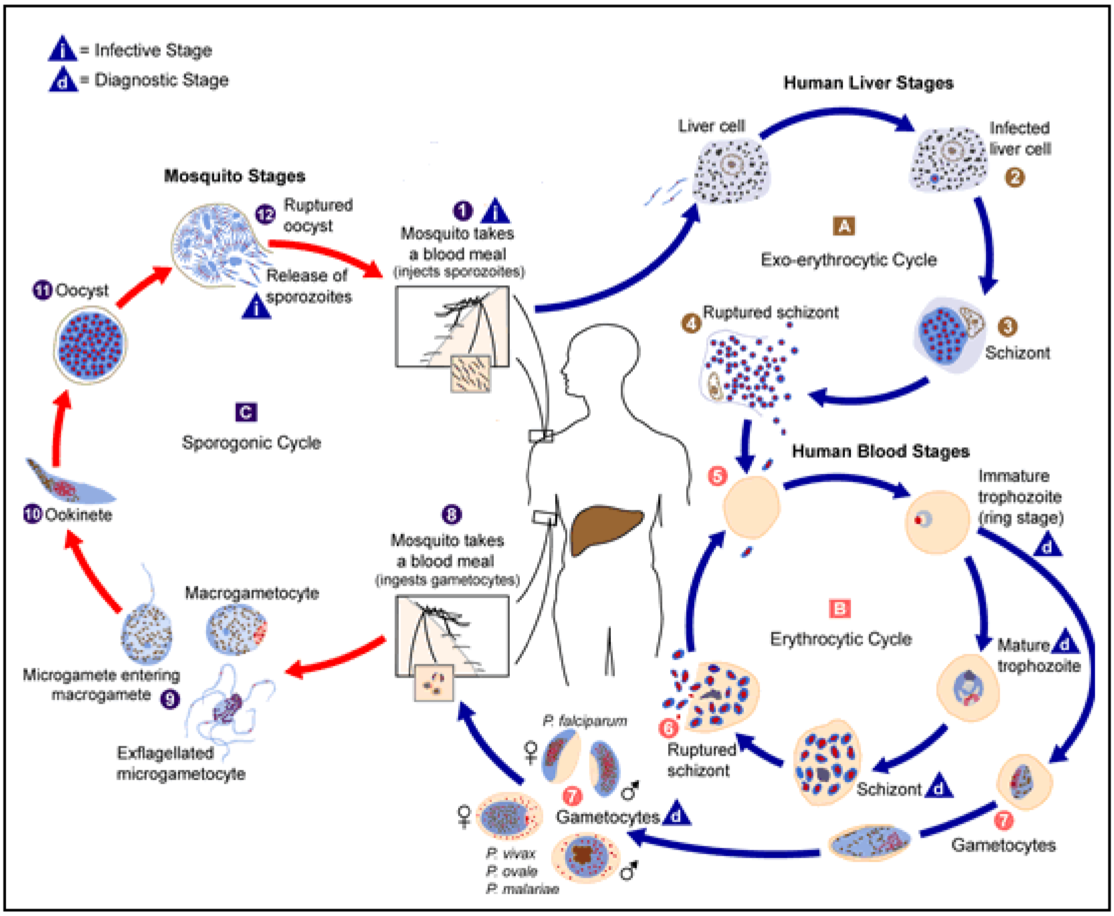


Figure: 3.1: *Schema of the life cycle of malaria (CDC, 2010)*

3.4 Symptoms of Malaria

The common first symptoms of malaria usually appear ten to fifteen days after the infection but this period can be longer due to the dormant stage which was discussed earlier. Severe malaria is almost exclusively caused by P. falciparum infection and usually arises 6-14 days after infection. It can cause severe often fatal malaria if not treated promptly with effective medicines (WHO, 2005). Malaria can have many symptoms (WHO/HTM/MAL, 2005; Hana et al., 2001) such as headache, nausea, vomiting, muscle pain and malaise, rigors consisting of severe shakes or muscle spasms and chills. The severity of the infection depends on which species of the malaria parasite is involved, and it can cause (WHO/HTM/MAL, 2005; Hana et al., 2001):

1. Enlargement of the spleen.
2. Liver tenderness.
3. Brain problems including seizures, and coma.
4. Problems of the immune system.
5. Affect on the structure of the blood corpuscles, anemia.

6. Kidney failure.
7. Respiratory failure.

Some groups of people have a higher risk of contracting malaria (WHO, 2010). These include young children, as they have not yet developed immunity and are therefore at risk of the severe forms of this illness. Also pregnant women who have no immunity to the disease, or are only semi-immune, are also at risk from an increased rate of miscarriage and maternal death, and their babies may have a low birth weight. In addition the risk of malaria for pregnant women infected with HIV is significantly increased, and they also risk passing the HIV infection to their babies. This heightened risk of malaria applies to all people infected with the HIV/AIDS virus. People who live in non endemic areas lack immunity to malaria and are therefore at a higher risk of contracting the disease when they travel to endemic areas.

3.5 Preventing and Treating Malaria

Malaria control is one of the main requisites in development of health care, and this disease requires early diagnosis and speedy treatment (Ridley, 2001). Once malaria is diagnosed there are currently a range of drugs available to treat malaria which can reduce the duration of the disease and prevent the majority of deaths (Ridley, 2001). In the future vaccines to prevent this disease hold out promise for future disease control (World Resources Institute (WRI) et al., 1998) but are not available at present.

The aim of malaria control is to reduce the numbers of parasite-infected mosquitoes and therefore hinder transmission of the vector of disease. Two main interventions are available for controlling the malaria vector; spraying insecticide indoors and use of insecticidal nets. All of that can be complemented with other locally-appropriate methods, such as larval control or environmental management (WHO, 2010). Some communities have controlled breeding of the vector by removing algae from breeding places, and use it as manure. Also coordinated efforts among multinational agencies, and private companies can help to reduce the disease incidence (WRI et al., 1998). Based on the insecticide regulation from the World Health Organization (WHO, 2010) there are only 12 types of these insecticides can be use for indoor residual spraying.

The most common drug treatments for malaria include; chloroquine, qualaquin hydroxychloroquine, mefloquine and a combination of atovaquone and proguanil (CDC, 2010). In some parts of the world there may be drug resistance for various reasons (WHO, 2010). For example, some patients do not complete their treatment and stop taking the malaria drugs in the early stages of recovery when the parasite is still in the blood. In these cases such as these the parasite will survive and be drug resistant if it is transmitted to another person. Drug resistance may develop and spread to a wider community, presenting a considerable public health problem due to lack of alternative treatments (WHO, 2010).

3.6 Relationship between Malaria and Climate

Data of atmospheric variables such as: temperature, rainfall, wind, relative humidity and cloudiness are described as climate variables (McMichael et al., 2003). Climate variability occurs on many time scales, however weather events usually occur on a daily time scale and these variables are associated with many health impacts. Climate variability at other scales also affects health (Harold et al., 2000).

The vector of malaria (Anopheline mosquito) and its parasite are sensitive to three main climate factors; temperature, rainfall and relative humidity (Hana et al., 2001). Climate predicts, to a large degree, the natural distribution of malaria (Bouma et al., 1996). Pampana, (1969) noted that the absolute temperature and its duration can affect the life cycle of malaria, but that this varies by parasite species. The development time of the Anopheline egg decreases as the temperature increases from 21°C to 27°C (Patz et al., 1998; Patz et al., 2000). Also McMichael et al., (1996) and Hana et al., (2001) indicate that 25 - 27°C is the optimum breeding temperature for both the mosquito and parasite, with 40°C being the maximum temperature. The life cycle of some malaria species below 20°C is limited, but colder than this the species can survive as the vector often lives in houses where the temperature is warmer. 8-10°C has been identified as the minimum temperature required for mosquito development whereas a minimum range between 14-19°C is suitable for parasite development (Hana et al., 2001) (Table 3.1).

Table 3.1: *Minimum, optimum and maximum temperature for anopheles mosquito (from Hana et al., 2001; McMichael et al., 1996)*

	Mosquito	Parasite
Minimum	8–10^{o}C	14–19^{o}C
Optimum	25–27^{o}C	25–27^{o}C
Maximum	40^{o}C	40^{o}C

Rainfall is another factor affecting survival of anopheline mosquitoes, by providing breeding sites, as this vector breeds in water habitats (Oaks et al., 1991). However, the amount of rainfall is important as breeding larvae can be flushed away by excessive rainfall or rainfall associated with stormy conditions (Pampana, 1969). Also time of year whether in the wet or dry season, and taking into account the amount and intensity of rainfall can have an impact upon malaria survival rates.

Rainfall also increases relative humidity and modifies temperature, thus it can affects malaria transmission through these mechanisms (Pampana, 1969). Although plasmodium parasites are unaffected by relative humidity, the activity and survival of anopheline mosquitoes can be limited when the average monthly relative humidity is below 60% (Pampana, 1969).

Regarding climate change, increase of temperature by time can increase the survival of mosquitoes, and this could be the reason that malaria can now survive at higher altitudes (Patz and Lindsay, 1999). Also it would be able to transmit some species of malaria that were not present in free malaria area depending on the change of the environmental conditions for the parasite or mosquito (Pampana, 1969).

3.7 Previous Studies into Malaria (Transmission, Vector and Incidents) and Climate Variables

This section on previous studies into malaria and weather will focus on semi arid areas across the world. One study which has looked at the relationship between malaria and environmental factors was undertaken in eastern Sudan (Hamad et al., 2002). It was carried out in two villages close to Gedaref city. Malaria case incidence was compared with the number of mosquitoes detected and with rainfall, relative humidity, maximum, minimum and mean temperatures, wind speed and direction. Climate data was also compared to data on the numbers of both adult anopheline mosquitoes and their immature stages. These were sampled bi-monthly in each village for two dry seasons and two transmission seasons from April 1994 to October 1995. The study showed that the abundance of mosquitoes was positively related to monthly rainfall, maximum temperature and relative humidity. From the end of the short rainy season in October until February there was a gradual drop in the number of mosquitoes. Vectors re-appeared in June as the humidity rose with the onset of rain. Despite the hot dry season between February and May, sporadic asymptomatic malaria infections were detected in the two villages.

In SW Uganda (Kabarole District), researchers analyzed the incidence of reported clinical malaria cases and its correlation with rainfall between 1995 and 1998. The data showed a positive relationship exists between rainfall and malaria incidence. In October - December 1997 rainfall was above the upper 95% confidence limit of previous years, and this was associated with a big increase in plasmodium falciparum infection (Kilian et al., 1999).

Malaria rates in Zimbabwe during 1913 – 1993 (Freeman et al., 1996) were compared to weather data and the results showed that, rainfall has little effect on the number of malaria cases. However, temperature appears to have an impact on malaria. Greater than average mean temperatures in September were correlated with an increase in the severity of malaria in the following year.

In Pakistan, malaria transmission was associated with the seasonality of rainfall over September and October. A relationship was also observed with temperature during November and December, and with humidity in December (Bouma et al., 1996).

Another study in Sri Lanka (Briet et al., 2008) (a) found that the relationship between rainfall and malaria cases in most districts varied during study period (1972 – 2005). Four analytical methods were explored: (I) Cross-correlation (monthly malaria cases and monthly total rainfall). (II) Cross-correlation with pre-whitening: (Cross-correlation with the seasonality and autocorrelation removed by simple pre-whitening allows for detection of the time lags of rainfall preceding malaria). (III) Inter-annual, and seasonal inter-annual regression (the series of differenced transformed annual malaria cases was studied to determine the correlation to total annual rainfall). The cross-correlation results showed that malaria cases in most districts were positively associated with rainfall with a 0-4 month lag. However, they were also negatively associated with rainfall with a 4-9 month lag. Also low seasonal rainfall was associated with low seasonal malaria, and high seasonal rainfall was associated with high seasonal malaria. Using the cross-correlation with pre-whitening method (including an autocorrelation term to control for the previous months malaria) malaria was only significantly associated with rainfall in five out of 25 districts at a lag of 0-1 month. Only 6 from the 25 districts showed a negative relationship with rainfall at a 2-5 month lag. Although malaria decreases with annual rainfall by inter-annual analysis method for eight districts in the centre-west of the country, the seasonal this method showed that the effect of rainfall on malaria varied according to the season and geography. Districts in the east showed positive correlations with rainfall, however the relationship in the centre-west and in the north shows significant negative correlations for rainfall during February to June. A spatial malaria study was undertaken using the same data as the previous paper (Briet et al., 2008) (b). This confirmed that after controlling for spatial autocorrelation season and rainfall were positively associated with malaria.

One study in the highlands of Kenya showed that climate did not play an important role in malaria transmission because average temperature and rainfall did not change during the time that malaria rates changed (Malakooti et al., 1998). Another study in the highland Tea Estates of Kericho, Western Kenya (Dennis et al., 2002) confirmed that while the total hospital admissions of malaria over 30 years (1966–1995) increased significantly, all meteorological variables showed no significant relationships with disease. This was observed when these variables were combined into a monthly suitability index for malaria transmission. Therefore the researchers concluded that recent climate changes have not caused the highland malaria resurgence in this area. However, epidemics of malaria in different areas of the highlands of Kenya in third study found that increased rainfall was related to the epidemic (Kigotho, 1997).

A study in Central India investigated whether climate and malaria were related in a highly malarious village during the periods 1967-2000. The result showed no relationship between rainfall and malaria incidence (Singh et al., 2002). Another study examined the relationship between climate change and malaria in India (Bhattacharya et al., 2006). It noted a positive correlation between malaria transmission and relative humidity when the range 55 to 80 %. It also found that maximum number of reported cases of malarial occurred when the average temperature between 15 to 30°C.

In the Ethiopian highlands (Debre), there was a positive correlation between malaria incidence and with increasing of temperature from 1968 to 1993 (Tulu, 1996). Another study in Ethiopia (Woube, 1997) found mixed associations between malaria and rainfall. In 1993 there was high rainfall and no malaria incidence, but in 1984 -85 there was very little rainfall but a high malaria incidence. The study noted that epidemics were usually attributed to higher temperatures, rainfall and relative humidity. However, another Ethiopian study (Teklehaimanot et al., 2004) compared malaria incidence between two areas depending on the temperature. In the hot area rainfall was followed quickly by an increase in malaria cases. Minimum temperature was non-significant. In the cold area rainfall was also correlated with increasing malaria but after a longer delay. The same delay was associated with minimum temperature.

A study in Nouna and the villages of Cisse and Goni in Burkina Faso (Ye et al., 2007) studied the effect of meteorological conditions upon clinical malaria risk among children. It confirmed that weather has a positive significant influence on malaria rates among children under five years old. Mean temperature was the best predictor of clinical malaria incidence, and the risk of clinical malaria increased with mean temperature up to 27 °C. For rainfall only the effect was observed when it was over 100mm. In highland regions the limiting factor for malaria appeared to be the low temperature because of the high altitude.

In Like Bufundi, Kilibwoni, East Africa, located at an altitude above 2000m, the associations between climate and malaria morbidity were studied (Kristan et al., 2008). A peak in rainfall during April-May was followed by a peak in malaria occurrence in June. The second peak of rainfall in August was preceded by a low temperature in July. This was followed by a peak in malaria incidence in October.

Alam et al., (2008) studied the relationship between weather and the incidence of malaria in the Chittagong Hill Tracts in Bangladesh (1997 – 2005). The analysis was conducted by dividing the seasons into two. The first season from April to October is warm and wet and the other November to March is cool and dry. They noted that during first season there is a considerable increase in malaria cases. In the second, mosquitoes are less active with a decline in cases of malaria. They mentioned that optimal relative humidity for mosquito survival is 60 %, and a high relative humidity lengthens the life of the mosquito.

Another study investigated the impact of temperature and rainfall upon malaria in Lagos Nigeria between 1990 and 2003 (Oluleye and Akinbobola, 2010). Temperature and malaria were highly positively correlated between February and December but negative associations occurred in November. Rainfall and malaria were highly positively correlated during January, September, November, and December. Negative associations were observed in the months of April, June and October.

Another study examined the correlation between monthly climatic variables and malaria in Shuchen County, China (Bi P et al., 2003). The climatic variables were maximum, mean and minimum temperature, relative humidity and rainfall. The dependant variable was the malaria incidence. The study examined the correlation between malaria incidence and each climatic variable while controlling for auto-correlation in the data. There were highly positive correlations ($P<0.0001$) with each climate variable lagged at one month. The study noted that minimum temperature seemed to play a more important role than maximum temperature in affecting malaria incidence. The study notes that other factors can play role in the transmission of malaria such as ecological and environmental issues, also social and economic determinants. However, for forecasting malaria climatic variables are best suited.

The previous studies have all examined the Influence of climate variables upon malaria cases. The review will now focus upon studies which have examined the influence of climate variables upon vector abundance. An entomological study was conducted into the spatial and temporal variations in malaria transmission in a low endemicity area in Tanzania (Oesterholt et al., 2006). Part of this study investigated the relationship between vector abundance (Anopheles arabiensis) and precipitation. The study noted that the peak mosquito numbers followed the peak of rainfall.

Amerasinghe et al., (1999) studied malaria vectors (Anopheline mosquitoes) in a traditional dry zone village in Sri Lanka. Monthly malaria incidence, during the study period, was not significantly correlated with monthly rainfall. However, it was correlated indirectly with rainfall. Abundance of some species of Anopheline mosquito were correlated with the previous months rainfall. Positive significant correlations were found for *An. annularis, An. subpictus, An. Vagus* and *An. varuna*. Malaria incidence in the study was also correlated with the abundance of Anopheline species. A positive significant correlation was seen between an outbreak of malaria and the numbers of some species Anopheline one month earlier.

The focus of this thesis is Saudi Arabia and in this country there are several studies related to malaria and weather. In Gellwa, Al-Baha Region, located in SW Saudi Arabia a malaria outbreak occurred (A1-Abdullatif et al., 1996). Between January 1 to March 31, 1996, 476 confirmed malaria cases were reported from in and around the Eliab Valley. This was an increase from the usual numbers of cases reported each year from 1990 to 1995 (between 32 and 176). In 1996, following heavy rainfall in Tehama, many valleys were flooded and the malaria increase was attributed to this. The study also reports that seasonal peak in malaria incidence in Saudi Arabia occurs between January and March.

Another study Gaafar et al., (1998) examined the clinical aspects of malaria in the Asir Region, Saudi Arabia. The researchers reported 334 confirmed malaria cases in Asir Central Hospital, Abha, during the period 1991-1995. This study has emphasized that malaria is still a health problem in the Asir region. Cases were seen throughout the year, with two peaks, in February and June. These peaks are most likely to be related to the rainy and hot seasons, respectively. In Riyadh Alkhalife, (2003) studied malaria infections between 1996 and 2001, and found that an annual peak of malaria incidence occurred between February and April.

Another important study was conducted in Jazan SW Saudi (Al-Jaser, 2006). They tried to determine the yearly correlation between weather data and malaria between 1997 and 2002. The data showed a significant positive correlation between relative humidity and malaria cases, but a significant negative correlation between temperature and malaria. The researcher noted that the number of malaria cases has declined significantly after the year 2000, when an outbreak of the Rift Valley fever happened in Jazan and Asir.

Table 3.2 summarises the main studies (statistically) of the correlation between malaria or its vector and climate variables.

***Table 3.2**: Summary of the main studies relating to malaria*

No	The author	Place	Dependent Variable	Independent Variable	The relationship & Lag time (month)
1	Hamad et al., 2002	Easter Sudan	Abundance of mosquitoes	Rainfall Max Temperature Humidity	Positive 1-3
2	Kilian, et al., 1999	SW Uganda	No. of malaria cases	Rainfall	Positive
3	Freeman et al., 1996	Zimbabwe	No. of malaria cases	Temperature	Positive
4	Bouma et al., 1996	Pakistan	malaria incidence	Rainfall Temperature humidity	Positive 0-1 Positive 1-2 Positive 2
5	Briet (a) et al., 2008	Sri Lanka	No. of malaria cases	Rainfall	Positive 0-4 Negative 4-9
6	Malakooti et al., 1998	highlands of Kenya	Malaria transmission	Different Climate variables	No relationship
7	Kigotho, 1997	Different highlands of Kenya	No. of malaria cases	Rainfall	positive
8	Bhattacharya et al., 2006	India	malaria incidence	Temperature humidity	positive
9	Tulu, 1996	Ethiopian highlands	No. of malaria cases	Rainfall Temperature humidity	positive
10	Ye et al., 2007	Burkina Faso	No. of malaria cases for the children	Mean temperature Rainfall	Positive
11	Kristan et al., 2008	Kilibwoni, East Africa	malaria incidence	Rainfall	Positive 1-2
12	Oluleye and Akinbobola, 2010	Lagos Nigeria	malaria incidence	Temperature Rainfall	Mixed relationship depending upon the time of year
13	Bi P et al., 2003	Shuchen County, China	malaria incidence	max, mean and min temperature Humidity Rainfall	Positive 1
14	Amerasinghe et al., 1999	dry zone in Sri Lanka	Abundance of mosquitoes	Rainfall	Positive 1
15	A1-Abdullatif et al., 1996	SW Saudi Arabia	No. of malaria cases	Rainfall	Positive 1-3
16	Gaafar et al., 1998	Asir Region, Saudi Arabia	No. of malaria cases	Temperature Rainfall	Positive
17	Al-Jaser, 2006	Jazan Saudi	No. of malaria cases	Temperature Humidity	Negative Positive

The literature review highlights a number of important points:

1- A wide range of study designs have been used ranging from purely observational to those conducting statistical analyses. The complexity of statistical analyses varies as well.
2- Numerous different climate variables have been used including temperature, rainfall and humidity
3- Most but not all studies showed that climate variables have an impact upon malaria incidence. However, the impact of specific weather variables can be either positive or negative depending upon the setting and also the season. Lagging the climate variables is an important feature of some studies.
4- Other studies support these findings by showing that weather influences the abundance of the malaria vector (anopheles mosquito), and others found that the vector abundance has an effect upon the incidence of malaria.
5- Weather conditions are not the only factor which can affect malaria, and that there are many other factors such as ecological and environmental conditions, social and economical determinants. Some studies noted that climatic variables are best suited to predict future trends (Bi P et al., 2003).
6- There have been few studies in Saudi Arabia focusing upon the influence of climate variables upon the disease.

Based on the previous studies, it is clear that there is an urgent need to study and research the influence of climate variables upon the presence of malaria in Saudi Arabia, and in endemic areas such as Asir Region specifically. Building upon the literature review such, a study should examine a wide range of weather variables and also consider that any relationships with weather may vary seasonally. A statistical analysis seems the most appropriate study design and this may need to consider factors such as autocorrelation in these data as some previous studies have done.

3.8 Malaria in Saudi Arabia

Malaria is endemic in parts of the country with high rainfall. Transmission is confined to the SW (Jazan, Asir and A1-Baha Regions) but also occurs in some isolated rural areas in Makah and Madinah Regions. Figure 2.1 (Chapter 2) shows the distribution of malaria in across of Saudi Arabia and some species of pathogenic mosquitoes in each endemic or low endemic area (MOH, 2006; Al-Saghayer and Alattas, 2006).

Figure 3.2 shows the number of malaria cases in Saudi Arabia between 1980 and 2009. These data show a sharp decrease in malaria cases in the last ten years except an outbreak which happened at the end of 1997 and into 1998. The transmission of malaria is seasonal with peak incidence from October to April (Al-Saghayer et al., 1996). More than 50% of the total cases per year occur in Jazan, Asir, and Makah Regions (MOH, 2006). The population living in the most endemic areas is 1.7 million (~5% of the country's population) (Al-Harthy and Jamjoom, M, 2007). Many of the current cases of malaria reported in Saudi Arabia are imported from other regions or from overseas. Some cases are imported by pilgrims during Hajj to the Holy Cities (Makkah & Madinah). As an example, in 2008 the Ministry of Health in Saudi Arabia reported 2864 positive cases of malaria. From this 249 (8.7%) were indigenous cases (MOH Statistical Books, 2009). Of these cases 109 cases (43.8%) were from the Asir Region, 35.7% from Jazan and 12.9% from Qunfedah Aria. There were no indigenous cases in Riyadh and Al-Ahsa, Eastern Region, Taife, Qassim, Tabuk, Hail, the northern border, Najran, Al Baha and Qurayat. A malaria expert working in the Ministry of Health in Saudi Arabia (Dr S. Algaryah 2009 pers. Comm.; Al-Saghayer, and Alattas, 2006) noted that weather variables especially rainfall, play an important role in the incidence of indigenise malaria in the country. He gave the example of an outbreak of malaria cases during 1998 after a large amount of rainfall in some parts of Saudi Arabia during the end of 1997 and beginning of 1998 (see Figure 3.2).

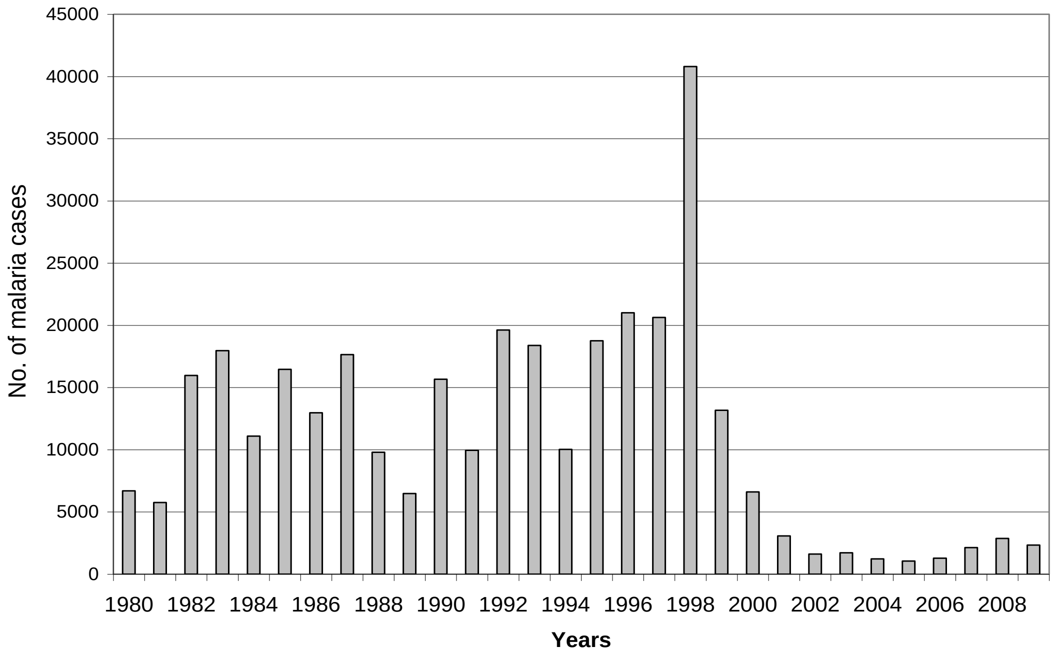


Figure 3.2: *Number of malaria cases in Saudi Arabia (1980-2009) (MOH, the Statistical Books 2000-2009; Al-Saghayer S, and Alattas M, 2006)*

- Topographical Classification of Asir Region and Endemic Areas:

Asir Region is located in the SW Saudi Arabia and is divided into the emirate quarter and eleven governorates (CDSI, 2005) as illustrated in Figure2.9. This region is in the tropical zone as are some countries in the east of Africa (Abdoon and Alshahrani, 2003). It has a varied terrain ranging from highlands, high mountains (2000 to ~3000m above sea level) and the lowlands (Tehama) parallel to the Red Sea (Gaafar et al., 1998). It also includes a large area of the desert and hills to the north and east as far as Bishah and Tathlith. The mountain range has the highest rainfall in Saudi Arabia (MEPS, 2007).

Malaria is endemic in the lowlands (Tehama) in Asir Region (Figure 3.3) (Haddad, 1990). In the last few years the number of malaria cases has spread to adjoining areas of higher elevation, such as Abha and Khamise city (MOH, 2006).

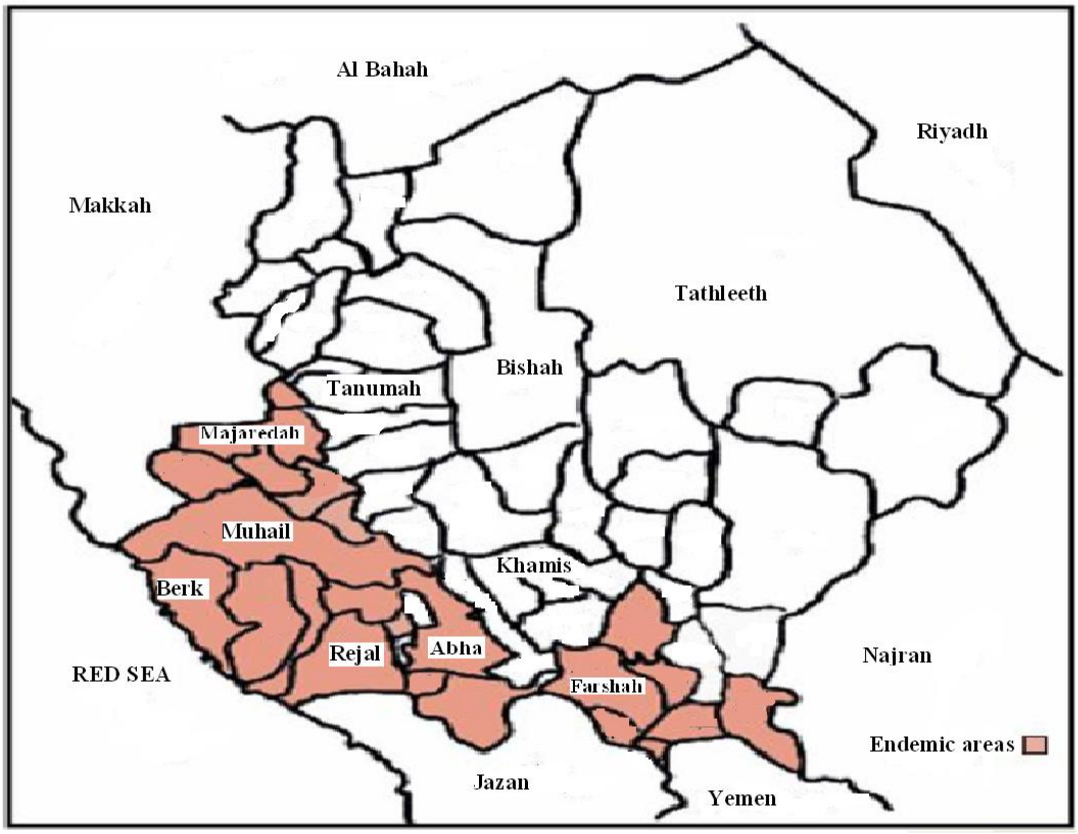


Figure 3.3: *Endemic sectors in Asir Region. Adapted from (The Vector Control Administration in Asir Region, 2007)*

Depending on the endemic areas of malaria and topography, this region can divide into four main malarial sectors (Dr A. Abdoon 2007 pers. Comm.; MEPS, 2007) (Figure 3.4):

1. Tehama of Qahtan (TQ) is located among high mountains such as Farshah Al-Jauah, Al-Ergain and Wadi-Alhaiah. This sector is in the lowlands with an altitude between 800 and 1300m, and most of its areas called the foothills. Farshah Area has the main health center in TQ, and high malaria incidence. More than 90% of the pathogenic mosquitoes in these areas are Arabians.
2. Tehama of Asir (TA), area can divide into two sections:
    a) Foothills such as Al-Majaredah, Muhail and Rejal-Alma, which have the highest malaria incidence in Asir. It is among the mountains and the valleys with many appropriate places for the vector (mosquito). The altitude varies between 300 and 900m. The main vector in this area is Arabians.
    b) Red Sea Costal Plain (RSCP) such as Al-Gahma, Al-Berk, Al-Huraidah. These areas have low malaria incidence and the main vector is Sergenti. All

of the vectors in this area dependent on open water tanks and swampland. The altitude in this area is between 0 and 200m.

3. North-East of Asir such as Bishah, Tathlith. The altitude for this sector is 1000 – 2000m. This sector has had no local transmission of malaria for over ten years. It had a few local cases before 1995, but all were imported from endemic areas.
4. Highlands (The Sarawat Mountains) which have altitudes 2000 – ~3000m such as Abha, Khamise, Al-Numas. These areas have the highest rainfall in Saudi Arabia (542mm) (MEPS, 2007) but no local transmission of malaria. However, there are many reported cases in some health centers and the main region laboratory in this sector. These cases are likely to have come from endemic areas in the lowlands.

The endemic areas in Asir (TA and TQ) are drained by valleys, which are usually wet except in some dry seasons, and so provide suitable habitats for mosquito breeding (Alzahrani, 2007). These valleys maintain a continuous steady flow of water into the foothills area especially in TQ and some parts of TA.

Omar et al., (1999) described that in the malaria endemic areas of Asir there are two categories of the population at risk. The first are permanent residents living in the foothills (Tehama) or in the coastal plain. The second group is residents from the non-malaria's areas in the highlands, who travel for recreational activities to the endemic lowland areas during the transmission season.

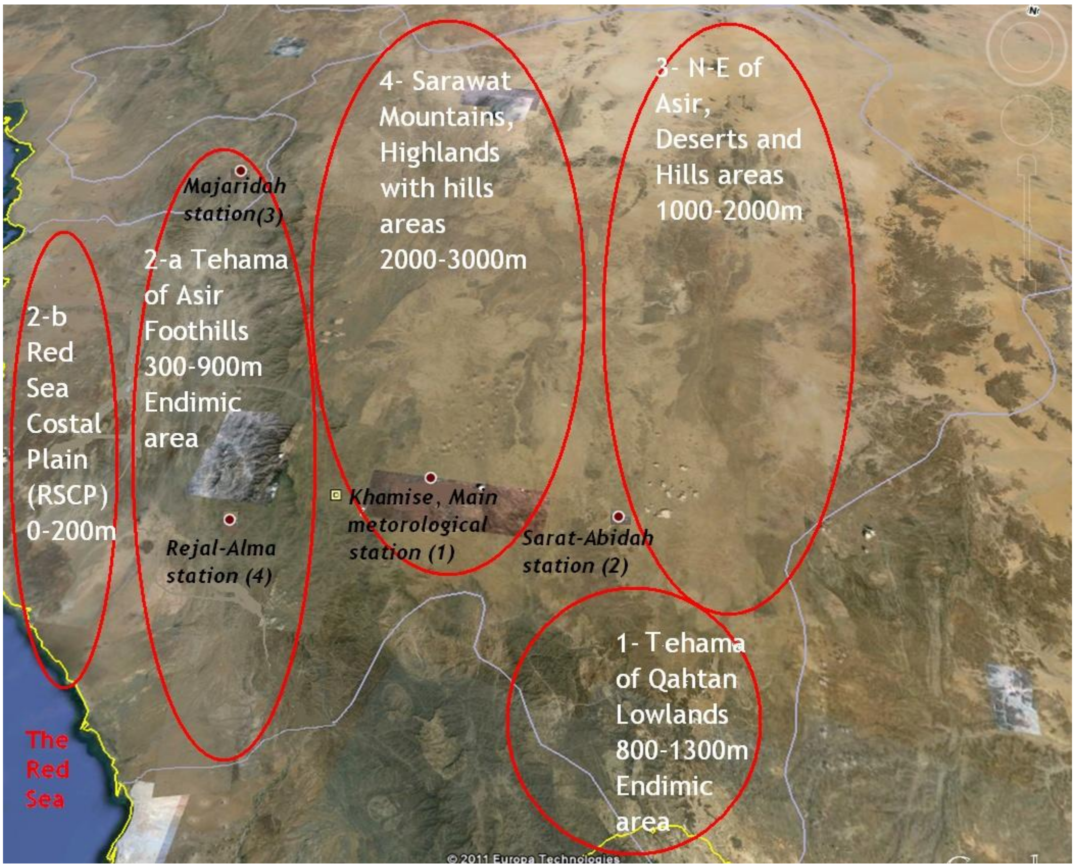


Figure 3.4: *Topographic map for Asir Region including the weather stations*

3.9 Controlling of Malaria Transmission in Asir Region

There is a strategy for anti-malaria control measures in each endemic area of Saudi Arabia and this strategy depends upon the following guidelines (MOH, The Statistical Book, 2006; Dr A. Abdoon 2007 pers. Comm.)

a. Spraying of the breeding foci of mosquito to control the larva. This method is wide spread all over the Saudi Arabia except the mosquito free areas.
b. Spraying the houses (indoor) with insecticides that have residual effect. It is used in the areas of high density of malaria (Figure 3.5)
c. Spraying the narrow spaces with a spray of minute particulates to reach to deep spaces. This method is used in areas with high cases of malaria.
d. Mechanical control method.
e. Wide spread of nets impregnated with insecticides.
f. Removal of breeding habitats and water body unnecessary beside the valleys (Figure 3.6).
g. Health education program.
h. Collaboration with the governmental and private sector in control measures.

Figure 3.5: *Spraying the houses (Indoor) with insecticides that have residual effect in endemic areas of Asir Region.*
(The Vector Control Administration in Asir Region, 2007)

Figure 3.6*: Removal of breeding habitats and unnecessary water body beside the valleys (The Vector Control Administration in Asir Region, 2007)*

The Vector Control Administration in Asir Region has made important progress regarding the control of malaria. In addition to the general strategy of ministry, their improved plan for Asir depends on four main issues (Dr A. Abdoon 2007 pers. Comm.):

1. Control of places which have water born malaria parasite or transmission occurrences by spraying particular types of pesticides depending on the vector type. This usually happens in open water areas such as valleys, water tanks and dams. This type of spraying occurs all year round by a huge number of technical workers and a massive amount of equipment, cars, tents and sprays etc.

2. Seasonal spraying of houses, using pesticide which has a residual effect up to three months. This step happens in three stages (Table 3.3) (Figure 3.5):
   A. First stage in TQ between August and October.
   B. Second stage in TQ and TA between November and January.
   C. Third stage in TQ and TA between February and April.
3. Space Spraying (Fogging), vehicle-mounted machines and hand-held sprayers used for outdoor (ULV and fogging) and indoor (ULV) coverage to control any unusual increase in cases or vectors. These occur in the affected and nearby areas.
4. Intersectoral Collaboration, A joint committee meetings with related department in the region (e.g. Water & Electricity Department, Agriculture, Education, and Municipality addition to the Ministry of Culture and Information).

Table 3.3: *Seasonal spray of houses in Asir Region*

No.	Areas	Time	First stage Aug - Oct	Second stage Nov – Jan	Third stage Feb - Apr
1	TQ	9 months	Yes	Yes	Yes
2	TA	6 months	No	Yes	Yes

TQ: Tehama of Qahtan TA: Tehama of Asir

Malaria cases in Asir have decreased sharply over the last 15 years. The Vector Control Administration in Asir gave five main reasons for this decrease (Dr A. Abdoon 2007 pers. Comm.):

1. Climate change, as after 1998 rainfall has declined during these years, therefore the cases decreased.
2. Improved facilities and an increased number of professionals, technicians and workers.
3. Good immigration control to free this region from illegal refugees who are coming from endemic areas carrying this illness.
4. Cooperation with The Vector Control Administration in the neighbouring Jazan Region in the border areas.
5. A massive spray against rift valley fever for more than six months which started in Asir and Jazan 2000. This was carried out by many related governmental agencies using airplanes, cars and manpower.

3.10 Chapter Rationale and Hypotheses

The influence of climate variables upon malaria is important to understand for a number of reasons:

1. Based on the findings and understanding of how malaria is affected by weather it should be possible to design an early warning system from the weather patterns to predict incidence (Bouma & Van Derkaay, 1996). This would be useful for current health service planning, for example identifying periods when enhanced insecticide spraying is required.
2. If weather changes as a result of climate change then this data could help predict the impact of this change on malaria in Asir Region.
3. It can help clarify the important modes of transmission in the region.

This study tests the hypotheses that there are relationships between weather (maximum, mean and minimum temperature, rainfall and relative humidity) and malaria cases in Asir Region.

3.11 Data and Method

3.11.1 Sources of Data

Official letters were issued, instructing authorized personnel to collect health and weather data. A standard form was provided to the personnel, so that the data could be received in a standard format. The total number of malaria cases in the whole of Asir Region each month from the first of Jan 1995 to the end of Dec 2006 was reported. In addition, the total number of cases in each epidemic sector in Asir for the same period was reported separately. All the malaria data were obtained from the Vector Control Administration, Health Affairs Directorate in Asir. This department represents The Ministry of Health in this region. The data has been collected from all hospitals and primary health care centers (public or private) and also the Main Parasitology Laboratory in Abha (The Vector Control Administration 1995 -2006). All the reported malaria cases were confirmed by a positive blood film (mainly asexual forms). Dr A. Abdoon 2007 pers. Comm. states that more than 90% of reported cases are indigenous cases, however, there are some other indigenous cases from Asir were reported in other regions of Saudi Arabia or abroad.

These malaria data needed to be associated with weather data for this region. Unfortunately it was only possible to obtain weather data for a few locations and this had a large influence on the design of the analysis. Three models were constructed. The first was an analysis of malaria in the whole of Asir, and the next two focused upon malaria in the two endemic sectors TA and TQ. Further details are provided below:

1. Malaria cases in overall Asir Region against Khamise weather data (Maximum, mean and minimum temperature, rainfall and relative humidity, Station 1 Figure 3.4). Khamise is the second main city in the region, and covers the largest occupied sector in the middle of this region (MOH, 2006). Weather data were available for all months.
2. Malaria cases in TA (Muhail, Rejal-Alma, Marabah, and Majaredah). These sectors were grouped as they all had similar malaria seasonality. They were related to the maximum and minimum temperature of Majaredah (See station 3 Figure 3.4, data available for 132 out of 144 months) and rainfall of Rejal-Alma (See station 4 Figure 3.4), data available for 132 out of 144 months). No humidity data was available for this area
3. Malaria cases in TQ against maximum, mean and minimum temperature, relative humidity of Khamise (Station 1 Figure 3.4) and rainfall of Sarat-Abeda (Station 2 Figure 3.4, data available for 132 out of 144 months). These stations are outside the sector but were used because there were no weather stations within, so there was no alternative but to use nearby stations.

Weather data for Khamise were obtained from The Center of Information and Documentation in the Meteorological and Environmental Protection Section (MEPS) of the Ministry of Defence and Aviation in Saudi Arabia. Weather data for Sarat-Abeda, Rejal-Alma and Majaredah were obtained from the Ministry of Water and Electricity. Monthly averages were obtained by dividing the monthly totals by the number of days in each month.

3.11.2 Malaria Data Description

Monthly averages of malaria cases in the Asir Region between 1995 and 2006 (Figure 3.7) show transmission of the parasite throughout the year. However, there is a clear seasonality with peak incidence between December and April, with the highest average cases in March (298.5) followed by February (276.3 cases). The averages of cases during the summer are lower, with the lowest number of cases in July (37 cases) and there is a slight peak in September. The standard deviation bars on the graph indicate that there is a large variability from year to year in monthly cases of malaria.

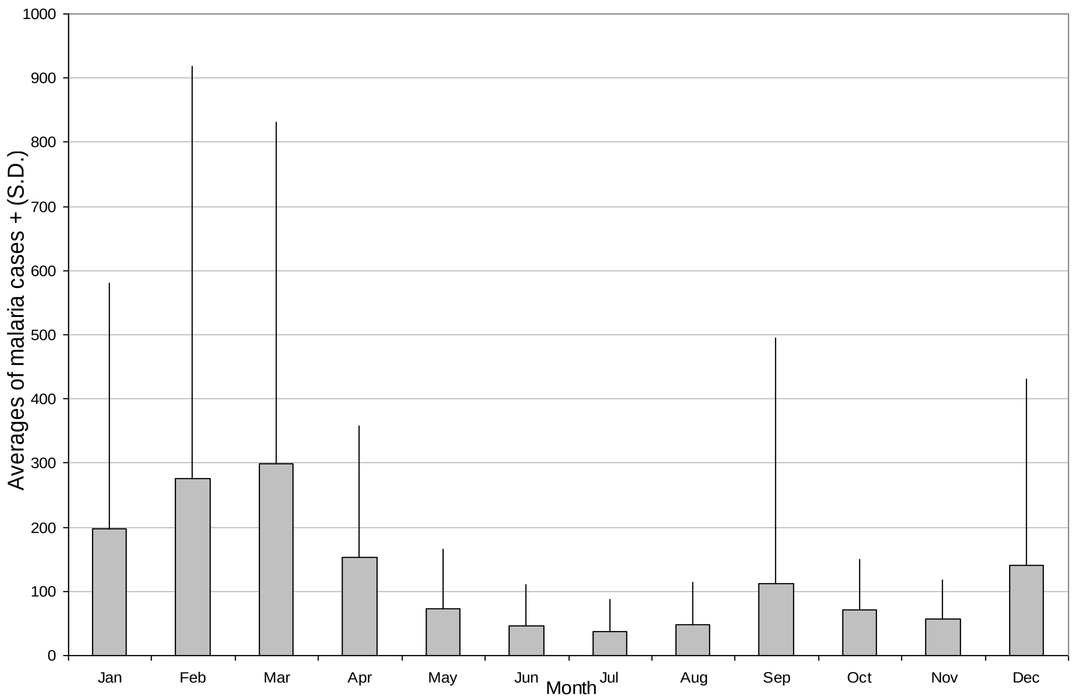


Figure 3.7: *Monthly averages of malaria cases in Asir Region (1995 - 2006)*

Figure 3.8 shows the data for the two main endemic sectors in Asir (TA and TQ). There is a clear seasonality for these sectors at different time of the year. In TA there is a peak of incidence between December and April, with the highest average cases in March (262.1 cases) followed by February (226.6 cases). The average number of cases during the summer is lower, with the lowest number in August (9.9 cases). There is some seasonality in TQ with a slight peak in incidence between August and October. The highest average number of cases was in September (93.6 case) followed by October (44 cases). The average number of cases during the rest of the year is lower, with the lowest number in February (7.9 cases). The standard deviation bars on the graph again indicate much variability from year to year in monthly malaria cases for both sectors.

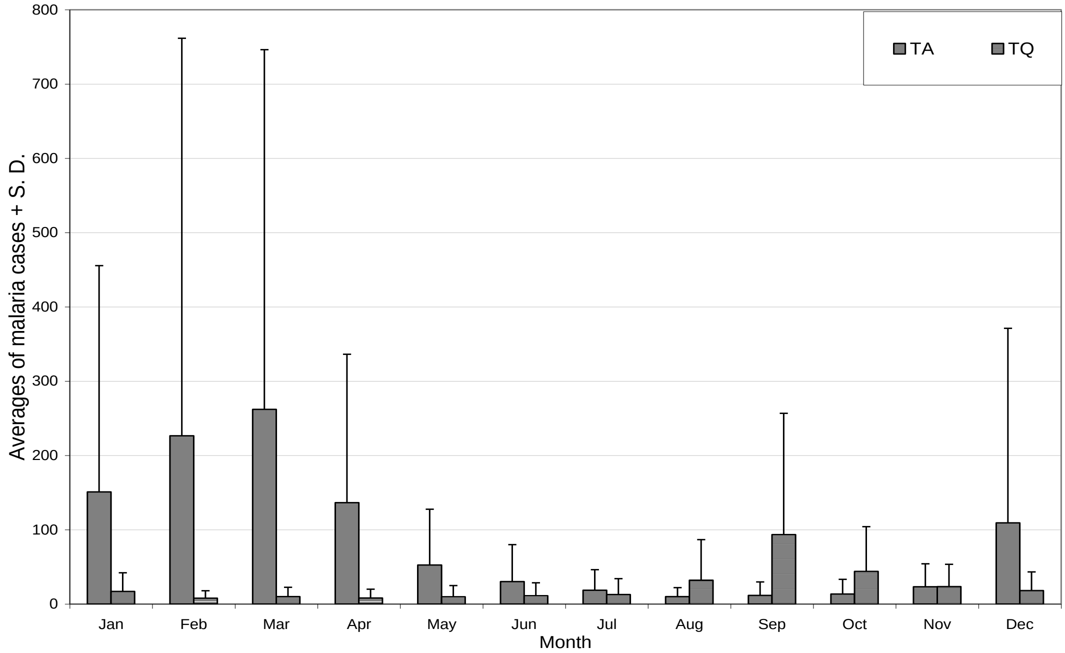


Figure 3.8: *Monthly averages of malaria cases in TA and TQ (1995 - 2006)*

3.11.3 Temperature Data Description

The average maximum, mean and minimum temperature in Khamise city is shown in Figure 3.9. The highest average maximum and mean temperatures occur in June (32.3, 24.6^{0}C respectively).The highest average minimum temperature occurs during July (18.1^{0}C). The lowest average temperature occurs in January for maximum, mean and minimum temperature (21.7, 14.6 and 8.5^{0}C respectively).

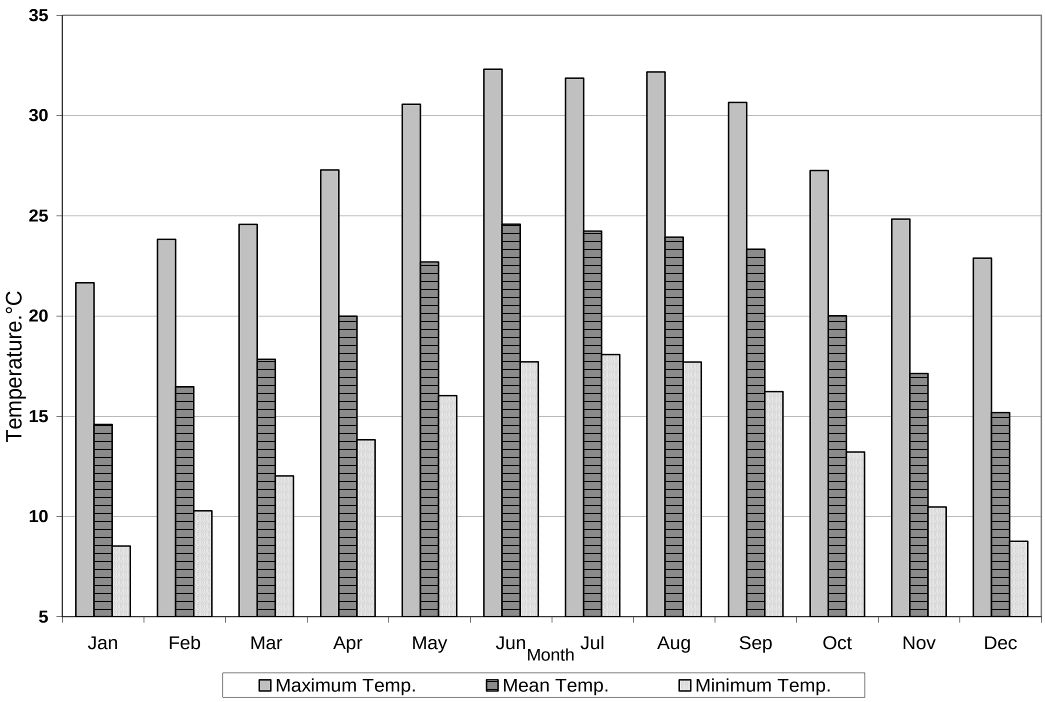


Figure 3.9: *Maximum, mean and minimum averages temperature in Khamise 1995 -2006*

The averages maximum and minimum temperature for Marjaredah is shown in Figure 3.10. The highest averages maximum temperature occur in June (41.98^{0}C) and the highest minimum in July (29.55^{0}C). The lowest averages maximum and minimum temperature occur in January (31.85 and 20.34^{0}C respectively).

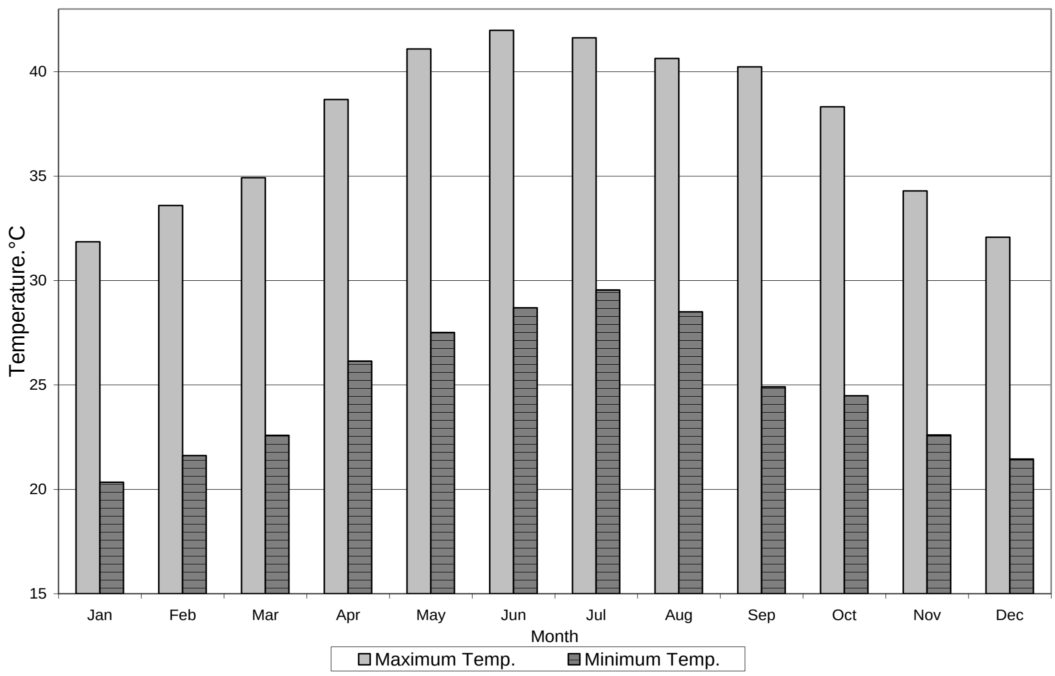


Figure 3.10: *Maximum and minimum averages temperature in Majaredah 1995 -2006*

3.11.4 Rainfall Data Description

The monthly average rainfall in Khamise City (Figure 3.11) shows peak rainfall between March and August with the highest occurring in April (40.5mm) followed by August (30.9mm). During the rest of the year rainfall is low with a minimum occurring in February (1.6mm). The standard deviation bars on the graph indicates extreme variability from year to year.

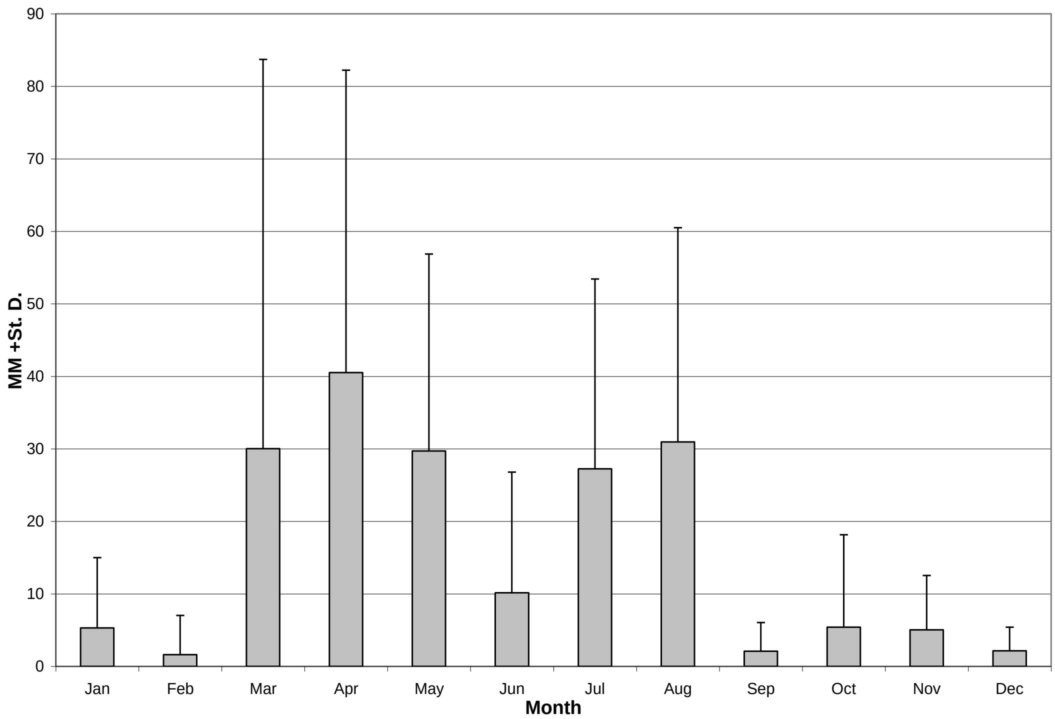


***Figure 3.11**: Monthly averages rainfall in Khamise City (1995 -2006)*

The monthly average of rainfall in Rejal-Alma (Figure 3.12) shows seasonality with peak rainfall between December and April. The highest averages were in March (80.1mm) followed by April (64.4mm). The average rainfall during the summer and autumn are lower with the lowest averages occurring in October (13.5mm). A small peak occurs in August. The monthly averages rainfall in Sarat-abeda (Figure 3.12) shows seasonality with two peaks occurring during spring and autumn. The highest average rainfall was in August (34.4mm) followed by October (30.0mm). The averages during the summer and winter are lower with the lowest rainfall occurring in June (3.2mm). The standard deviation bars on the graph indicate that there is a large variability from year to year in monthly rainfall for both sectors.

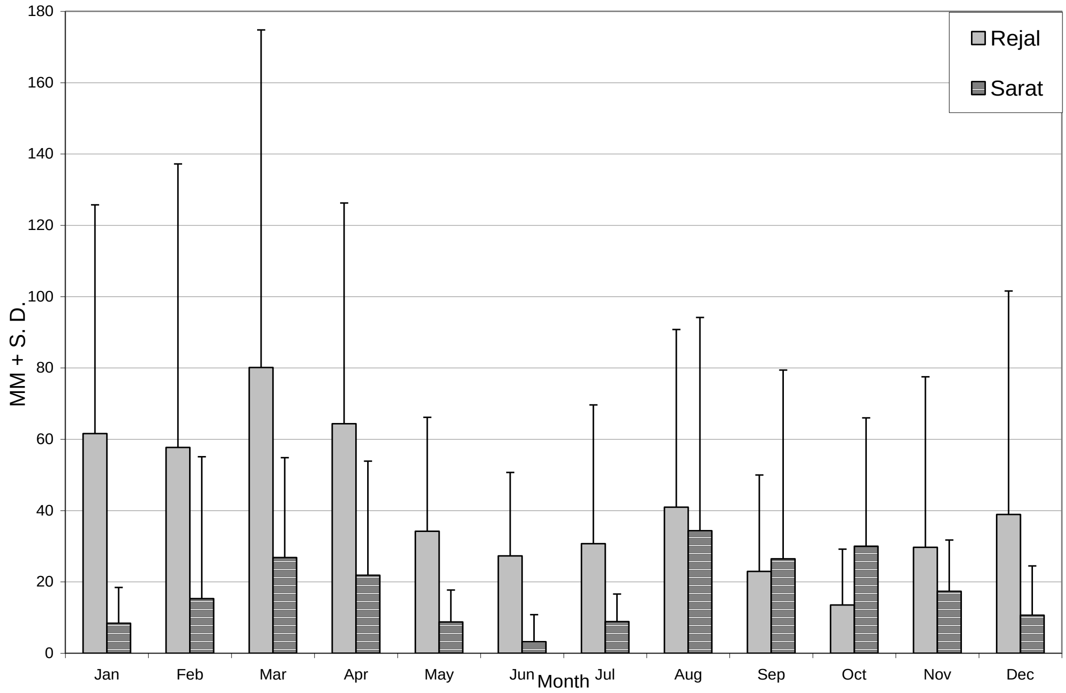


Figure 3.12: *Monthly averages rainfall in Rejal-Alma and Sarat-Abida 1995 -2006*

3.11.5 Relative Humidity Data Description

The monthly average relative humidity in Khamise City (Figure 3.13) shows a peak during the months of November to March with the highest percentage occurring in Jan (66.26%). The lowest percentage of humidity was in September (37.13%).

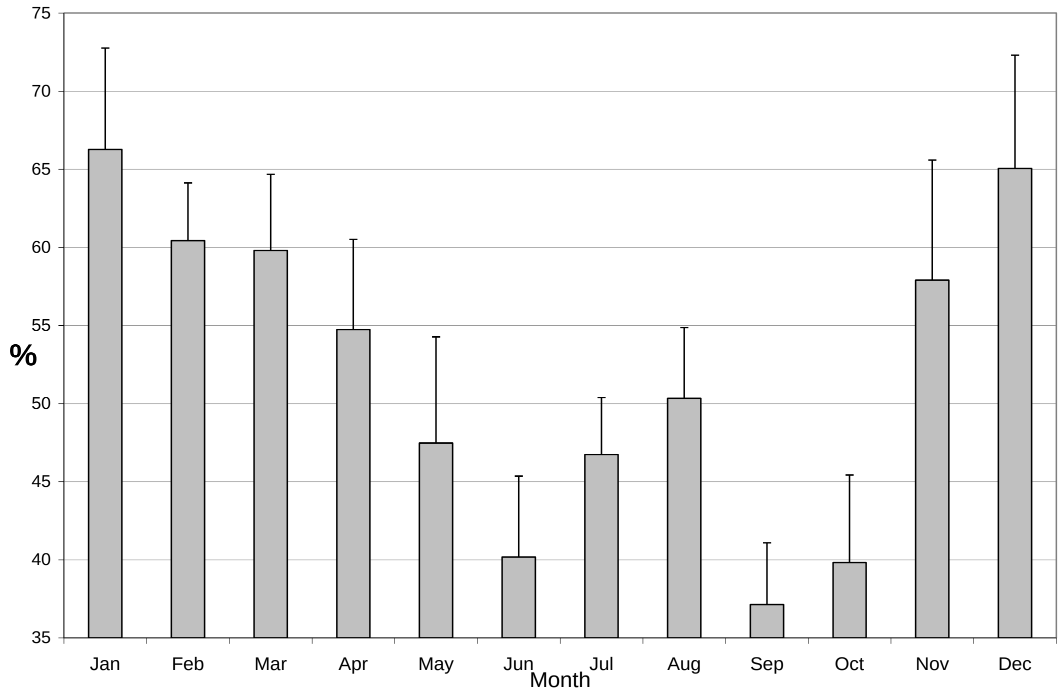


Figure 3.13*: Monthly averages relative humidity in Khamise 1995 – 2006*

3.11.6 Statistical Analysis Data Preparation

The analysis to examine the relationship between monthly cases of malaria and the selected weather data proceeded in a number of stages.

A histogram of the distribution of all malaria cases in Asir Region was constructed and this showed a positively skewed distribution, with a majority of lower values and a few somewhat higher ones. This was confirmed through descriptive statistics. This may cause problems when we come to perform regression analysis. We therefore took the natural logarithm (adding 1 to zero values) for malaria cases to produce Ln malaria. The distribution of this is shown in Figure 3.14 and descriptive statistics are presented in Table 3.4. These demonstrate that taking the natural logarithm of malaria largely corrected this problem. For similar reasons the natural logarithm was taken of malaria cases in TA and TQ.

In terms of the independent variables, rainfall of Khamise City also demonstrated a skewed distribution. Therefore, we took the natural logarithm of rainfall (adding 1 to zero values) to get (Ln rainfall). Figure 3.15 shows a histogram of rainfall after transformation. Table 3.5 presents the descriptive statistic of this distribution. The same action was been taken for rainfall in TA and TQ.

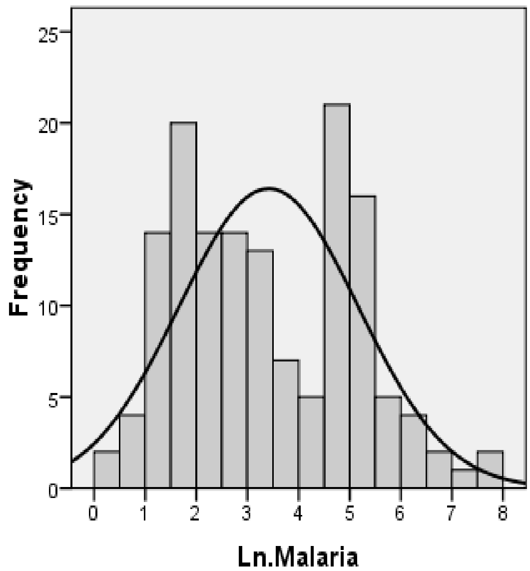


Figure 3.14: *Frequency of natural logarithm of malaria (Ln.M) in overall Asir Region (1995 – 2006)*

***Table 3.4**: Descriptive statistics for Ln malaria of overall Asir*

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
Ln Malaria	144	.00	7.74	3.4	1.75	Statistic	Std. Error
						.223	.202

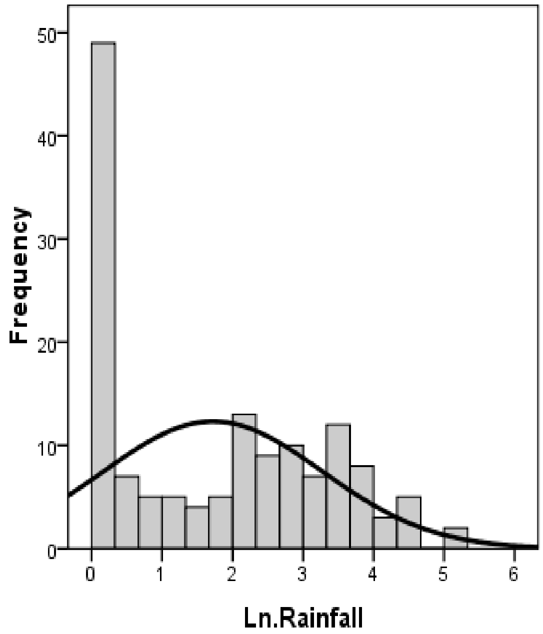


***Figure 3.15:** Frequency of logarithm rainfall (Ln. R) in Khamise (1995 – 2006)*

***Table 3.5:** Descriptive statistics of Ln rainfall in Khamise*

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
Ln Rainfall	144	0	5.3	1.72	1.55	Statistic	Std. Error
						0.27	0.20

The data were adjusted for effects that could bias the results. The long term trend in Ln malaria in Asir region is shown in Figure 3.16, and the long term in Ln malaria in TA and TQ are shown in Figure 3.17. Over the study period the total number of malaria cases indicates a sharp decline from the end of the nineties with a peak of cases in 1998. In order to control for this effect the natural logarithm of malaria cases were put into a regression against time (each month numbered from 1 to 144). The unstandardised residual from this model represent the natural logarithm of malaria cases with the long term trend in incidence removed. This was performed on the malaria data for the whole of Asir region, TA and TQ.

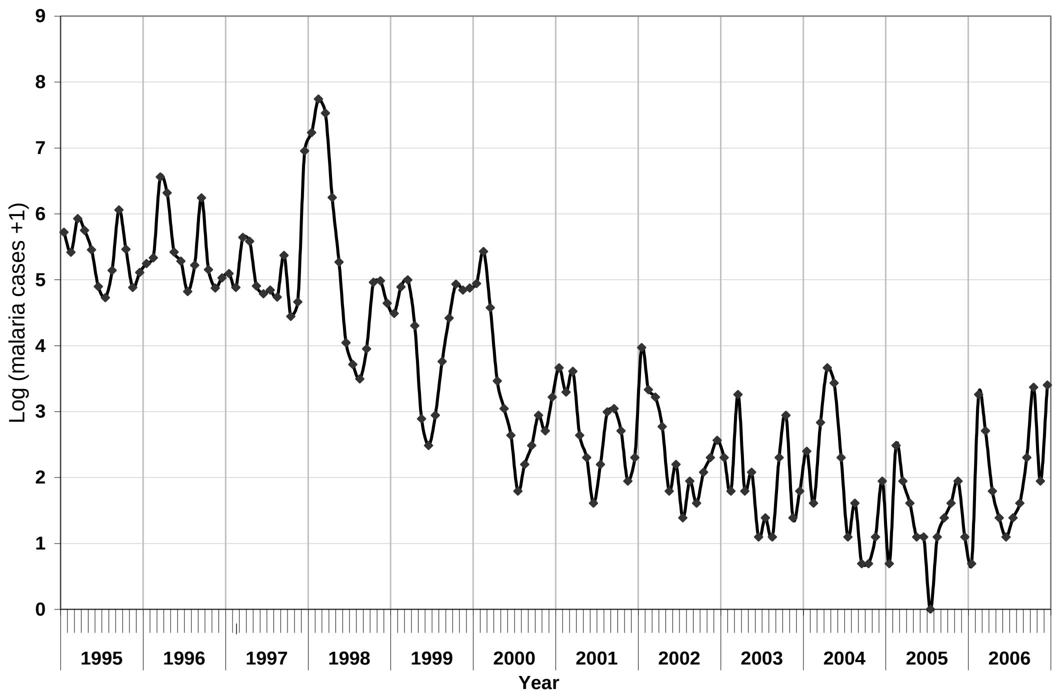


Figure 3.16: *Yearly Ln malaria in Asir Region (1995 - 2006)*

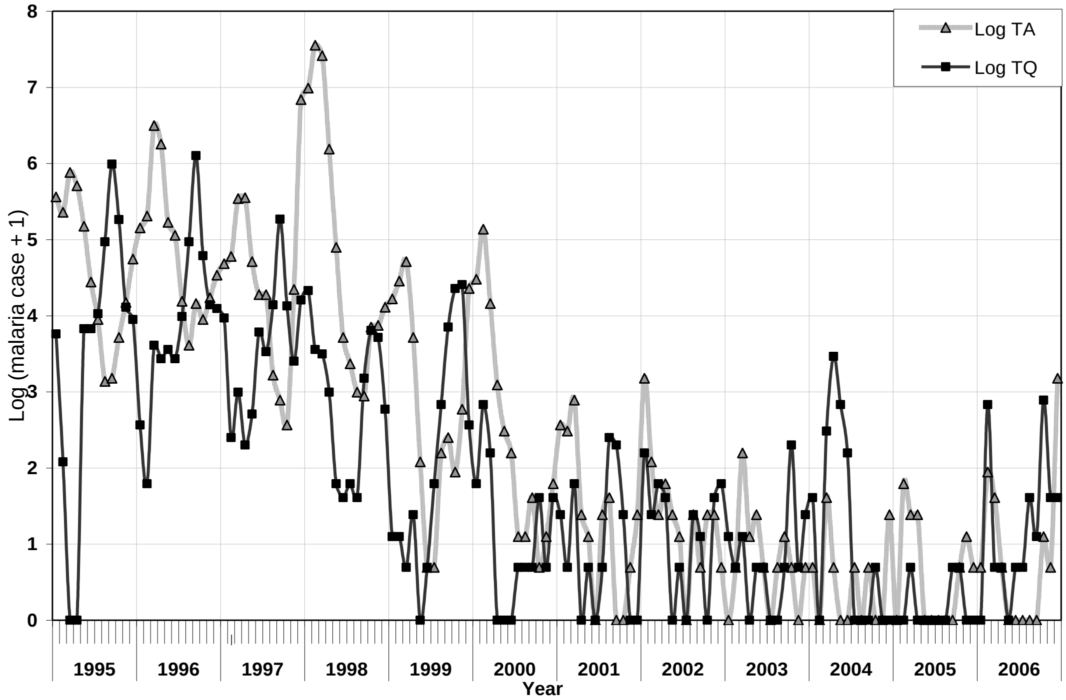


Figure 3.17: *Yearly Ln malaria in TA and TQ sectors (1995 - 2006)*

3.11.7 Statistical Analysis

The literature review has demonstrated that the relationship between malaria and weather may vary according to the time of the year. There may also be a lag in the relationship between weather and malaria. Therefore, the analysis proceeded in stages.

In the first stage scatter plots were created of the detrended natural logarithm of malaria (DT Ln malaria) for every month against each of the weather variables. The purpose of this analysis was to determine which months should be grouped together based upon relationships with the weather variables (i.e. group consecutive months with positive or negative relationships with weather together). Unfortunately, this method proved difficult to implement because it was often unclear which months should be grouped. Also the relationship between weather and malaria may be lagged and so theoretically the analysis should be repeated for every lagged weather variable. Therefore this method was not taken further (for results see Appendix A.1), and replaced with one where the annual malaria time series was examined and groups of months determined based upon the trends in this graph (i.e. months of high incidence during the winter). For overall Asir this procedure led to three separate time periods which were April to August, September to November and December to March (See Figure 3.7). TA was separated into two time periods April to August and September to March (See Figure 3.8). TQ was separated into April to September and October to March (See Figure 3.8).

For each of time periods linear regressions of DT Ln Malaria against each of the lagged weather variables were created (lagged up to 6 months). We then examined these relationships and combined the weather from the two months with the strongest association. In most cases the strongest relationships were between DT Ln Malaria and the weather in the current and previous month. Therefore, for consistency these two lags were chosen in all cases. Because these models contained data from multiple months it became important to control for seasonality. Therefore, all models were analyzed incorporating dummy variables for each of the individual months. Finally in these analyses it was not possible to assume that the malaria rate in one month is unrelated to the malaria rate in the next month, and this is known as autocorrelation. Therefore the malaria in the previous month was added into these models as an independent variable. Due to the low numbers of cases in some months and the problems that this might cause in a regression an ordinal logistic regression of Ln malaria cases was additionally applied. This was achieved by recoding Ln malaria into four categories of increasing malaria incidence. These were then used in an ordinal logistic regression to produce an analysis that is more robust to the distribution of the data.

Multiple regression analysis was examined in the final stage of the statistical analysis. This method describes the effect of the two or three weather data together against detrended logarithm of malaria cases. The purpose of this test is to identify which weather variable has more influence upon malaria cases than others.

All of the data were analyzed using SPSS v.16 / v.18 for Windows and Microsoft Excel 2003 / 2007.

3.12 Results

3.12.1 Malaria with Maximum Temperature in Asir

Linear regressions and ordinal logistic regressions of DT Ln malaria against maximum temperature are presented for the whole year in Table 3.6 and April to August model in Table 3.7. Models for the rest of year (September to November and December to March) for this variable and all similar variables which do not have any significant relationship are not presented in this chapter but appear in AppendixA.2. In these tables 0P represents the models where the independent variables are not lagged, 1P represents the independent variables lagged by 1 month and so on. The results for the combined lags are presented on the final line of each table. In the analysis we also investigated weather instead of using the average maximum temperature each month it would be better to use the maximum temperature from any one day in the month. Such an analysis was performed (See AppendixA.3) but as the results were no different from using the average maximum temperature each month this was not taken any further.

Table 3.6*: DT Ln malaria and maximum temperature in Asir (Whole Year)*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.104	.001	-.108	0.166	-.080	.195	-.140	.002	-.720	.001	-.750	.034
1 P	-.109	.001	-.132	.096	.080	.193	-.155	.001	-.738	.001	.515	.091
2 P	-.092	.001	-.176	.025	.095	.125	-.122	.008	-.678	.001	-.201	.497
3 P	-.044	.041	-.158	.044	-.037	.558	-.091	.041	-.891	.001	-.907	.011
4 P	.013	.548	-.163	.039	-.064	.315	-.026	-.55	-.788	.001	-.291	.363
5 P	.061	.005	-.176	.036	-.065	.303	.022	.620	-.915	.001	-.690	.040
6 P	.095	.001	-.165	.040	-.063	.323	.056	.213	-.109	.001	-.845	.021
0-1 P	-.118	.001	-.167	.075	-.114	.120	-.158	.001	-1.13	.001	-.929	.028

0P: Current month. P: previous month. Cof.: Coefficients. P: ***P*** value (= or<). 0-1 P: Average of 0P+1 P

Table 3.7: *DT Ln malaria and maximum temperature in Asir (April to Aug)*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.200	.00	-.200	.038	-.151	.032	-.28	.041	-.70	.035	-1.02	.069
1 P	-.138	.001	-.212	.013	-.120	.050	-.196	.028	-1.06	.002	-.886	.049
2 P	-.099	.001	-.201	.015	-.069	.274	-.134	.090	-1.09	.001	-.419	.315
3 P	-.098	.001	-.117	.021	-.062	.279	-.175	.045	-1.12	.001	-.789	.087
4 P	-.092	.039	-.109	.146	-.031	.578	-.251	.056	-.851	.002	-.310	.406
5 P	.014	.831	-.166	.040	-.086	.149	-.410	.025	-1.37	.001	-2.05	.035
6 P	.138	.004	-.133	.140	.006	.932	-.129	.326	-1.59	.001	-2.05	.036
0-1 P	-.175	.001	-.292	.006	-.191	.014	-.247	.027	-1.38	.002	-1.49	.034

The results indicated that in Asir over the whole year malaria cases appear to be negatively associated with maximum temperature in the current and previous month. However, in the linear regression, not all these associations were significant. When only the April to August period is examined, maximum temperature in the current and previous month is significantly associated with malaria incidence in all variants of the model.

3.12.2 Malaria with Maximum Temperature in Tehama of Asir (TA)

Linear regressions and ordinal logistic of DT Ln malaria against maximum temperature in TA are presented for the whole year and April to August in Tables 3.8 and 3.9.

Table 3.8: *DT Ln malaria and maximum temperature in TA (Whole Year)**

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.115	.001	.121	.128	-.038	.506	-.079	.092	-.064	.718	.046	.908
1 P	-.164	.001	.037	.639	-.048	.399	-.098	.037	-.39	.823	.205	.628
2 P	-.170	.001	-.061	.443	-.087	.125	-.121	.011	-.223	.215	-.666	.083
3 P	-.126	.001	-.103	.193	-.061	.287	-.082	.080	-.295	.107	-.500	.202
4 P	-.046	.079	-.108	.173	-.036	.527	-.027	.556	-.375	.050	-.308	.363
5 P	.051	.052	-.056	.486	.021	.720	.012	.800	-.501	.013	-.456	.062
6 P	.131	.001	.056	.487	.095	.097	.050	.277	.335	.076	.238	.474
0-1 P	-.156	.001	.124	.215	-.08	.399	-.101	.044	-.091	.684	-.161	.746

* Maximum temperature data: available for 132out of 144 months

Table 3.9: *DT Ln malaria and maximum temperature in TA (April to Aug)*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.199	.021	-.128	.292	-.006	.944	-.080	.665	.029	.925	-.052	.912
1 P	-.186	.001	.001	.997	-.087	.347	-.077	.435	-.001	.996	.019	.973
2 P	-.149	.001	-.117	.250	-.115	.119	-.098	.218	-.375	.187	-.736	.103
3 P	-.147	.001	-.258	.005	-.150	.035	-.107	.173	-.614	.046	-.101	.035
4 P	-.159	.001	-.194	.036	-.075	.290	-.113	.270	-.506	.068	.271	.475
5 P	-.070	.381	-.207	.039	-.063	.415	-.367	.047	-1.04	.008	-6.55	.034
6 P	.173	.001	-.050	.629	.143	.077	-.033	.757	-.529	.082	.428	.396
0-1 P	-.240	.001	.106	.500	-.075	.523	-.099	.477	.022	.954	-.035	.956

In the TA sector malaria cases are not consistently associated with maximum temperature in the current and previous month. This result applies to the whole year model and to the April to August model.

3.12.3 Malaria with maximum temperature in Tehama of Qahtan (TQ)

Linear regressions and ordinal logistic regressions of DT Ln malaria against maximum temperature in TQ are presented for the whole year in Table 3.10 and April to September in Table 3.11.

Table 3.10: *DT Ln malaria and maximum temperature in TQ (whole year)*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.021	.422	-.114	.260	-.032	.693	-.092	.039	-.611	.002	-.487	.040
1 P	.038	.151	-.083	.420	-.021	.791	-.042	.341	-.478	.013	-.207	.379
2 P	-.065	.014	-.243	.018	-.192	.016	-.012	.784	-.696	.001	-.679	.008
3 P	.076	.002	-.309	.002	-.162	.037	.012	.786	-.792	.001	-.526	.031
4 P	-.073	.003	-.266	.006	-.090	.263	.021	.636	-.843	.001	-.608	.020
5 P	.044	.079	-.294	.002	-.129	.092	.030	.500	-.794	.001	-.487	.064
6 P	.007	.798	-.299	.002	-.119	.126	.016	.722	-.908	.001	-.721	.010
0-1 P	.005	.844	-.148	.223	-.044	.644	-.078	.096	-.817	.001	-.533	.064

Table 3.11: *DT Ln malaria and maximum temperature in TQ (April to September)*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.082	.031	-.375	.025	-.306	.009	-.085	.192	-.714	.025	-1.50	.013
1 P	-.089	.045	-.317	.034	-.241	.022	-.032	.079	-.712	.013	-.598	.043
2 P	.074	.077	-.337	.012	-.249	.008	-.023	.730	-.839	.002	-.986	.036
3 P	.082	.127	-.363	.005	-.170	.073	-.022	.711	-1.08	.001	-.843	.038
4 P	.094	.133	-.291	.012	-.101	.276	-.058	.440	-.932	.001	-.622	.105
5 P	.058	.468	-.362	.002	-.205	.004	.198	.104	-1.10	.001	-1.08	.063
6 P	-.083	.259	-.363	.005	-.109	.239	-.271	.039	-1.32	.001	-1.08	.079
0-1 P	-.056	.038	-.484	.009	-.381	.003	-.073	.144	-1.05	.006	-1.38	.020

The results of TQ indicated that malaria cases are not consistently associated with temperature over the whole year. When the April to September period is focused upon maximum temperature in the current and previous month is significantly negatively associated with malaria in all but one variant of the model.

3.12.4 Malaria with Mean Temperature in Asir

Linear regressions and ordinal logistic regressions of DT Ln malaria against mean temperature in Asir are presented for April to August model in Table 3.12.

Tables 3.12: *DT Ln malaria and mean temperature in Asir (April to August)*

Model	Linear regression						Ordinal logistic					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation& seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.243	.001	-.324	.016	-.235	.015	-.366	.021	-1.52	.003	-2.53	.017
1 P	-.157	.001	-.317	.008	-.183	.038	-.236	.023	-2.52	.001	-2.7	.011
2 P	-.111	.001	-.286	.013	-.088	.323	-.149	.095	-1.55	.001	-.718	.255
3 P	-.102	.002	-.134	.244	.012	.887	-.151	.113	-1.28	.003	-.356	.563
4 P	-.110	.024	-.088	.518	-.037	.687	-.165	.223	-1.06	.015	-.023	.974
5 P	-.054	.470	-.053	.693	-.015	.875	-.232	.244	-1.88	.001	-1.26	.060
6 P	.198	.001	-.025	.874	.012	.916	.068	.622	-1.27	.022	-.484	.535
0-1 P	-.205	.001	-.463	.002	-.303	.006	-.309	.018	-3.42	.001	-6.39	.009

The results indicated that in Asir over April to August malaria cases appear to be significantly negatively associated with mean temperature in the current and previous month for the linear regression and the ordinal logistic models. This correlation is highly significant in all variant of the model.

3.12.5 Malaria with Mean Temperature in TQ

Linear regressions and ordinal logistic regressions of DT Ln malaria against mean temperature in TQ are presented for April to September model in Table 3.13.

***Table* 3.13**: *DT Ln malaria and mean temperature in TQ (April to September)*

Model	Linear regression						Ordinal logistic					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation& seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.013	.885	-.545	.018	-.516	.001	-.172	.238	-1.95	.001	-4.17	.002
1 P	.080	.166	-.472	.022	-.379	.008	-.041	.657	-1.54	.001	-1.48	.032
2 P	.092	.057	-.616	.001	-.379	.006	-.015	.942	-1.92	.001	-1.75	.016
3 P	.113	.006	-.351	.067	-.065	.643	.007	.918	-1.24	.002	-.355	.508
4 P	.129	.008	-.302	.100	-.174	.204	-.03	.970	-.973	.008	-.582	..264
5 P	.190	.011	-.212	.290	-.186	.152	-.08	.948	-.871	.025	-.262	.685
6 P	.023	.710	-.319	.140	-.260	.064	-.101	.442	-1.39	.003	-2.07	.026
0-1 P	.069	.348	-.754	.004	-.650	.001	-.090	.443	-2.96	.001	-5.11	.003

The results indicated that in TQ during April to September, malaria cases appear to be highly negatively associated with mean temperature in the current and previous month for all models except those including the temperature variables only.

3.12.6 Malaria with Minimum Temperature in Asir

Linear regressions and ordinal logistic regressions of DT Ln malaria against minimum temperature in Asir are presented for April to August model in Table 3.14.

Table 3.14: *DT Ln malaria and minimum temperature in Asir (April to August)*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.251	.001	-.288	.044	-.244	.082	-.314	.050	-1.67	.019	-4.27	.031
1 P	-.164	.001	-.341	.038	-.264	.024	-.208	.010	-2.29	.001	-7.22	.020
2 P	-.121	.001	-.221	.134	-.075	.488	-.113	.246	-.588	.200	.036	.958
3 P	-.098	.007	.127	.312	-.023	.789	-.069	.476	.197	.603	1.85	.020
4 P	-.095	.042	.103	.373	-.095	.042	-.012	.924	.365	.304	.357	.544
5 P	.064	.340	.162	.125	.075	.329	.075	.666	-.008	.981	-.140	.774
6 P	.214	.001	.093	.417	-.082	.337	.255	.097	.412	.254	.657	.256
0-1 P	-.208	.001	-.498	.026	-.392	.012	-.263	.050	-3.21	.001	-10.7	.025

The results in Asir indicated that during April to August, malaria cases appear to be significantly negatively associated with minimum temperature in the current and previous month for linear regression and ordinal logistic models.

3.12.7 Malaria with Minimum Temperature in TA

Linear regressions and ordinal logistic regressions of DT Ln malaria areas against minimum temperature in TA are presented for April to August in Table 3.15.

Table 3.15: *DT Ln malaria and minimum temperature in TA (April to August)*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.216	.009	.116	.298	-.100	.255	.043	.811	.450	.152	-.338	.440
1 P	-.187	.001	.019	.810	-.090	.305	-.049	.639	.201	.499	-.915	.133
2 P	-.172	.001	-.073	.617	-.048	.657	-.040	.679	.485	.218	2.086	.047
3 P	.1.59	.001	-.073	.617	-.048	.657	-.040	.679	.485	.218	2.086	.047
4 P	-.122	.043	.037	.805	-.027	.806	.004	.975	.366	.357	.011	.987
5 P	.071	.552	-.192	.215	-.213	.056	-.057	.817	-.157	.689	-1.14	.162
6 P	.338	.001	.062	.767	.221	.149	.147	.426	.535	.324	1.71	.073
0-1 P	-.231	.001	.088	.494	-.119	.224	-.030	.826	.408	.234	-.694	.208

In the TA sector malaria cases are not consistently associated with minimum temperature in the current and previous month for the April to August period.

3.12.8 Malaria with Minimum Temperature in TQ

Linear regressions and ordinal logistic regressions of DT Ln malaria against minimum temperature in TQ are presented for April to September in Table 3.16.

Table 3.16: *DT Ln malaria and minimum temperature in TQ (April to September)*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.004	.971	-.757	.021	-.541	.020	-.112	.472	-2.48	.001	-3.52	.020
1 P	.115	.073	-.569	.040	-.417	.032	.005	.962	-1.41	.011	-.787	.356
2 P	.109	.030	-.805	.001	-.378	.037	.012	.879	-1.55	.003	-.925	.236
3 P	.142	.001	.098	.642	.297	.065	.059	.426	.049	.890	1.15	.071
4 P	.151	.002	.056	.764	-.141	.312	.073	.388	.278	.402	-.037	.946
5 P	.250	.001	.262	.126	.087	.445	.166	.171	.449	.158	.838	.186
6 P	.125	.116	.122	.485	-.130	.267	.099	.455	.229	.463	-.425	.434
0-1 P	.094	.251	-.994	.007	-.724	.005	-.035	.787	-3.05	.001	-3.09	.032

The results indicated that in TQ only over the April to September model malaria cases appear to be significantly negatively associated with minimum temperature in the current and previous month for both linear regression and ordinal logistic method but not when only the temperature was included in the model.

3.12.9 Malaria with Rainfall in Asir

Linear regressions and ordinal logistic regressions of DT Ln malaria against rainfall in Asir are presented for April to August model in Table 3.17.

Table 3.17: *DT Ln malaria and Ln rainfall in Asir (April to August)*

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.227	.003	.217	.007	.115	.050	.414	.069	.447	.036	.717	.031
1 P	.169	.014	.170	.015	.107	.036	.500	.021	.652	.010	.568	.018
2 P	-.116	.053	.043	.552	.023	.668	.108	.499	.518	.039	.079	.806
3 P	-.100	.110	.055	.482	.029	.607	.083	.612	.376	.141	.470	.218
4 P	-.076	.241	-.019	.804	-.013	.823	.025	.880	.088	.708	-.375	.302
5 P	.045	.559	.023	.773	.022	.697	.202	.308	.221	.346	-.399	.319
6 P	-.028	.768	-.008	.927	-.016	.791	.081	.735	.130	.611	.323	.477
0-1 P	.440	.001	.400	.001	.244	.002	1.10	.003	1.27	.002	4.58	.025

Only the April to August model is presented. Rainfall in the current and previous month is highly positively significantly associated with malaria incidence in both the ordinal logistic and the linear regression models.

3.12.10 Malaria with rainfall in TA

Linear regressions and ordinal logistic regressions of DT Ln malaria cases against rainfall in TA are presented for whole year in Table 3.18 and April to August model in Table 3.19.

Table 3.18: *DT Ln malaria and with Ln rainfall in TA (Whole year)**

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.247	.001	.210	.001	.093	.015	.462	.001	.532	.001	.541	.037
1 P	.220	.001	.222	.001	.057	.045	.509	.001	.585	.001	.553	.023
2 P	.180	.003	.219	.001	.060.	.145	.468	.001	.562	.001	.301	.177
3 P	.177	.004	.224	.001	.058	.159	.555	.001	.737	.001	.694	.007
4 P	.095	.121	.150	.004	.13	.750	.482	.001	.643	.001	.273	.226
5 P	.030	.628	.101	.059	0.02	.962	.374	.001	.504	.001	.020	.925
6 P	.015	.810	.067	.215	.024	.541	.505	.001	.676	.001	.643	.013
0-1 P	.321	.001	.288	.001	.119	.013	.714	.001	.829	.001	.802	.014

*Rainfall data: available for 132out of 144 months

__Table 3.19:__ DT Ln malaria and with Ln rainfall in TA (April to August)

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.269	.001	.249	.001	.119	.028	.288	.005	.277	.035	.617	.036
1 P	.254	.001	.215	.001	.069	.205	.696	.003	.695	.004	1.06	.069
2 P	.181	.011	.222	.001	.048	.396	.970	.001	1.06	.001	.769	.068
3 P	.158	.021	.176	.003	.033	.505	1.44	.002	1.71	.002	1.0	.035
4 P	.045	.497	.073	.233	.081	.086	1.16	.001	1.35	.002	.602	.187
5 P	.041	.549	.056	.369	-.025	.586	.953	.001	1.18	.003	1.16	.121
6 P	.058	.419	.031	.631	.102	.229	.868	.001	1.12	.002	2.34	.104
0-1 P	.396	.001	.337	.001	.155	.025	.742	.006	.736	.007	1.11	.048

The results indicated that in TA over the whole year malaria cases appear to be significantly positively associated with rainfall in the current and previous month for both linear regression and ordinal logistic models. For the April to August period, malaria incidence is significantly associated with rainfall in the current and previous month in all variants of the model.

3.12.11 Malaria with Rainfall in TQ

Linear regressions and ordinal logistic regressions of DT Ln malaria against rainfall in TQ are presented for the whole year in Table 3.20 and April to September in Table 3.21.

*__Table 3.20:__ DT Ln malaria and Ln rainfall in TQ (whole year)**

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.377	.001	.388	.001	.238	.001	.654	.001	.808	.001	.771	.001
1 P	.329	.001	.346	.001	.0128	.041	.605	.001	.802	.001	.554	.006
2 P	.268	.001	.287	.001	.077	.202	.628	.001	.767	.001	.519	.006
3 P	.094	.165	.150	.028	.031	.571	.368	.002	.472	.001	.081	.658
4 P	-.015	.813	.021	.751	-.075	.161	.276	.019	.331	.010	.093	.571
5 P	.026	.696	.014	.836	.001	.994	.362	.003	.395	.003	.345	.048
6 P	-.038	.596	-.056	.403	-.063	.216	.206	.074	.278	.033	.073	.667
0-1 P	.494	.001	.496	.001	.271	.001	1.02	.001	1.3	.001	1.10	.001

*Rainfall data: available for 132out of 144 months

Table 3.21: *DT Ln malaria and rainfall in TQ (April to September)*

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof	P
0 P	.439	.001	.481	.001	.319	.001	.733	.001	.929	.001	1.36	.015
1 P	.411	.001	.477	.001	.243	.003	.611	.001	.889	.001	.857	.046
2 P	.230	.028	.330	.002	.064	.449	.350	.042	.523	.013	.125	.691
3 P	.080	.444	.196	.071	.052	.519	.176	.279	.251	.176	.568	.123
4 P	-.045	.649	-.060	.549	-.139	.053	.047	.769	.036	.834	.466	.120
5 P	.001	.998	-.079	.440	-.010	.874	.141	.385	.097	.579	.08	.980
6 P	-.181	.064	-.235	.116	-.146	.920	.054	.730	.079	.643	.497	.175
0-1 P	.576	.001	.626	.001	.391	.001	1.02	.001	.141	.001	1.58	.012

The results in TQ over the whole year and April to September model indicate that malaria cases appear to be significantly positively associated with rainfall in the current and previous month for both linear regression and ordinal logistic models.

3.12.12 Malaria with Relative Humidity in Asir

Linear regressions and ordinal logistic regressions of DT Ln malaria against relative humidity in Asir are presented for the whole year in Table 3.22 and April to August model in Table 3.23.

Table 3.22*: DT Ln malaria and relative humidity in Asir (Whole Year)*

Model	Linear regression						Ordinal logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation& seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.031	.001	.029	.036	.027	.013	.036	.023	.032	.032	.132	.024
1 P	.039	.001	.051	.001	.036	.001	.047	.005	.059	.032	.104	.075
2 P	.029	.001	.039	.005	.010	.408	.032	.047	.030	.371	.050	.385
3 P	.013	.082	.045	.001	.023	.046	.021	.185	.083	.021	.186	.005
4 P	-.007	.369	.033	.020	.007	.536	-.003	.838	.077	.029	.042	.464
5 P	.021	.007	.042	.003	.024	.035	.010	.504	.091	.012	.074	.175
6 P	-.030	.001	.024	.101	-.004	.743	-.012	.453	.086	.016	.029	.605
0-1 P	.044	.001	.059	.001	.047	.001	.053	.004	.070	.034	.180	.013

***Table 3.23**: DT Ln malaria and relative humidity in Asir (April to August)*

Model	Linear regression						Ordinal logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation& seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.041	.004	.021	.022	.013	.015	.082	.009	.090	.039	.230	.029
1 P	.050	.001	.036	.034	.023	.043	.100	.006	.204	.003	.212	.043
2 P	.030	.005	.024	.155	.004	.767	.065	.039	.180	.006	.078	.409
3 P	.039	.001	.036	.026	.016	.181	.062	.077	.103	.057	.168	.055
4 P	.036	.018	.026	.123	.001	.998	.049	.234	.062	.232	-.010	.903
5 P	.017	.271	.042	.007	.023	.043	.021	.605	.054	.269	.019	.794
6 P	-.023	.015	.030	.057	.006	.631	-.013	.582	.051	.304	.056	.453
0-1 P	.066	.001	.046	.034	.029	.048	.135	.005	.241	.004	.387	.017

The results in Asir over the whole year indicate that malaria cases appear to be significantly positively associated with relative humidity in the current and previous month. In the April to August model all the associations remain significant

3.12.13 Malaria with Relative Humidity in TQ

Linear regressions and ordinal logistic regressions of DT Ln malaria against relative humidity in TQ are presented for the whole year in Table 3.24 and April to September in Table 3.25.

***Table 3.24:** DT Ln malaria and relative humidity in TQ (whole year)*

Model	Linear regression						Ordinal logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation& seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.097	.040	.013	.035	.023	.033	.024	.015	.060	.047	.091	.037
1 P	.081	.010	.038	.035	.033	.021	.013	.012	.074	.031	.058	.042
2 P	.008	.371	.054	.003	.032	.027	.003	.869	.074	.030	.050	.233
3 P	.011	.247	.066	.001	.036	.012	.010	.752	.102	.004	.090	.042
4 P	.011	.239	.046	.008	.010	.561	.004	.794	.086	.015	.044	.307
5 P	-.005	.558	.043	.014	.015	.266	.001	.925	.084	.018	.056	.205
6 P	.002	.797	.029	.101	.001	.942	.003	.852	.067	.052	.026	.539
0-1 P	.091	.031	.039	.038	.041	.017	.023	.018	.108	.042	.113	.031

Table 3.25: *DT Ln malaria and relative humidity in TQ (April to September)*

Model	Linear regression						Ordinal logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation& seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.24	.211	.009	.762	.023	.268	.036	.249	.095	.067	.149	.087
1 P	.001	.968	.025	.383	.031	.113	.045	.142	.139	.101	.167	.042
2 P	-.016	.349	.058	.041	.035	.086	.021	.440	.147	.008	.142	.110
3 P	-.018	.211	.080	.002	.035	.076	.025	.293	.173	.002	.129	.075
4 P	-.018	.292	.051	.038	.004	.0831	.028	.338	.100	.033	.014	.854
5 P	.010	.638	.057	.016	.018	.278	.039	.274	.08	.081	.032	.667
6 P	.017	.229	.046	.059	.001	.965	.028	.253	.110	.026	.089	.274
0-1 P	.018	.441	.026	.462	.042	.091	.061	.110	.189	.007	.254	.020

The results over the whole year indicated that malaria cases in TQ appear to be positively associated with relative humidity in the current and previous month for both linear regression and ordinal logistic models. This is significant in all but the most basic form of the model. This correlation mostly disappears in the April to September model.

3.12.14 Multiple Regressions

In this section we will present the results from the normal and multiple regressions of DT Ln malaria cases against averages (current and one previous month) of three main weather data (Maximum Temperature, Rainfall and Relative Humidity). For temperature, we will present maximum temperate only in the multiple regressions as it has a similar seasonality to minimum and mean temperature and appeared to have the strongest associations with malaria.

A- Multiple Regressions of Malaria Cases in All Asir

The normal regressions for malaria in all Asir against maximum temperature, rainfall and relative humidity, in the current and previous month, for whole period are illustrated in Tables 3.26. Table 3.27 presents the multiple regressions for these variables.

The normal regressions for malaria in all Asir against maximum temperature, rainfall and relative humidity, in the current and previous month, for the April to August period are illustrated in Table 3.28. Table 3.29 presents the multiple regressions for these variables.

Table 3.26: *Regressions of DT Ln malaria cases of Asir for maximum temperature, rainfall and relative humidity for whole year*

Aver. of 0 P&1 P ---------- For All year Cases	Linear regression									Ordinal logistic								
	Variables Only			with seasonality			With auto correlation & Seasonality			Variables Only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.118	.001	.189	-.167	.075	.187	-.114	.120	.507	-.158	.001	-92.1	-1.13	.001	-83.2	-.929	.028	-40.7
Rainfall Only	.133	.056	.039	.057	.553	.177	.071	.338	.506	.076	.590	-98.9	.576	.014	-91.0	.401	.286	-43.1
Humidity Only	.044	.001	.187	.059	.001	.250	.047	.001	.550	.053	.004	94.8	.070	.034	92.7	.180	.013	40.2

Table 3.27: *Regressions of DT Ln Malaria cases of Asir with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) for whole year*

Aver. of 0 P&1 P / Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables Only			With Seasonality			With auto Correlation & Seasonality			Variables Only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	-.119	.001	.183	-.178	.090	.181	-.103	.206	.503	-.203	.001	-90.07	-1.05	.001	-82.95	-.908	.045	-40.66
Rainfall	.007	.916		-.025	.818		.24	.777		.327	.046		.175	.518		.057	.896	
Max.Tem	-.070	.044	.200	-.024	.813	.238	.004	.962	.542	-.145	.074	-92.11	-1.17	.001	-83.10	-.621	.184	-39.11
Humidity	.023	.085		.057	.003		.048	.001		.006	.842		.016	.036		.133	.037	
Rainfall	.044	.001	.200	-.087	.382	.249	-.039	.609	.547	.104	.473	-.94.51	.497	.049	-90.72	.029	.947	-40.21
Humidity	-.113	.070		.066	.001		.050	.001		.053	.044		.036	.019		.178	.021	
Max.Tem	-.50	.232	.198	-.059	.582	.238	-.011	.893	.540	.282	.008	-89.68	-1.11	.001	-82.81	-.673	.186	-39.04
Rainfall	-.061	.426		-.111	.297		.047	.571		.407	.031		.215	.445		-.179	.707	
Humidity	-.028	.059		.063	.002		.050	.001		.031	.374		-.026	.597		.140	.080	

Table 3.28: *Regressions of DT Ln malaria cases of Asir for maximum temperature, rainfall and relative humidity for April to August*

Aver. of 0 P&1 P / Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables Only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.175	.001	.318	-.292	.006	.316	-.191	.014	.643	-.247	.027	-38.1	-1.38	.002	-33.4	-1.49	.034	-16.1
Rainfall Only	.440	.001	.258	.400	.001	.403	.244	.002	.665	1.10	.003	-35.1	1.27	.002	-33.9	4.58	.025	-16.0
Humidity Only	.066	.001	.300	.046	.034	.276	.029	.048	.624	.135	.005	-36.0	.241	.004	-34.5	.387	.017	-14.7

Table 3.29: *Regressions of DT Ln malaria cases of Asir with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) for April to August*

Aver. of 0 P&1 P	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
Variables In Multiple Method	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	-.140	.001	.441	-.152	.152	.415	-.117	.140	.672	-.177	.140	-33.95	-1.13	.018	-30.60	-1.45	.052	-13.71
Rainfall	.321	.001		.336	.002		.197	.019		.997	.008		1.01	.026		1.59	.050	
Max.Tem	-.108	.050	.334	-.338	.063	.310	-.160	.086	.638	-.046	.801	-36.00	-1.04	.038	-32.04	-.999	.233	-13.89
Humidity	.033	.122		.019	.457		.011	.552		.150	.050		.148	.114		.307	.076	
Rainfall	.256	.020	.353	.394	.002	.392	231	.015	.659	.809	.046	-33.86	.890	.055	-32.47	.944	.238	-13.89
Humidity	.046	.003		.002	.924		.05	.790		.084	.125		.155	.101		.313	.071	
Max.Tem	-.115	.004	.432	-.184	.124	.408	-.135	.132	.667	-.082	.676	-33.77	-.999	.049	-30.32	-1.06	.216	-13.10
Rainfall	.342	.002		.366	.003		.214	.023		.865	.044		.865	.075		1.12	.223	
Humidity	.01	.713		.016	.544		.010	.659		.054	.546		.075	.465		.206	.291	

The results of multiple regressions for malaria in Asir through whole year demonstrated that in no models were more than one weather variable significant. We conclude therefore that the best model for the whole year is that of DT Ln malaria against humidity. Humidity was positively significant in all variants of the normal regression and in most cases had a better goodness of fit (adjusted R^2 and log likelihood ratio) and is a stronger significance than any of the other weather variables.

Multiple regressions for malaria in Asir during April to August demonstrated that there were no models where all the weather variables were consistently significant. We therefore conclude that the final model should be a normal regression with one weather variable. Both rainfall and humidity are positively significantly in all variants of the normal regression. However, we have chosen the model including rainfall as the final model as in most cases the significances and model fit is better than the model containing humidity

B- Multiple Regressions of Malaria Cases in TA Sector

The normal regressions for malaria in TA areas against maximum temperature and rainfall, in the current and previous month, for whole period are illustrated in Tables 3.30. Table 3.31 presents the multiple regressions for these variables.

The normal regressions for malaria in TA areas against maximum temperature and rainfall for April to August period are illustrated in Tables 3.32. Table 3.33 presents the multiple regressions for these variables.

Table 3.30: *Regressions of DT Ln malaria cases of TA for maximum temperature and rainfall for whole year*

Aver. of 0 P&1 P ---------- For All year Cases	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.156	.001	.239	.124	.215	.322	-.08	.399	.649	-.101	.044	-88.5	-.091	.684	-86.8	-.161	.746	-25.2
Rainfall Only	.321	.001	.162	.288	.001	.450	.119	.013	.670	.714	.001	-86.1	.829	.001	-62.3	.802	.014	-18.4

Table 3.31: *Regressions of DT Ln malaria cases of TA with multiple weather (maximum temperature and rainfall) for whole year*

Aver. of 0 P&1 P ------------- Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	-.163	.001	.508	.112	.262	.540	-.001	.987	.686	-.112	.095	-56.78	.222	.468	-54.08	.797	.303	-11.32
Rainfall	.365	.001		.341	.001		.168	.001		.827	.001		.875	.001		1.05	.031	

Table 3.32: *Regressions of DT Ln malaria cases of TA for maximum temperature and rainfall for April to August*

Aver. of 0 P&1 P ---------- For April To Aug	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.240	.001	.239	.106	.500	.274	-.075	.523	.612	-.099	.477	-37.8	.022	.954	-33.5	-.035	.956	-12.6
Rainfall Only	.396	.001	.351	.337	.001	.491	.155	.025	.669	.742	.006	-28.9	.736	.007	-28.7	1.11	.048	-7.33

Table 3.33: *Regressions of DT Ln malaria cases of TA with multiple weather (maximum temperature and rainfall) for April to August*

Aver. of 0 P&1 P ------------- Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	-.199	.001	.514	-.078	.610	.513	-.089	.502	.665	-.029	.870	- 25.80	-.543	.230	- 24.73	.443	.600	- 7.085
Rainfall	.351	.001		.342	.001		.156	.038		.759	.005		.781	.006		1.11	.046	

The results of multiple regressions for malaria in TA through whole year and in the April to August period no two weather variables were significant. Therefore, the regression containing only one weather variable was chosen as the final model. In these, rainfall was consistently positively significant in contrast to temperature. Additionally the models containing rainfall had better of fit. Therefore, the best model to describe DT Ln malaria in TA over the whole year and in the April to August period was one containing rainfall only.

C- Multiple Regressions of Malaria Cases in TQ Sector

The normal regressions for malaria in TQ against maximum temperature, rainfall and relative humidity, in the current and previous month, for whole period are illustrated in Tables 3.34. Table 3.35 presents the multiple regressions for these variables.

The normal regressions for malaria in TQ against maximum temperature, rainfall and relative humidity, in the current and previous month, for the April to August period re illustrated in Table 3.36. Table 3.37 multiple regressions for these variables.

***Table 3.34**: Regressions of DT Ln malaria cases of TQ for maximum temperature, rainfall and relative humidity for whole year*

Aver. of 0 P&1 P ---------- For All year Cases	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	.005	.844	.01	-.148	.223	.089	-.044	.644	.434	-.078	.096	-96.0	-.817	.001	-88.5	-.533	.064	-67.7
Rainfall Only	.494	.001	.278	.496	.001	.375	.271	.001	.549	1.02	.001	-69.1	1.3	.001	-63.1	1.10	.001	-47.5
Humidity Only	.091	.031	.01	.039	.038	.102	.041	.017	.465	.023	.081	-98.0	.108	.042	-.93.1	.113	.031	-67.6

Table 3.35: *Regressions of DT Ln malaria cases of TQ with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) for whole year*

Aver. of 0 P&1 P / Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			With Seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	.040	.128	.272	.095	.397	.359	.055	.567	.536	-.023	.688	-68.69	-.569	.048	-60.63	-.304	.370	-46.97
Rainfall	.497	.001		.507	.001		.278	.001		.986	.001		1.22	.001		1.04	.001	
Max.Tem	-.030	.526	-.01	-.069	.610	.093	.076	.476	.455	-.061	.440	-96.00	-.698	.009	-87.89	-.320	.317	-66.56
Humidity	-.017	.354		.031	.210		.047	.016		.008	.785		.051	.283		.086	.138	
Rainfall	.505	.001	.302	.490	.001	.371	.254	.001	.551	1.01	.001	-69.11	1.29	.001	-61.45	1.06	.001	-46.44
Humidity	-.023	.221		.010	.626		.022	.209		.004	.848		.103	.084		.096	.157	
Max.Tem	-.17	.692	.282	.148	.240	.359	.132	.214	.543	-.029	.759	-68.68	-.441	.160	-60.10	-.124	.738	-46.28
Rainfall	.496	.001		.505	.001		.271	.001		.987	.001		1.23	.001		1.04	.001	
Humidity	-.028	.098		.022	.345		.033	.098		-.003	.932		.065	.312		.086	.247	

Table 3.36: *Regressions of DT Ln malaria Cases of TQ for maximum temperature, rainfall and relative humidity for April to September*

Aver. of 0 P&1 P ---------- For April To Sep	Linear regression									Ordinal logistic								
	Variables only			With Seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.056	.038	.01	-.484	.009	.175	-.381	.003	.606	-.073	.144	-49.6	-1.05	.006	-44.6	-1.38	.020	-21.2
Rainfall Only	.576	.001	.338	.626	.001	.470	.391	.001	.697	1.02	.001	-35.7	.141	.001	-32.1	1.58	.012	-14.9
Humidity Only	.018	.441	.01	.026	.462	.091	.042	.091	.569	.061	.110	-48.3	.189	.007	-.44.8	.254	.020	-21.2

Table 3.37: *Regressions of DT Ln malaria cases of TQ with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) for April to September*

Aver. of 0 P&1 P	Linear regression									Ordinal logistic								
	Variables only			With Seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
Variables In Multiple Method	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	.193	.001	.442	-.108	.524	.465	-.191	.133	.704	.363	.043	- 33.64	-.196	.627	- 31.48	-.506	.462	- 14.62
Rainfall	.682	.001		.601	.001		.342	.001		1.34	.001		1.37	.001		1.41	.035	
Max.Tem	.044	.677	-.017	-.556	.010	.168	-.361	.017	.600	.220	.194	- 47.45	-.756	.075	- 43.13	-.982	.131	- 19.96
Humidity	.005	.886		-.027	.502		.007	.803		.126	.048		.128	.098		.176	.130	
Rainfall	.664	.001	.434	.629	.001	.461	.379	.001	.695	1.06	.001	- 35.57	1.47	.001	- 28.46	1.76	.018	- 12.81
Humidity	-.068	.001		-.007	.820		.019	.443		-.021	.677		.257	.014		.345	.085	
Max.Tem	.123	.138	.443	-.159	.407	.459	-.185	.198	.699	.629	.014	- 31.90	.024	.964	- 28.46	-.364	.676	- 12.73
Rainfall	.686	.001		.597	.001		.342	.001		1.29	.001		1.47	.001		1.91	.026	
Humidity	.033	.302		.021	.561		.003	.916		.160	.075		.260	.025		.390	.093	

The results of multiple regressions for malaria in TQ through whole year and the April to September period demonstrated that no two weather variables were consistently significant. Therefore, the final models chosen included one weather variable only. Over the whole year and in the April to September period rainfall was clearly the most significant positive variable with better model fits than any of the other weather variables.

3.13 Discussion and Conclusion

Malaria is endemic in lowlands of Asir Region (Haddad, 1990), which can be divided into two areas; Tehama of Asir which includes foothills with coastal plain, and Tehama of Qahtan. This disease is less endemic in the coastal plain, but more endemic along the valleys and foothills (Abdoon and Alshahrani, 2003). This study tests the hypotheses that there are relationships between weather and malaria cases in this region, and examines the influence of climate variables upon malaria cases.

During this study several difficulties were encountered. The main one was the limited weather data for some selected areas in Asir, and missing information from within this data. This meant that it was not possible to produce models for each malaria endemic area in Asir. For example, we have combined several sectors for malaria data in TA including Muhail, Rejal-Alma, Marabah and Majaredah, into one group. Although all these areas are in the lowland (foothills) and have the same seasonality of malaria, it would have been preferable to examine each separately but the weather data was not available for each sector. It also would have been good to examine the impact of humidity upon malaria in TA but data was not available.

The situation in TQ was even more difficult as no weather stations were available within this area. Instead we had to use the temperature and humidity from Khamise and rainfall of Sarat-Abeda which were outside the sector boundaries. These stations were used because there were no weather stations within. Although these stations were chosen because of their close similarity to the weather in TQ, this can cause problems in the analysis if the variations in temperature, rainfall and humidity in TQ are different to those in the two chosen weather stations.

In the results, malaria incidence was compared to temperature across Asir. The results presented little evidence that temperature is an important factor affecting variations in malaria cases. Temperature was significant in some of the original regressions but no temperature variables were significant in the final models. In all cases, other weather variables demonstrated stronger associations with malaria cases.

This lack of association was surprising because the optimum temperature for the vector of malaria (mosquito) to live and breed is 25 to 27 ^{0}C and maximum temperature for both vectors and parasites, is 40°C (McMichael et al., 1996; Hana et al., 2001). In TA the average maximum temperature (Majaredah) reaches over 40^{0}C between May and August. Therefore this high temperature could kill the mosquito, which may provide an unsuitable condition for the transmission of malaria. As temperature is not significant in the models, this suggests that there is a little variability in these high temperatures or that the mosquitoes are able to shelter away from such extremes. Temperature has been shown to be associated with malaria in a study in Jazan Region (Southwest of Saudi Arabia) (Al-Jaser, 2006) which has almost similar conditions to the lowlands of Asir Region. In the literature review many other studies were identified which highlighted the importance of temperature to malaria transmission. Examples are Burkina Faso, (Ye et al., 2007), China (Bi P et al., 2003) and Bangladesh (Alam et al., 2008).

In TA and TQ and in overall Asir, the final model included rainfall only. We therefore conclude that rainfall is the strongest predictor of malaria in the summer period and over the whole year. However, because rainfall was not significant in the models for other times of the year, we conclude that the whole year result is driven by the summer result. The results indicate that less rainfall leads to a lower number of malaria cases. Figure 3.12 shows that rainfall is low during the summer period which may explain why it is not important at other times of the year. At other times of the year there may be enough rainfall for mosquito breeding. It is also interesting to note the strategy of malaria control in Asir (see table 3.3). This shows that no control activities happen between May and July in TQ and between May and October in TA, although the pesticides which are used in the third stage of seasonal spraying (February to end of April), have a residual effect for up to three months. This lack of summer control may be another reason why associations with weather are only observed during this period.

These results are consistent with previous studies that have found that rainfall is one of the weather phenomena which play a significant role in malaria. Biologically, this is plausible as Oaks et al., (1991) mentioned that rainfall is one of the main factors affecting survival of anopheline mosquitoes by helping to provide suitable breeding conditions. Hence, the survival of anopheline (vector of malaria) may lead to an increase malaria cases. Pampana, (1969) discusses that too much rainfall, or rainfall accompanied by storm conditions, can flush away breeding larvae and so reduce survival. There was no evidence of this in the present study. Flash flooding does not usually happen in Asir Region, and the region has a lot of dams which can hold the water for long time. These dams can provide suitable breeding conditions for the vector (Dr A. Abdoon 2007 pers. Comm.). Not only the amount and intensity of rainfall, but also the time of year, whether in the wet or dry season, affects malaria survival. This is seen in this study with rainfall only being important in the dry summer period. Also low amounts of rainfall may not be appropriate for the mosquito as it needs breeding sites (Briet (b) et al., 2008).

The importance of rainfall highlighted in this study is consistent also with other studies the same zone of the world (The Afro-tropical Zone) and in Saudi Arabia. In Sudan, Hamad et al., (2002) showed that, the abundance of mosquitoes in this area was positively related to monthly rainfall. In Ethiopia, Teklehaimanot et al., (2004) noted that rainfall was followed within a short time by an increase in malaria cases. In SW Saudi Arabia an unusual increase of malaria happened at the beginning of 1996 coinciding with heavy rainfall when many valleys were flooded (A1-Abdullatif et al., 1996). In Asir region in 2008 the peak in malaria cases coincided with high unexpected rainfall (MOH, The Statistical Book, 2009). During last three months in 2008 most of Asir Region received high unexpected rainfall which may have led to that increase of malaria cases (Dr A. Abdoon 2007 pers. Comm.).

The time lag used in this study (rainfall in the current and previous month) is also consistent with previous research. Bi P et al., (2003) mentioned that there was a highly positive correlation between monthly rainfall and malaria in Shuchen County, China lagged at one month. In Sri Lanka Briet (a) et al., (2008) found a correlation between malaria and rainfall lagged 0-4 months lag. In Like Bufundi, Kilibwoni, East Africa, a peak in rainfall during April-May was followed by a peak in malaria occurrence one to 2 months later in June (Kristan et al., 2008). The current study in Asir Region is consistent with these studies for the lag time between rainfall and malaria incidence.

The results also indicated that relative humidity appears to be of importance for transmission of malaria as there is some evidence that when the humidity is high, there are more cases of malaria. However, humidity was only significant in the model for all Asir which combines malaria data from all over the region. Due to data limitations it was not possible to test its effect in TA. In TQ it was not significant. The possible importance of humidity is consistent with Al-Jaser, (2006) which found a significant positive correlation between relative humidity and malaria cases in Jazan. Pampana, (1969) noted that if the average monthly relative humidity is below 60%, it is believed that the life of the mosquito is so shortened that there is no malaria transmission. Alam et al., (2008) demonstrated that, the optimal relative humidity for mosquito survival is 60%, and a high relative humidity lengthens the life of the mosquito. In the current study, averages relative humidity were much lower than 60% over the summer which may explain humidity’s importance. In India, Bhattacharya et al., (2006) noted that the average relative humidity range (55 to 80 per cent) remains correlated with malaria transmission.

In summary, this study showed that weather variations factors play an important role in affecting malaria cases in Asir Region during the summer months. At other times of the year, weather variations do not appear important. Rainfall was the most important factor associated with malaria in TA and TQ with greater rainfall in the current and previous month leading to more malaria cases. Relative humidity may also play a role in malaria transmission. Although this study shows that weather has an influence upon malaria in Asir, it is important to recognize that malaria is becoming less of a problem in general but still a significant problem in some endemic areas. Overall, the study shows that the total number of yearly malaria cases has declined sharply, more than 90% from the end of the nineties compared to the end of the study period. The reasons for this were provided in the literature review.

Chapter 4

Influence of Climate Variables upon Leishmaniasis Cases in Asir Region, Saudi Arabia

4.1 Introduction

Leishmaniasis is an important public health problem in several countries and is considered to be the vector borne disease with the second highest number of affected people in the world after malaria (Chaves et al., 2006). It has been estimated by World Health Organization that globally there are 14 million people who are infected, and each year about 2 million new cases occur (WHO, 2009; Faulde et al, 2009). Annually there are over 70,000 deaths (WHO, 2009). This disease is considered the 6th most important endemic diseases in the world by the World Health Organisation (WHO, 2007). In addition to immediate health consequences leishmaniasis is associated with about 2.4 million disabilities globally. One of the most common forms, cutaneous leishmaniasis, is rarely fatal but it can lead to tissue destruction, scarring and serious visible impairment. These can lead to social stigma due to deformation of the face with permanent scarring (Murray et al., 2005; Reithinger et al., 2007; CFSPH, 2009). Other forms can affect the mucous membranes which cause disfiguring nose lesions (mucocutaneous leishmaniasis), or damage internal organs (visceral leishmaniasis) (CFSPH, 2009).

Leishmaniasis is a group of zoonotic diseases transmitted to humans and animals by the bite of phlebotomine sandflies (Figure 4.1). The infective agents are several species of flagellated protozoan parasites (Reithinger et al., 2001). There are more than 1000 known species of sandfly in the world, of which only 70 species are known to transmit diseases such as Leishmaniasis (Murray et al., 2005). Only female phlebotomine sandflies suck blood leading to Leishmaniasis. Male sandflies rarely bites humans and do not transmit this disease. Sandflies transmit other viral and bacterial diseases, but they are particularly the vector of leishmaniasis (Reithinger et al., 2001). Sandflies feed on mammals, birds and both sexes takes sugar meals to maintain their daily activity (TDR, 2002). Sandflies do not make noise when they fly and are also small being around one-third the size of a mosquito. Their bite is also painless (CDC, 2010). This means that people may be unaware of sandflies and their biting.

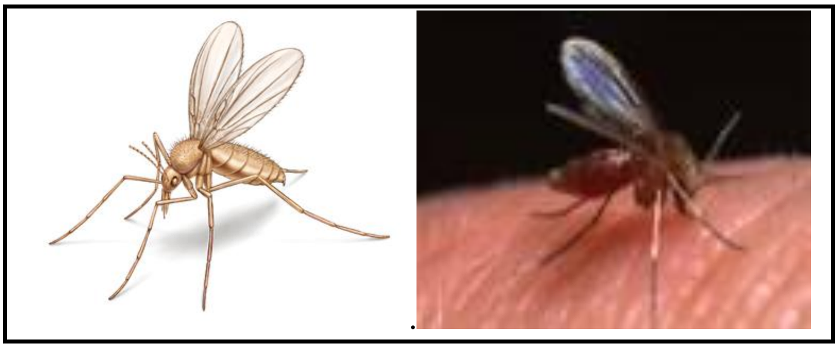


Figure 4.1: *Phlebotomine sandfly (Kamiura, A. and Reforma, L, 2007)*

There are several different clinical forms of leishmaniasis, but the most common are; cutaneous leishmaniasis (CL), visceral leishmaniasis (VL) and mucocutaneous leishmaniasis (MCL) (Figure 4.2). In addition to these three major forms, there are others such as diffuse cutaneous leishmaniasis, recidivans leishmaniasis, and post-kala-azar dermal leishmaniasis (Croft et al., 2006). CL causes skin sores caused by leishmania major. It is common in rural areas with dogs and bush mammals being reservoir hosts. Another cause of CL L tropica is more common in urban areas and leads to CL in humans and dogs. L. Aethiopica also leads to CL with hyraxes being the reservoir hosts (Wittner et al., 2000). One of the most important vectors of CL is Phlebotomus papatasi, a common human-biting sandfly species found all over North Africa, through Eurasia, and into India (Hanafi et al., 2007). VL affects the internal organs of the body such as spleen, liver, and bone marrow and it can be fatal. It is caused by leishmania infantum species and the common vector is phlebotomus sergenti, a known vector of phlebotomus Tropica (TDR, 2002). MCL is a complication of simple CL, and it involves the mucosa, soft tissue and cartilage of the respiratory system (WHO, 2009).

Leishmania transmission is sensitive to weather and climate conditions, and Cross et al., (1996) state that: one of the most important factors in leishmaniasis distributions are environmental conditions such as weather.

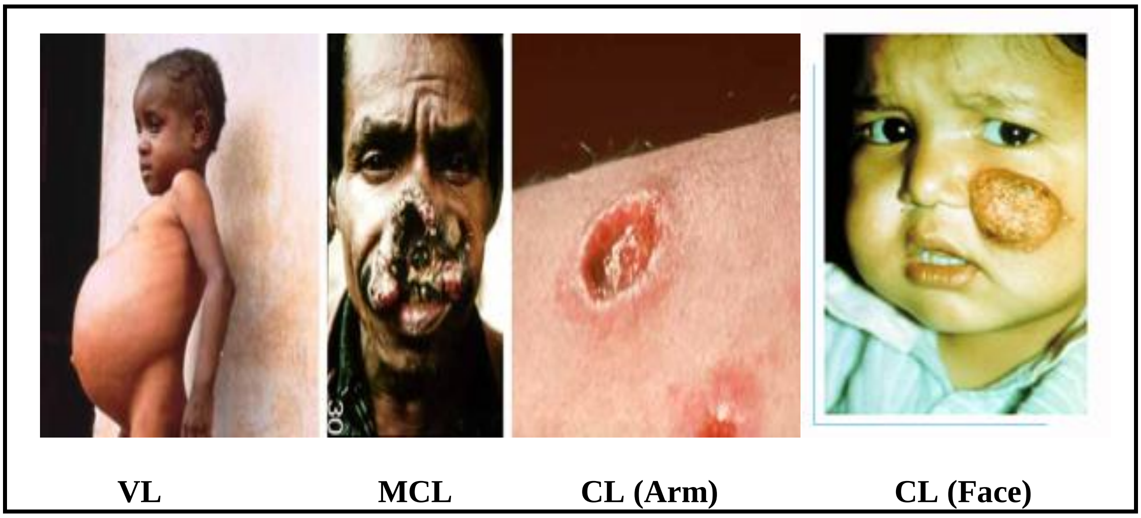


***Figure 4.2**: Clinical presentations of leishmaniasis (Narciso et al., 2007; Kamiura, A. and Reforma, L, 2007)*

This chapter will start by providing an overview of the geographic distribution of leishmaniasis. It will then present information on the transmission of leishmania and its life cycle. How this illness may be prevented and treated will then be discussed. We will then present a literature review of leishmaniasis and how it is related to weather.

The analysis section of the chapter will begin by presenting information on leishmaniasis in Saudi Arabia and how it is currently controlled. The aims and hypothesis for the study will then be discussed. The data sources to be used for the study will then be presented followed by an overview of the methods. The results will then be presented which will analyze statistically the relationships with weather. The chapter will end with a discussion and conclusion.

4.2 Geographic Distribution

Leishmaniasis is distributed in around 90 countries of the world most of which are in the developing countries (16 developed countries and 74 developing countries), and there are approximately 350 million people are at risk of leishmaniasis in these areas (Schriefer et al, 2009; Cardenas et al, 2006). Tropical and subtropical countries are the most affected by this illness (WHO, 2000). The settings in which leishmaniasis is found ranges from rain forests in Central and South America to deserts in West Asia (WHO, 1994).

In terms of the types of leishmaniasis, more than 90% of CL occurs in parts of Afghanistan, Algeria, Iran, Iraq, Saudi Arabia, Syria, Brazil and Peru (CDC, 2008; TDR, 2002), but it is found also in Mexico, Central America, and South America, southern Europe and particularly East and North Africa (WHO, 2007) (Figure 4.3). Currently Kabul is thought to have the highest incidence of CL in the world (76500 - 200,000 cases/year with a population of 3.5 - 5 million) (Reithinger et al., 2005). More than 90% of VL cases are found in India, Bangladesh, Nepal, Sudan, some parts of the Middle East and Brazil (WHO, 2007). Ninety percent of MCL occurs in Central and South America, Bolivia, Peru and Brazil, and in East of Africa (Costa, 2011).

Al-Hammad, (2003) states that the distribution and spread of leishmaniasis across the world is affected by several factors including: topography, population migration, hygiene factors, micro-environmental factors, host factors, occupational factors, weather factors and global warming.

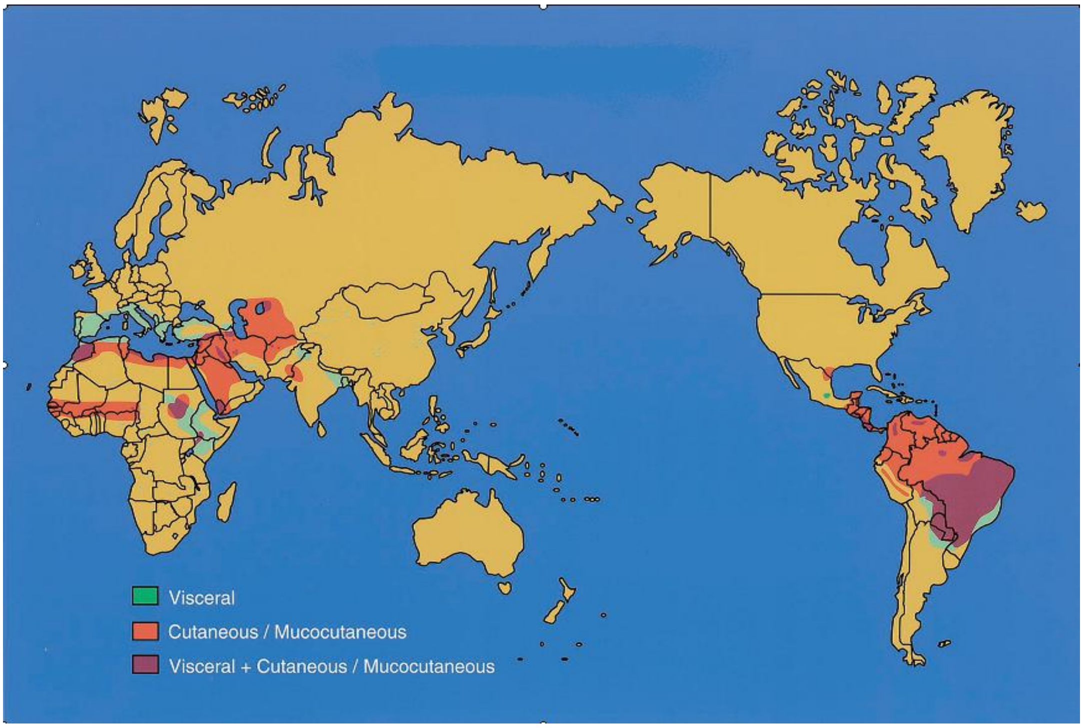


Figure 4.3: *Distribution of CL, MCL and VL in the World (Kamiura, A. and Reforma, L, 2007)*

4.3 Leishmania Transmission and its Life Cycle

Transmission of leishmania is most often zoonotic (transmitted to humans from animals) where an animal is the reservoir hosts (such as dogs and small rodents). In the case of leishmaniasis sandflies act as the vector. It also can be anthropontic where man is the reservoir host and source of infections (TDR, 2002; Rey, 2007). Leishmaniasis in humans and other mammals is caused by 21 of the 70 species of pathogenic sandfly (Al-Amru, 2002). However this is disputed by Reithinger et al., (2007) who state that there are about 40 species or subspecies which are vectors. Another 40 species may also be involved in leishmaniasis transmission.

Figure 4.4 shows the life cycle of leishmaniasis according to the US Centre for Disease Control and Prevention (CDC, 2010). The cycle consists two host stages involving humans and sandflies. It starts when an infected female sandfly (phlebotomine) injects promastigotes into the skin of an animal or person during its blood meal. In the human stages these promastigotes transform into amastigotes and multiply in infected cells inside macrophages. They then affect different tissues depending on the specie of leishmania. In the sandfly stages, an uninfected sandfly takes its blood meal from an infected person or animal and then becomes infected when it ingests the amastigotes. The amastigotes transform into promastigotes and multiply in the midgut of the fly. The promastigotes divide in the midgut and transfer to the mouthparts, where the insect is ready to make another infection and thus the cycle begins again (CDC, 2010; Rey, 2007).

Sandflies are usually most active in twilight, the evening, and night-time hours (from dusk to dawn) and are less active during the hottest time of the day. However, they will bite if they are disturbed, such as when a person brushes up against the trunk of a tree where sandflies are resting (Al-Amru, 2002).

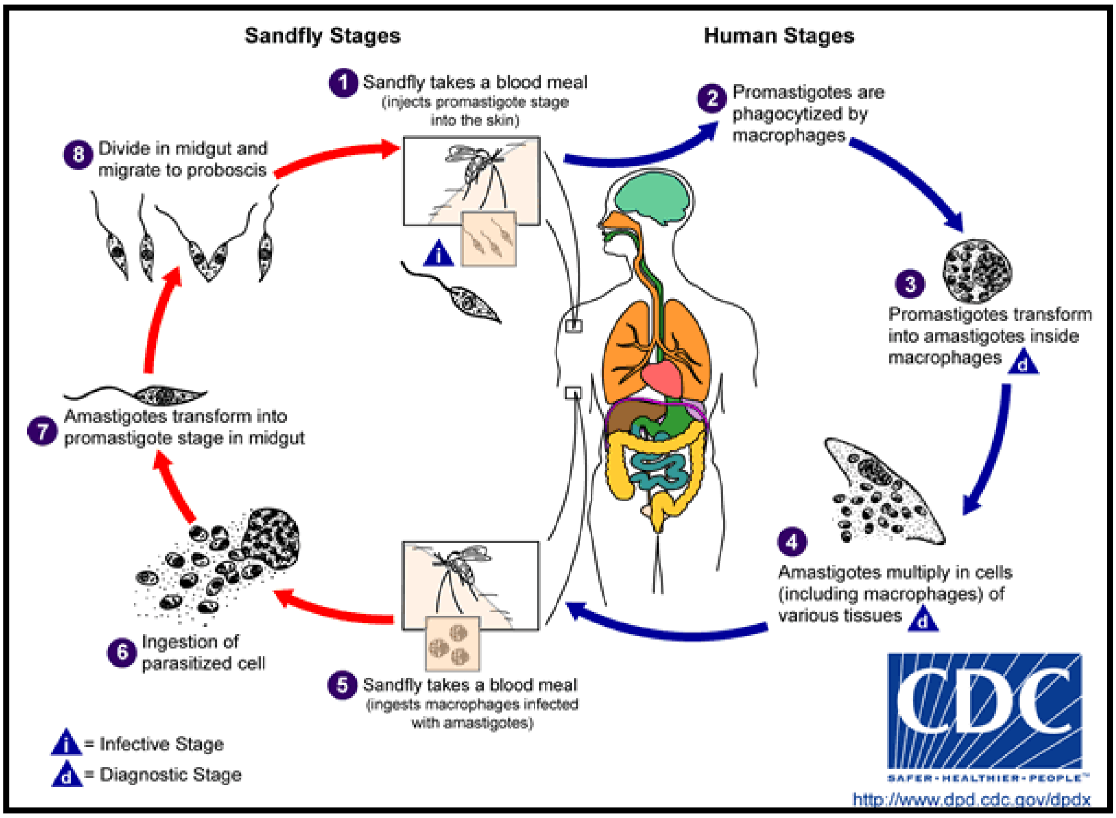


Figure 4.4: *Life cycle of leishmaniasis* (CDC, 2010)

In terms of transmission the female sandfly lays its eggs in the bark of trees, old buildings, in cracks in the walls of houses, in animal houses and in household rubbish. This because it needs the shelter and humidity provided by these environments for egg development. In terms of range the female sandfly covers an area from a few hundred to several hundred metres around its habitat during its search for blood (WHO, 2010).

Gubler et al., (2001) and Hunter, (2003) discuss how changes in temperature may influence the transmission of vector borne diseases. Possible influences include increases or decreases in vector survival, changes to the rate of vector population growth and also changes in feeding behaviour. In addition changes to the susceptibility of vectors to pathogens, alterations to incubation periods and lastly changes in the seasonality of vector activity and pathogen transmission are all possible. Also they mention that rainfall changes can impact the risk of transmission of vector-borne disease. Increased rainfall can increase vegetation and allow expansion in the population of vertebrate hosts whilst flooding may eliminate habitat for both vectors and vertebrate hosts. Finally flooding may force vertebrate hosts into closer contact with humans. Therefore a changing climate is likely to change transmission dynamics in many regions, e.g. increased temperature, abnormal rainfall or higher relative humidity. Leishmaniasis is perceived as the vector-borne disease most likely to be affected by global climate change (Al-Amru, 2002).

4.4 Previous Studies and Relationship between Sandflies or Leishmaniasis with Climate and Weather Conditions

There are only a few studies that look at the direct influence of weather upon leishmaniasis cases. However, there is good evidence of a close linkage between the abundance of sandflies and leishmaniasis cases (Amru, 2002; Al-Tawfiq et al., 2004; Al- Ibrahim et al., 2005). Therefore this section will try to present studies which examine the relationship between the environment and weather conditions with the abundances of both sandflies and leishmaniasis cases. In this section we will try to discuss studies from around the world before focussing upon studies conducted in the Middle east and finally in Saudi Arabia and the study area Asir Region.

4.4.1 Sandflies with Climate and Weather

Cross and Hyams, (1996) through research in Southwest Asia state that one of the most important factors for the distribution of the sandfly species *P. papatasi* (the main vector for leishmaniasis) and hence leishmaniasis distributions are environmental conditions such as weather. Through a review of the literature they state that temperature and humidity play an important role in the lifecycle and development stages of the sandfly. Adults and larvae are sensitive to high temperatures and low humidity. In laboratory experiments, all adult sandflies died within two hours at temperatures above 40°C. However, below this temperature, increasing temperature can shorten the incubation period and life cycle of the fly which could increase disease transmission. Temperatures below 10°C are unfavourable for sandfly survival. However, cold does not necessarily lead to death and under cold conditions as sandfly larvae have the ability to become dormant until conditions improve. In Southeast Asia the colder winter period is absent of sandflies with an increasing population at the beginning of spring. The number of sandfly survivors increase with increased relative humidity (Cross and Hyams, 1996).

Temperature may also affect the daily activity rates of sandflies. In terms of the daily activity, a study of P. papatasi in Iraq demonstrated that biting starts after sunset and increases gradually till the maximum activity in the middle of the night when the temperature is lower and the humidity higher. Biting activity in Central Iraq showed a decrease to 13% at 03:00 hr and stopped after sunrise (Cross and Hyams, 1996).

The researchers predicted the seasonal and geographical distribution of papatasi in this region based on 115 weather stations via an appropriate analysis model. Interestingly this model also simulated the effect of global warming. Currently leishmaniasis was endemic at 62% of the weather stations. However, under climate change they predict that a further 12% of stations could become endemic if the temperature increase by 1°C. An additional 15% of stations would become endemic if the increase was 3°C. If the increase is 5°C the additional percentage will be 10%. In addition to changes in endemic stations they also conclude that seasonal disease transmission could be extended throughout all months of year in 6% of locations with a 3°C rise in temperature. This figure will increase to 25% with a 5°C rise (Cross and Hyams, 1996).

Moving away from South East Asia, in Pondicherry, India Srinivasan et al., (1993) studied the population dynamics of P. papatasi. They selected three villages to monitor the density of sandflies for the period from March 1988 to February 1990 in different seasons; summer which is from March to June, rainy from July to October and winter from November to February. The findings showed a positive correlation between daily survival of sandflies and relative humidity and a negative correlation with temperature. The high temperature and low relative humidity during summer may have affected the survival of sandfly. The declining trend of sandflies population was observed in winter, when the temperature was low, and also during summer, when temperature was high. Rainfall was found to have a significant influence on the density of sandflies as the rainfall in June and July was followed by increase in the population of sandflies till October. However, a sudden decrease in sandfly numbers was observed in November and December which, the author’s state may have been due to heavy rain destroying breeding sites.

In Rajasthan, India Singh, (1999) investigated the role of climatological factors in the seasonality of phlebotomine sandflies. They found a total of eight phlebotomine species in houses. The phlebotomines were found only at temperatures between 17 and 36°C. However the optimum temperature distribution varied with species. For example the optimum range for *P. papatasi* was from 28 to 34°C, *P. sergenti* from 31 to 33°C. The species *Sergentomyia* are also vectors of leishmaniasis and the optimum range for *S. punjabensis* is from 27 to 30°C, *S. babu* from 28 to 33°C, *S. baghdadis* from 27 to 34°C and *S. christophersi* from 29 to 33°C. The maximum phlebotomine prevalence (39.4%) was recorded in September when the average temperature and RH were 32.1°C and 58.1%, respectively. The minimum phlebotomine prevalence was found in January (1.2%) having an average temperature of 20.8°C and 46.3% relative humidity. This result suggested that these species are well adapted to the conditions of high temperatures and low RH. The statistical analyses noted that temperature has a positive significant correlation with phlebotomine abundance.

In the Cukurova Plain, Turkey, Kasap et al., (2009) found that the maximum abundance of sandflies was recorded in the hottest season (26.9 to 31.2 °C) and also in the driest season when the relative humidity was comparatively low (46.6 to 56.8%) during the period from June to September. In terms of relative humidity the study contradicts with Cross et al., (1996) who state that the number of sandfly survivors increases with increased relative humidity. This contradiction could be due to different locations and also the fact that the increase in humidity occurs at the same time as high temperatures which are favourable to sandfly survival.

In Morocco, leishmaniasis is endemic and widespread throughout the country and is considered a serious public health problem (Guernaoui et al., 2006). Seasonal fluctuations of sandfly populations in the urban area of Marrakech, Morocco were studied by Boussaa et al., (2005). Sandflies in this area were collected, between October 2002 and September 2003. They found that the sandflies were active throughout the year, but that the major activity was in two periods: The first was in October and November with a peak on November and the second one, which had higher activity, was during the months of April–July with a peak in May. The maximum and minimum monthly temperatures in the two periods were between 23 and 36°C, and 11 and 19°C, respectively. The study suggested that male sandflies were more sensitive to temperature than females. They concluded that the seasonal patterns related to environmental factors such as topography and climate variables and specifically temperature in this study.

The relationship between sandflies and altitude in the High-Atlas Mountains of Morocco was studied by Guernaoui et al, (2006). Sandflies were captured from 25 stations at various altitudes (400–1400m). It was noted that altitude can play a role in terms of the distribution of sandfly species and the density of each vector. The highest abundance for *P. papatasi* was at (400-599m) and the lowest at more than 1199m. However, the highest density for *P. perniciosus* was at (1000-1199m) with the lowest at (400-599m). It showed there were fewer of all species at altitude over 1199.

In a study carried out in Iran between May 1995 and May 1996 Yaghoobi et al., (1999) noted that the activity of P. papatasi starts from the last days of April or early May and extends to mid October. They found two peaks in abundance one in mid or late June and the second one in early or mid September. There was a decrease in sandfly density at the end of October which they attributed to the rains which can destroy or damage the breeding sites (Hunter, 2003). This decrease remained until the end of March which was attributed to the cold weather. There were no sandflies found in the area between November and March. Another study in the centre of Iran (Yaghoobi et al., 2001) demonstrated that sandflies in this area started to appear in late May and disappeared at the end of October. There are two peaks in the density curve of P. papatasi, one in late May or June and the second at the end of September as the active season in this time. A decrease of sandfly density was observed in the end of October and the researchers thought it is due to the rains. Also due to cold weather there was no sandflies during November to March.

The sandfly species pattern was studied in some parts in Argentina by Salomon et al., (2008). This study reports that the epidemic risk may be associated with climate. The activity season of the most abundant sandfly species begins from March to April (autumn), with its highest peak in November (spring). However during dry and cold weather in winter, only a few flies were found. The abundance of these species increased during the rainy season and decreased during the months of lower rainfall or higher temperatures.

Molina et al., (2008) found that in Colombia the seasonal density of the most abundant sandfly species were correlated with the average monthly rainfall, maximum temperature, and relative humidity. The mean monthly density of this species increased during the rainy months from April to October and decreased during the months without rainfall (January to March). A multiple linear regression between the most abundant species and rainfall, maximum temperature, and relative humidity showed a positive significant correlation for these species (P=0.001, 0.003 and 0.002 respectively).

4.4.2 Leishmaniasis with Climate and Weather

In a study of the seasonality transmission of leishmaniasis carried out in the state of Campeche, Mexico between February 1993 and March 1995. Narvaez et al., (2003) report that leishmaniasis transmission occurs from November to March. They concluded that the winter season with its high humidity and low temperature have ideal ecological conditions for transmission. If the incubation period (approximately 3 months) is taken into account the total number of leishmaniasis cases peak between March and July. Very few cases are reported between June and November.

In North-eastern Colombia, Cardenas et al., (2006) studied impact of climate variability in the occurrence of leishmaniasis. This study focuses on the impact of the El Nino Southern Oscillation between 1985 and 2002. During El Nino (dry seasons) in 1987, 1992–1994, 1997, and 2002, leishmaniasis cases increased, however during La Nina (wet season). In 1988–1989, 1995–1996, and 1998–2001 the number of cases decreased. The study concluded that there is evidence linking leishmaniasis to climate variables, and suggested that annual changes in weather conditions play an important role in varying the incidence of vector borne diseases including leishmaniasis. They also conclude that the occurrence of drought followed by rainfall is likely to increase leishmaniasis incidence. This is because drought can lead to waning immunity in humans and a consequent increase in cases when transmission conditions become favourable (Cardenas et al., 2006). This is supported by Gage et al., (2008) who state that the decrease in transmission in endemic areas after a reduction in rainfall may actually increase the occurrence of the disease due to a decline in the immunity of the populations in this area.

In the state of Bahia, Brazil, rainy seasons following the El-Nino led to increases in both the densities of sandfly and subsequent infection rates of leishmaniasis in high-risk populations (Franke et al., 2002). The authors state that the lag between leishmaniasis cases and the rainy season is around 2-6 months. In addition the time from the beginning of symptoms to diagnosis approximately is 3 months. This study also reported that the number of positive cases increased for 2 years following droughts associated with El Nino. One result of these droughts was low vector densities which led to reductions in the immunity of the susceptible humans and lower sandfly populations in endemic areas.

Faulde et al., (2008) studied a CL outbreak in Mazar-e Sharif, northern Afghanistan. Case leishmaniasis data (Anthroponotic Cutaneous leishmaniasis ACL and Zoonatic ZCL) were collected in this area from March 2004 to March 2006. ACL is caused by Leishmania Tropica and mainly transmitted in this area by the sandfly Phlebotomus sergenti. ZCL is caused by Leishmania major. More than 95% of the CL cases were ZCL while less than 5% were ACL. The peak transmission of ZCL was in August and September and is correlated with dry and hot season. ACL transmission usually starts in November with the first case in December and it may be positive associated with the cold and wet winter. The result showed that ACL is endemic in this area with peak during February and March. There were no cases reported from September to November. The incubation period varies between leishmaniasis types and for example ACL the period was found to be 4 - 6 weeks. However it is 8 - 12 weeks for ZCL.

Cross et al., (1996) used weather data to predict the seasonal, geographic and distribution of *P. papatasi* in SW Asia. They hypothesised that the distribution of *P. papatasi* might be highly dependant on the temperature and relative humidity (environmental conditions). They designed a computer model with the occurrence of sandfly as dependent variables and temperature and relative humidity data as independent variables. They found that the greatest activity of sandfly may lead to a high risk of leishmaniasis infection during the months of spring and summer with positive association. As an extension to this study the researchers (Cross et al., 1996) studied the potential effect of global warming on the geographic and seasonal distribution of this species of sandfly. They found that higher temperatures could greatly increase both the geographic and seasonal distribution of sandfly. The geographic distribution may also extend to nearby areas where the sandfly populations are currently too small to maintain endemicity.

CL in some parts of Yemen was studied by Khatri et al., (2004). They suggest that altitude plays a big role in the distribution of CL as the majority of patients originated from the plateau and mountainous range (1800–2000m) of Hajjah city and a few patients from the adjacent regions.

4.4.3 Sandflies of Leishmaniasis with Climate and Weather in Saudi Arabia

In Saudi Arabia much research on sandflies and leishmaniasis has been carried out. Al-Amro., (2002) studied the geographical distribution of 24 sandfly species in Saudi Arabia and also the relationship between the seasonal insect density and the number of leishmaniasis cases. It demonstrates that Riyadh, Qasime (Central regions) and Alahsa Regions (Eastern Saudi Arabia) have the highest case numbers of CL. Jazan and Asir Regions have the highest case numbers of VL. The researchers report that the Asir Region, where this study will be focussed, has around 13 species of sandfly including *P. papatasi, P. bergeroti, P. chinesis P. arabicus*, *P. orientalis*, *P. saevus* and *P. sergenti*. The study also report that the highest daily activity period of the insects vary by species but that almost twilight is the best time especially if the weather condition are suitable (windless and cloudy).

The Ministry of Health in Saudi Arabia, 2000 reports a highly significant correlation between the density of sandfly and positive cases of CL. However, the lag between sandflies and illness is between two and five months, because the illness will occur after an incubation period following a sandfly bite (MOH, 2000). This lag depends upon the species of sandfly and on the environmental conditions. They also state that significant under-reporting of cases occurs as some patients do not go to any medical centre for treatment as they treat themselves. Other cases are only seen by medical centres when the disease has reached advanced stages.

El-badry et al., (2009) studied the distribution of sandfly in four surrounding areas of Al Madenah Region (Al-Nekheil), Saudi Arabia. The average temperature is high over summer and moderate during winter (August mean 38°C and January mean 25°C and). They collected 621 sandflies, from March 2006 to November 2007, and found six species of sandfly; *papatasi* represented more than 70% of the sandfly population. They noted that there is an increase of this insect from May to September due to the weather conditions.

An epidemiological study of CL over 46 years in eastern Saudi Arabia (Al-Tawfiq et al., 2004) presents evidence that the seasonal pattern of the disease correlates with the known activity of the lag time from a person being bitten to the development of skin lesions to the presentation of patients to physicians. There was a peak of sandfly activity in April and September followed by a peak of CL cases in September and January, and this lag explains the differences of these peaks.

One of the most important research studies on the vector of leishmaniasis in Asir Region was conducted by Ibrahim et al, (2005). A total of 1896 sandflies were collected from 3 topographically different zones during June 1999 to May 2001. They note that altitude has an effect on sandfly, as they found the density of the insect was higher in the lowland (foothills) compared to the highland (mountains). This may indicate that the activation of this insect and their development stages (eggs – larva - pupae – adults) prefer warm lowland conditions. Low temperature, fog and strong winds in the highlands may make these areas unsuitable for sandflies. This study indicated that the highest abundance of sandflies was recorded during spring and summer, and the lowest density was during November to February. They suggest that this is due to the low temperature, high relative humidity and strong winds during winter.

4.4.4 Literature Review Summary

Table 4.1 summarises the main studies (statistically) of the correlation between leishmaniasis or its vector and climate variables.

Table 4.1: *Summary of the main studies relating to leishmaniasis*

No	The author	Place	Dependent Variable	Independent Variable	The relationship & Lag time (month)
1	Cross and Hyams, 1996	Southwest Asia	density of Sandfly	Temperature Humidity	Positive
2	Srinivasan et al., 1993	Pondicherry, India	density of sandflies	Temperature Humidity Rainfall Rainfall	Negative Positive Positive 2-4 Negative 5-7
3	Singh, 1999	Rajasthan, India	phlebotomines	temperature	Positive
4	Kasap et al., 2009	Cukurova Plain, Turkey	abundance of sandflies	Temperature Humidity	Positive Negative
5	Guernaoui et al., 2006	Morocco	abundance of sandflies	Temperature	Positive
6	Yaghoobi et al., 1999	Iran	density of sandflies	Temperature	Negative
7	Salomon et al., 2008	some parts in Argentina	abundance of sandflies	Rainfall Temperature	Positive
8	Molina et al., 2008	Colombia	density of sandfly	Temperature Rainfall Humidity	Positive Positive 1-6 Positive
9`	Cardenas et al., 2006	North-eastern Colombia	leishmaniasis cases	Rainfall	Negative
10	Narvaez et al., 2003	Campeche, Mexico	L. incidence	Temperature Humidity	Negative 3 Positive 3
11	Franke et al., 2002	Bahia, Brazil	Number of leishmaniasis cases	Rainfall	Positive 2-6
12	Faulde et al., 2008	Mazar-eSharif, Afghanistan	Number of leishmaniasis cases	Temperature Rainfall	Negative Positive
13	Al-Amro., 2002	Saudi Arabia	Number of CL cases	density of sandfly	Positive 2-5
14	Al-Tawfiq et al., 2004	eastern Saudi Arabia	Number of CL cases	density of sandfly	Positive 1-5
15	Ibrahim et al, 2005	Asir Region, Saudi Arabia	Density of sandfly	Temperature	Positive

The literature review highlights a number of important points:

1. A wide range of study designs have been used to investigate the relationships between leishmaniasis and weather. These range from purely observational (e.g. more leishmaniasis in summer), but very few conduct statistical analyses of leishmaniasis cases and associations with weather.
2. Numerous different climate variables have been used in previous studies including temperature, rainfall, wind and relative humidity.

3. Most, but not all studies, showed that climate variables have an impact upon CL incidence. However, the impact of specific climate variables can be either positive or negative depending upon the geographical setting and season.
4. Lagging the weather variables is an important feature of these studies. Studies in Saudi Arabia suggest a 2-5 month lag between weather and cases. This lag also depends on the type of leishmaniasis.
5. Many studies support these findings by showing that weather influences the abundance of the leishmaniasis vector (sandfly). Others found that the vector abundance has an effect upon the incidence of leishmaniasis.
6. Weather conditions are not the only factor which can affect Leishmaniasis. There are many other factors such as ecological and environmental conditions, social and economical determinants.
7. There have been few studies in Saudi Arabia focusing upon the influence of weather upon this disease.

Based on the previous studies, it is clear that there is an urgent need to study the influence of weather variables upon the presence of CL in Saudi Arabia, and in endemic areas such as Asir Region. The previous studies appear very location specific and so the results cannot be easily translated to Asir. Within Asir this also means that different models may have to be produced for different geographical areas. Building upon the literature review such a study should examine a wide range of weather variables and also consider that any relationships with weather may vary seasonally. Variables will need to be lagged to account for incubation periods and reporting lags. A statistical analysis seems the most appropriate study design and this may need to consider factors such as autocorrelation in these data. Few previous studies have conducted a rigorously statistical analysis of CL.

4.5 Sandfly and Leishmaniasis in Saudi Arabia

There are two main species of leishmaniasis in the country; CL and VL (Al-Amru, 2002). The Ministry of Health (MOH, 2006) showed that there were 3980 cases of leishmaniasis (CL and VL) in Saudi Arabia in 2005 and 4165 cases in 2004. Alkhawajah, (1998) states, that the most common manifestation of leishmaniasis in this country is CL. It is found all over the country but there is a great variation in the prevalence rate between different regions (MOH, 2008). In terms of geographical distribution of CL during 2007 the region of Qaseem had the highest percentage of cases (25.9%) followed by Al-Ahsa (24.9%) and Madinah (18.8%). No cases have been reported in Northern region, Al-Jouf, Qurayyat and Qunfedah Regions (MOH, 2008). VL occurs in some parts of the south and south east of Saudi such as Jazan, Asir and Albahah Regions with a few cases in the rest of Saudi (Al-Amru, 2002).

The seasonal variation in CL in Saudi Arabia is presented in Figure 4.5. This figure demonstrates a peak of CL during the winter (December to March) and these four months account for 37 % of the total cases occurring each year. Another small peak occurs between July and October. The least number of cases was reported in May representing less than 4% of the annual total. During the period 2002-2006 the annual cases of CL were 4454, 3842, 4123, 3883 and 3602 respectively. In 2007 the incidence of CL was 13.9/100,000 population while it was 15.2/100,000 population in 2006 (MOH, 2008).

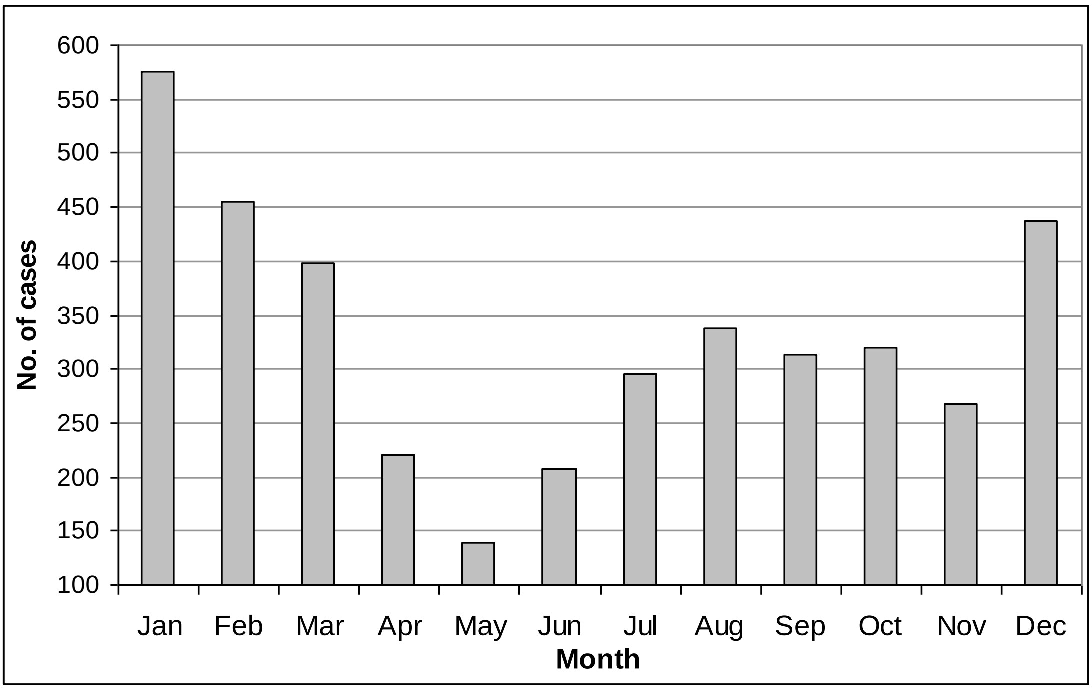


Figure 4.5 *Monthly averages of CL cases in Saudi Arabia (2002-2006)*

In terms of trends over time Figure 4.6 presents the number of CL cases in Saudi Arabia from 1983 to 2009. This figure shows a dramatic decrease of cases through out the last two decades, and cases are now less than a quarter of their levels in the 1980’s.

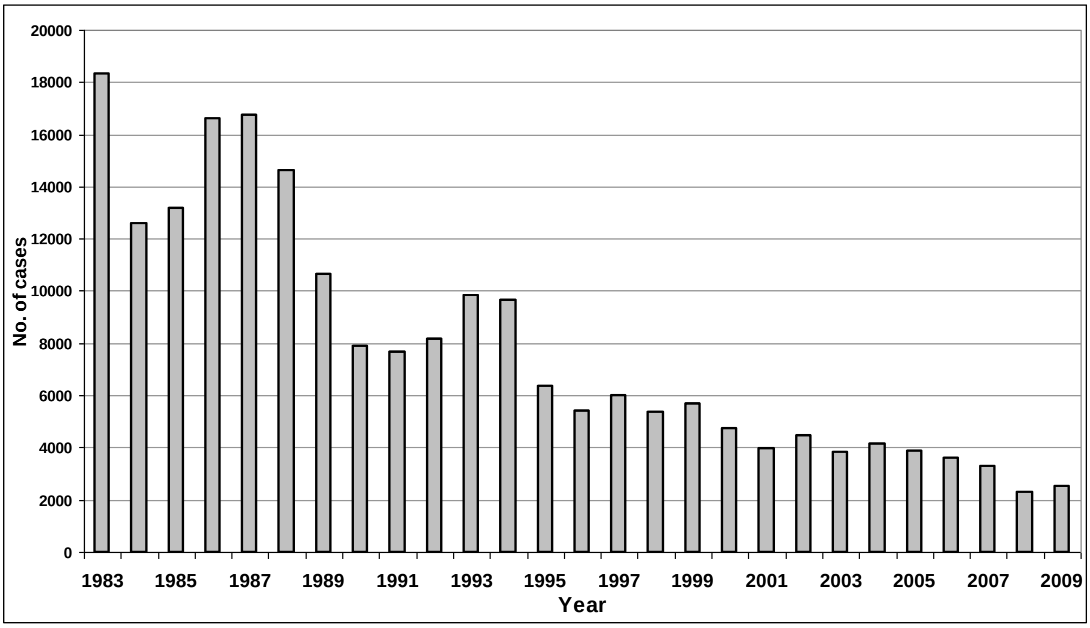


Figure 4.6: *The number of (CL) cases in Saudi Arabia (1983- 2009) (MOH, The Statistical Books 2000-2009; MOH, 2006)*

There are only a few studies on the vector sandfly abundances in Saudi Arabia and one study has investigated the relationship between altitude and density of sandfly in this country. This is presented in Figure 4.7. This figure shows that the highest density of sandfly was for *P. papatasi* specie at 500 – 750m altitude followed by *P. sergenti* at the same altitude, then *P. orientals* at 1750 – 2000m. In the highest altitudes (>1750m) *P. orientals* and *P. arabicus* are the most common sandfly species.

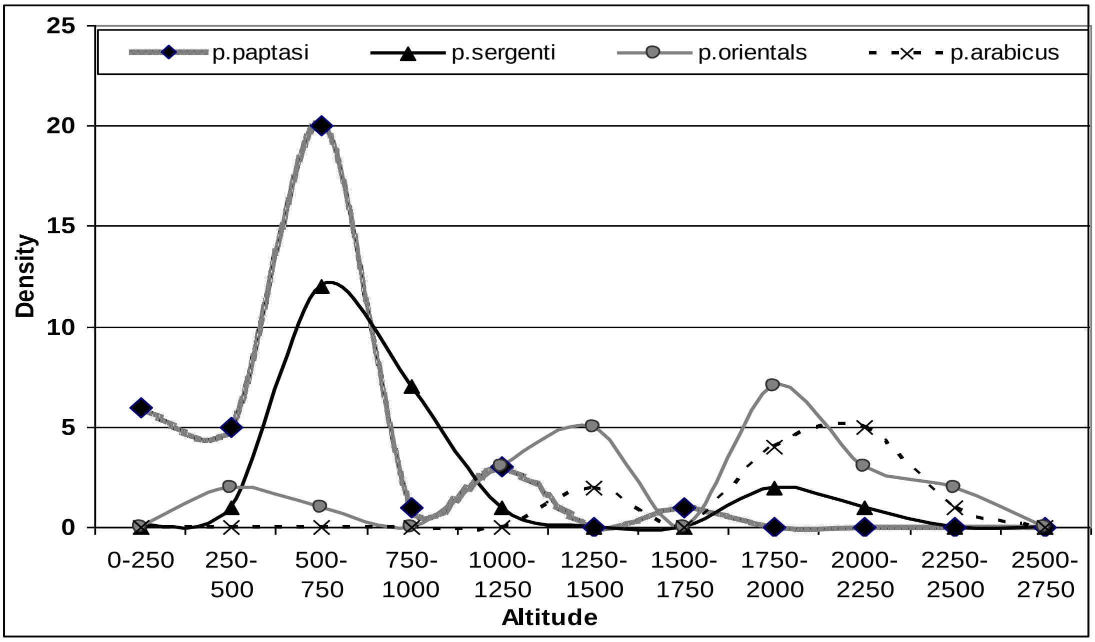


Figure 4.7: *The relationship between altitude and density of some species of sandfly in Saudi Arabia. Adapted from (Buttiker et al., 1983; Al-Amru, 2002)*

In terms of the relationships between sandfly numbers and leishmaniasis Figure 4.8 plots the result of both the density of sandfly and positive cases of CL in Al-Dereya city (20 km from Riyadh) during October 1997 to February 1999 (Al-Amru, 2002), however, it shows no association between sandfly numbers and CL.

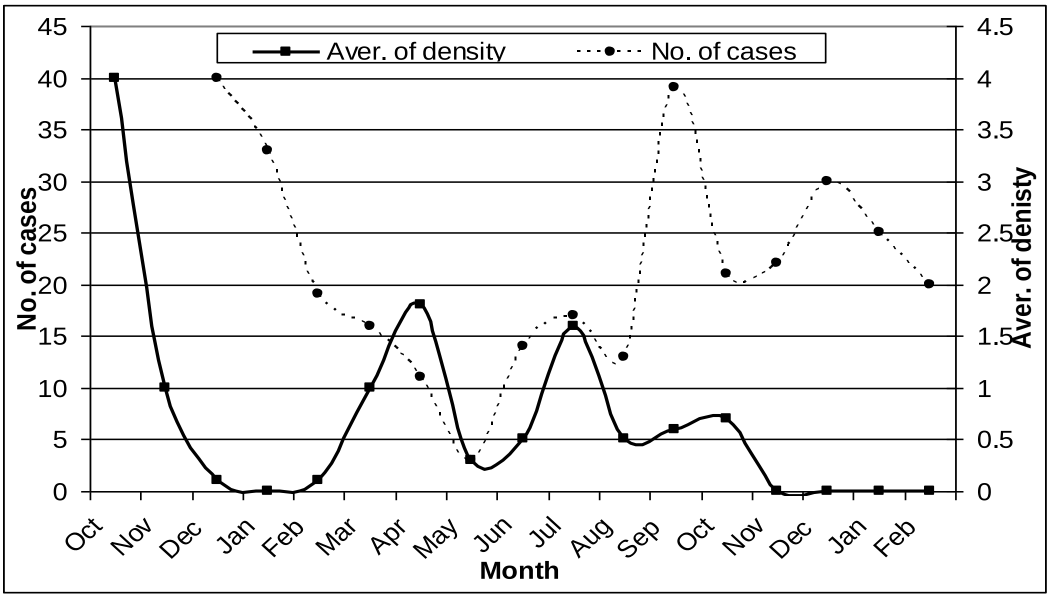


Figure 4.8: *The correlation between density of sandfly and the number of CL cases in Al-Dereya City, Saudi Arabia. Adapted from (Buttiker et al., 1983; Al-Amru, 2002)*

4.6 Leishmaniasis in Asir Region (Study Area)

This study will occur in the Asir Region which is located in SW Saudi Arabia. During the period of this study (1996 – 2007) there were few VL cases in all Asir Region (Table 4.2). Therefore this study will focus upon CL. This is more common in this region (see previous section) and occurs on the foothills and high plateau of Asir Region (Ibrahim et al., 2005). The distribution of this illness is influenced by little known geographical and climate factors (Al-Zahrani et al., 1989).

Table 4.2 *Number of visceral leishmaniasis cases in all Asir Region (1996-2007) (VCA, MOH)*

Year	96	97	98	99	00	01	02	03	04	05	06	07
No. of cases	14	5	4	4	8	13	10	3	3	2	3	3

4.7 Topographical Classification of Asir Region and Endemic Areas

Topographically, climatically and endemically this region can be divided into three main sectors for CL (Dr A. Abdoon 2007 pers. Comm.; MEPS, 2007; Gaafar et al., 1997) (Figure 4.9 and 4.10):

1. Asir Sarawat Mountains (became a part of Highlands Group): A series of high mountains extending from the north of Asir Region to the south along the coastal plains of the Red Sea (2000 -~3000m above sea level). This area covers districts such as Abha, Khamise, Tanoma and Dhahran. The annual average temperature for this sector is 17.7$^{\mathbf{0}}$C, average rainfall is 500mm (the highest rainfall in Saudi Arabia), and annual average relative humidity of 53.1%. These areas have the highest occurrence of leishmaniasis in Asir Region, and *P. arabicus* specie is the main vector.
2. Asir Plateau (became a part of Highlands Group): In the NE Asir with an elevation range of between 1000 and 2000m, decreasing to the east. This area covers districts such as Tathlith, Bishah and Tareeb. The annual average temperature for this sector is 19.5$^{\mathbf{0}}$C, with 250mm annual rainfall and an annual average relative humidity of 44.4%. This sector has many wadies which all flow eastward. It has little leishmaniasis incidence and *P. arabicus* specie is the main vector.
3. Tehama (Lowlands Group became a part Tehama): Receives an annual rainfall of more than 350mm, and temperature ranges between 25$^{\mathbf{0}}$C and 49$^{\mathbf{0}}$C, and the relative humidity varies from 55% in summer to 70% in winter. This area can be divided into two sections:
   a. Foothills such as Al-Majaredah, Muhail and Rejal-Alma, where the altitude is between 300 and 900m. This area has the highest occurrence of leishmaniasis after the highlands in Asir Region and *P. papatasi* specie is the main vector.
   b. Red Sea Costal Plain (RSCP) such as Al-Gahma, Al-Berk, Al-Huraidah. The altitude in this area is between 0 and 200m. The lowest leishmaniasis occurs in the region, and *P. papatasi* specie is the main vector.

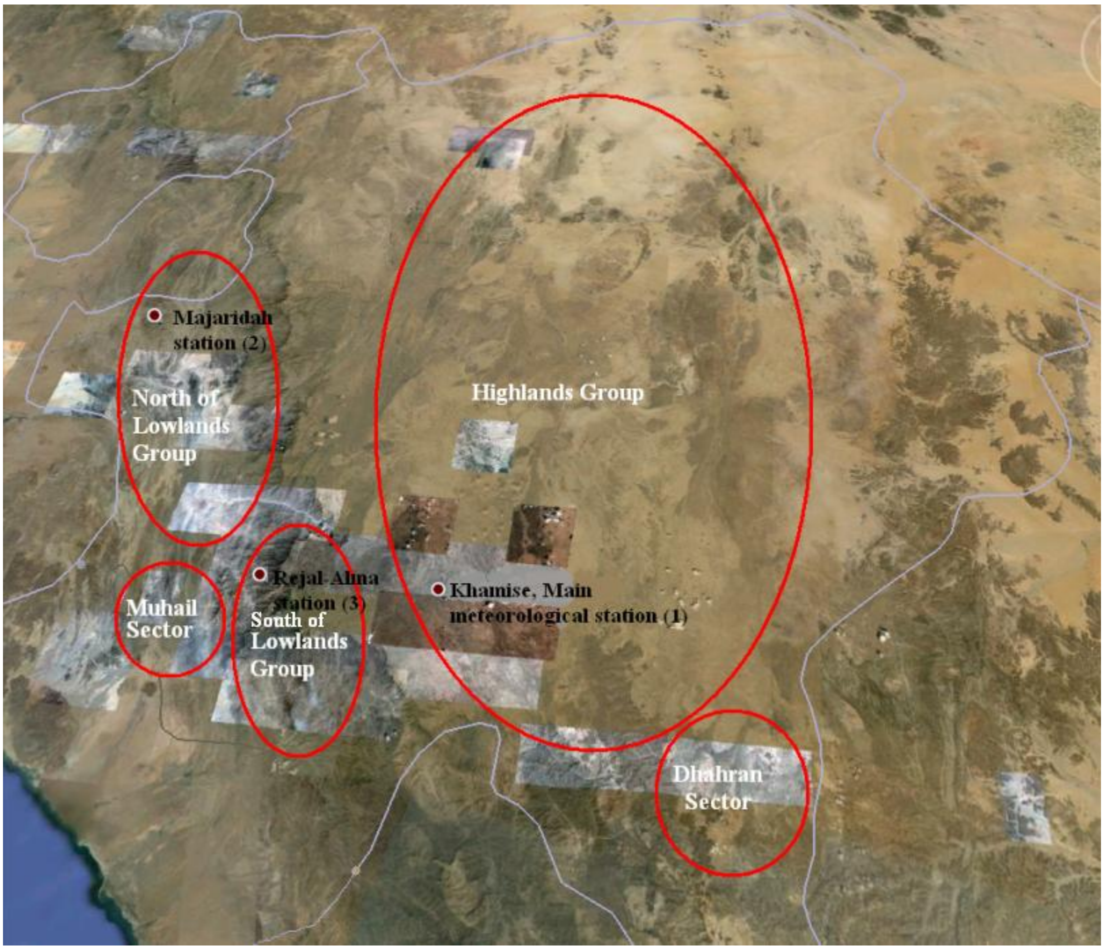


Figure 4.9: *Topographic map of Asir Region including weather stations*

4.8 Control of Leishmaniasis Transmission in Asir

The control methods against leishmaniasis can act to control the vector, the host (reservoir) or human behaviours which bring people into contract with the vector. The World Health Organisation has set up regional programmes to improve health systems to allow access to innovation (WHO, 2009). The control of leishmaniasis can be reached by breaking the transmission cycle of an agent (Al-Hammed, 2003). WHO, (2007) recommends two main interventions to control the vector; spraying insecticide indoors and use of insecticidal nets (Bed nets). Control of sandfly may occur inadvertently through other interventions. For example in 1950s and 1960s DDT was used in some part of the world for malaria control and was thought to have markedly reduced the sandfly population as well (Al-Hammed, 2003). A variety of insecticides can be used to control sandfly including DDT, Malathion, Propoxus, Fenitrothion, and synthetic pyrethroids. Insecticide control can be effective for adults of sandfly, pupae of sandfly and larva (Al-Hammed, 2003). The activity of sandflies play an important role in determining the period of maximum risk of leishmaniasis transmission and hence when control programmes are necessary (El-badry et al., 2009). In addition to the control of the vector, there are other control methods for the disease, such as control of reservoirs, protection of people and health education (Al-Hammad, 2003).

Malaria control programmes, based on indoor residual insecticide spraying have had a side benefit for leishmaniasis incidence (Farrell, 2002). Saudi Arabia has adopted an appropriate programme for the control of both diseases; malaria and leishmaniasis (Ref. Section 3.9). Therefore the malaria programme has had an impact upon the incidence of leishmaniasis particularly in Asir and Jazan Regions (Dr A. Abdoon 2007 pers. Comm.). In Asir region, the MOH has a strategy for the control of disease vectors in each endemic area. This strategy depends upon several guidelines (Al-Hammad, 2003; MOH, year statistical book, 2006; Dr A. Abdoon 2007 pers. Comm.):

a. Spraying of the breeding foci of vector to control the larva. This method is widespread all over the endemic areas of Saudi Arabia and starts at the onset of sandfly activity.
b. Spraying the houses (deep cracks in walls, dark corners and humid areas) caves, rodent burrows, garbage areas and abattoirs with insecticides that additionally have a residual effect.
c. Control of carrier animals and rodents.
d. Mechanical control method, which can involve the use of various nets to protect against the vector (sandfly). Examples include bed nets, fine-mesh netting for windows and doors, and use of insecticide treated nets.
e. Widespread distribution of nets impregnated with insecticides.
f. Health education programmes in schools and gathering places to educate people how to protect their selves from this disease.
g. Collaboration through cooperative agreements with local and central health departments, academic institutions and other governmental or private-sector organizations related to public health.

4.9 Chapter Rationale and Hypotheses

The influence of weather upon CL cases is important to understand for a number of reasons:

1. Based on the findings of this study and an understanding of how CL is affected by weather it should be possible to design an early warning system to predict incidence. This would be useful for health service planning, for example identifying periods when enhanced insecticide spraying is required.
2. If weather alters under climate change then this data could help predict the impact of this change on CL in Asir Region.
3. It can help clarify the important modes of transmission in the region.
4. It improves our understanding disease transmission dynamics (Boussaa et al., 2005).

This study tests the hypotheses that there are relationships between weather (maximum, mean and minimum temperature, rainfall and relative humidity) and CL cases in Asir Region.

4.10 Data and Method

4.10.1 Sources of Data

Official letters were issued, instructing authorized personal to collect health and weather data. The numbers of CL cases in each month from the first of Jan 1996 to the end of Dec 2007 for the whole of Asir Region were obtained from the Vector Control Administration, Health Affairs Directorate in Asir. This department represents The Ministry of Health in this region. The data represents all reported cases of CL in Asir region and has been collected from every hospital and primary health care centres (public or private) and the Main Parasitology Laboratory in Abha (Annual reports of the Vector Control Administration, Health Affairs Directorate in Asir, 1996- 2007, VCA, MOH). A case of cutaneous leishmaniasis is a person showing clinical signs (skin or mucosal lesions) with parasitological confirmation of the diagnosis by positive smear or culture. For each case the sector where it was reported was known, as well as the month that the sample was reported and analysed. This however, presents a number of issues. Firstly, because we only have the reporting sector and not the address where the patient lived, it is possible that the person acquired CL outside that sector. This is likely to be the case with the Main Parasitology Laboratory in Abha which collects data from across the whole region.

Once the CL data was collected the aim was to obtain corresponding weather data for each district within Asir. However, this proved impossible due to the limited availability of data for many districts within Asir. Weather data (maximum, mean and minimum temperature, rainfall and humidity) were collected from Khamise city. This city is the second main city in the region, and covers the largest occupied sector in the middle of the region (MOH, 2006). These data were obtained from The Centre of Information and Documentation in the Meteorological and Environmental Protection section of the Ministry of Defence and Aviation in Saudi Arabia. Other weather data for the lowlands were obtained from Majaredah (maximum and minimum temperature for 132 out of 144 months) and Rejal-Alma (rainfall for 132 out of 144 months) from the Ministry of Water and Electricity. All locations of weather stations in Asir Region are illustrated in Figure 4.9.

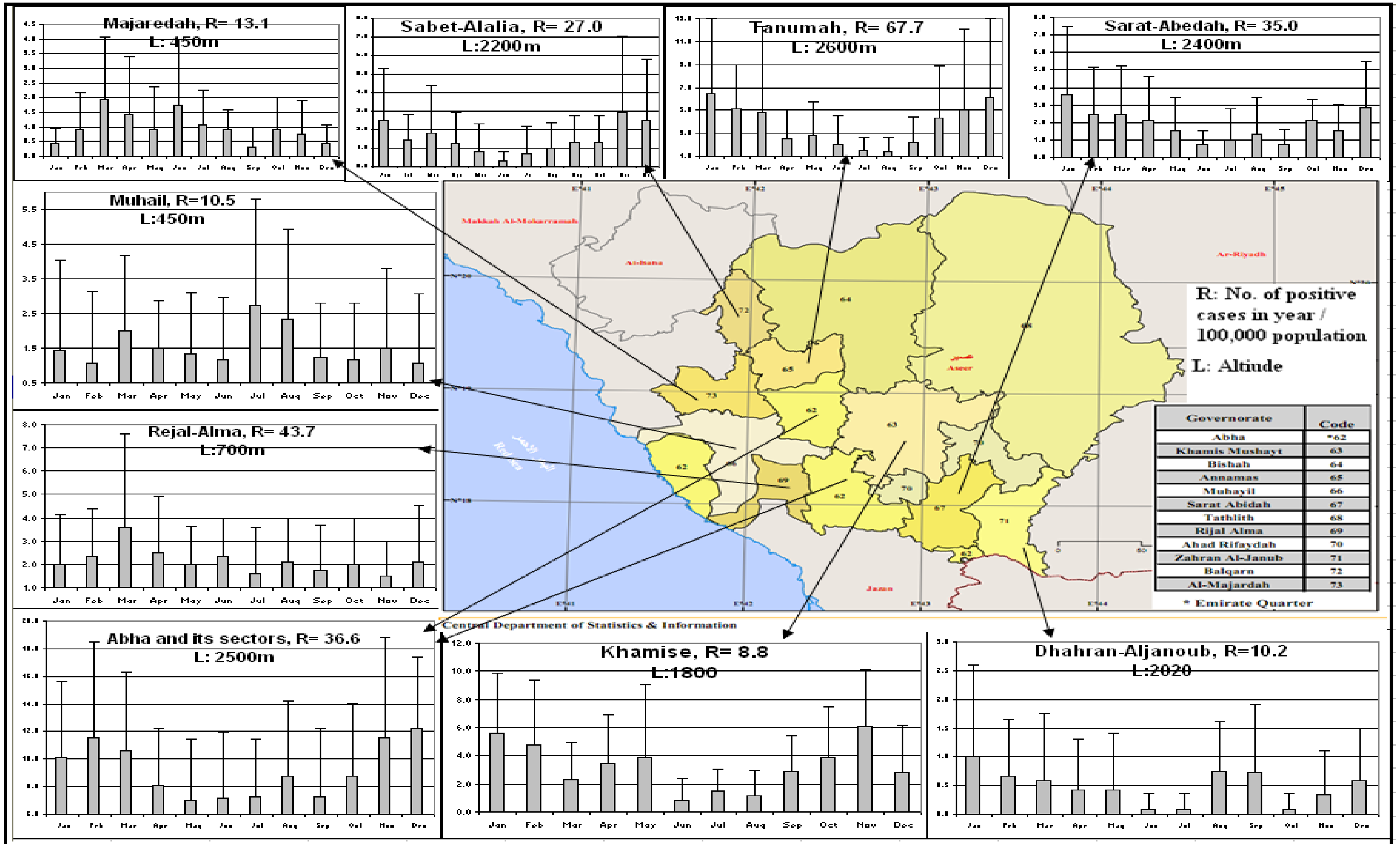
4.10.2 CL Geography:

As indicated in Section 4.7 there are wide differences in topology and weather within Asir. Consequently there are likely to be differences in leishmaniasis incidence and seasonality between sectors. To investigate this further the overall incidence rates and histograms of CL were produced for each of the sectors within Asir. Data exists for nine sectors: Abha, Khamise, Sarat-Abedah, Muhail, Majaredah, Rejal-Alma, Dhahran-Aljanoub, Tanoma and Sabt-Alalaya. One sector was not included in the analysis (Ahad-Rifadah) as it only had a few cases during the period of this study (8 cases). In addition a few cases (11 cases) existed for unclassified sectors during the study period (Dr A. Abdoon 2007 pers. Comm.).

The overall leishmaniasis incidence rates for each sector and histograms of monthly incidence are presented in Figure 4.10. In most of the highlands areas such as Abha, Khamise, Sarat-Abidah, Tanoma and Sabt-Alalaya there are clear seasonalities with peak incidence between October and March. The average numbers of cases during the summer are lower. The rates (representing the number of positive cases in the year/100,000 population) of these sectors are 36.6, 8.8, 35.5, 67.7 and 27.0 respectively. In lowlands such as Majaredah and Rejal-Alma there is much less seasonality that in the highlands, with peak averages of cases occurring between

February and June, and the averages of cases in the rest of the year are little lower. The rates for these sectors are 1.31 and 4.37 respectively. The rest of the infected sectors in Asir are Muhail and Dhahran-Aljanoub which do not give us clear seasonality with rates of 1.05 and 1.02 respectively.

Differences in incidence between sectors may be due to differences in reporting. However, varying seasonalities are more likely to be due to transmission differences between sectors. The limited weather data available across Asir imply that it is not possible to examine the associations between CL cases and weather for all sectors in Asir individually.



Governorate	Code
Abha	*62
Khamis Mushayt	63
Bishah	64
Annamas	65
Muhayil	66
Sarat Abidah	67
Tathlith	68
Rijal Alma	69
Ahad Rifaydah	70
Zahran Al-Janub	71
Balqarn	72
Al-Majardah	73

* Emirate Quarter

Figure 4.10: *Annual rate and monthly average of CL cases in sectors of Asir Region (1996-2007). Adapted from (CDSI, 2005)*

For the analysis four models were constructed. The first was an analysis of CL in all Asir against Khamise weather data (Maximum, mean and minimum temperature, rainfall and relative humidity, Station 1 Figure 4.9). The following sectors were grouped together based upon sectors with similar seasonal patterns described in the previous paragraph and presented in Figure 4.10. The most appropriate weather data for each group was also selected:

- First Group (Highlands Group): CL cases in 7 sectors: Abha, Khamise, Sarat-Abedah, Tanoma, and Sabt-Alalaya against Khamise weather data (Maximum, mean and minimum temperature, rainfall and relative humidity, Station 1 Figure 4.9).
- Second Group (Lowlands Group): CL case in Majaredah and Rejal-Alma against Majaredah temperature (maximum and minimum, Station 2 Figure 4.9) and Rejal-Alma rainfall (Station 3 Figure 4.9). No relative humidity data was available for this area.
- Third Group (Different Lands Group): Muhail and Dhahran-Aljanoub. The data for this group has not been analysed for two important reasons: As shown in Figure 4.10 a low number of cases were reported during the study period. The second reason is that no representative weather data exists for this group of sectors.

4.10.3 CL Data Description

The monthly averages of CL cases in the whole of Asir Region during the study period are presented in Figure 4.11 and show a transmission of the parasite throughout the year. However, there is a clear seasonality with peak incidence between October and March, with the highest average number of cases in January (37.5) followed by February (30.5). The average number of cases during the summer is lower, with the lowest number occurring in June (16.8). The standard deviation bars on the graph indicate that there is a large variability from year to year in monthly cases of CL.

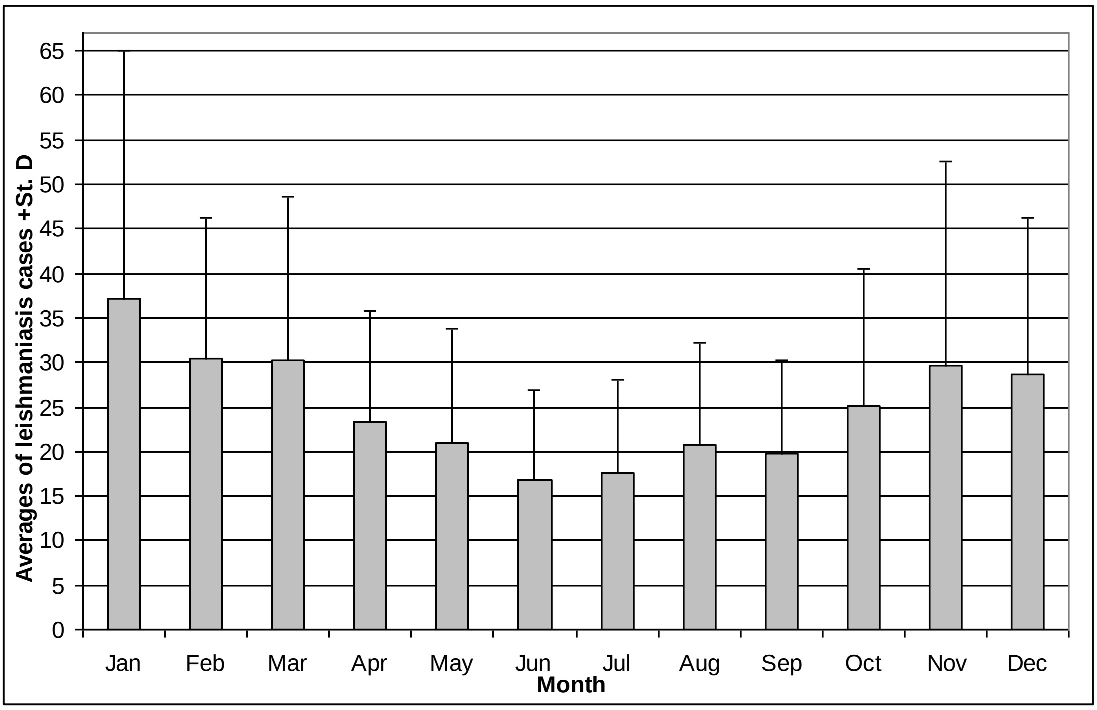


Figure 4.11: *Monthly averages of CL cases in All Asir Region (1996 - 2007)*

Most of the CL cases in Asir are in the first group (highlands) and so the monthly patterns of cases are similar between the two. Figure 4.12 shows the monthly averages of CL cases in the highlands group during study period. There is a clear seasonality with peak averages of cases between October and March, with the highest average cases in Jan (28.2) followed by November (27.8). The average numbers of cases during the summer are lower, with the lowest number of cases in June (11.08). The standard deviation bars on the graph indicate that there is a large variability from year to year in monthly cases of CL.

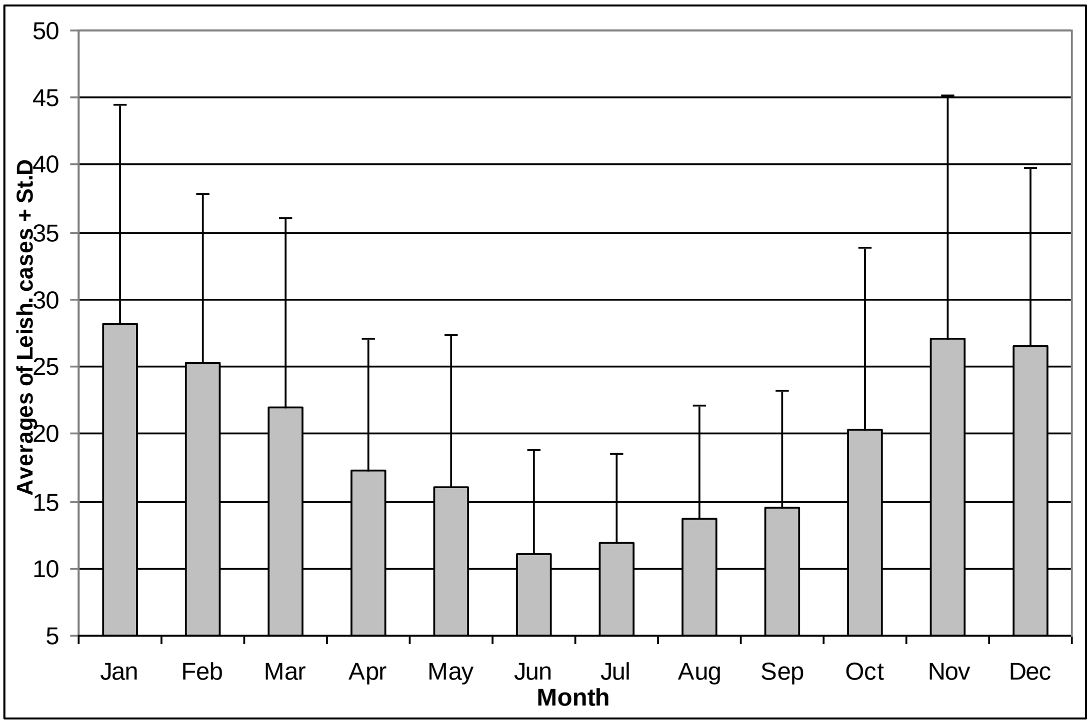


Figure 4.12: *Monthly averages of CL cases in the first group (Highlands) of Asir Region (1996 - 2007)*

Figure 4.13 shows monthly averages of CL cases in the lowlands group (Group 2) in Asir Region during study period. There is much less seasonality than in the highlands group with the peak cases occurring between February and June, with the highest average cases in March (5.5) followed by June (4.1). The averages of cases in the rest of the year are little lower, with the lowest averages of cases in September (2.1). The standard deviation bars on the graph indicates that there is a large variability from year to year in monthly cases of CL.

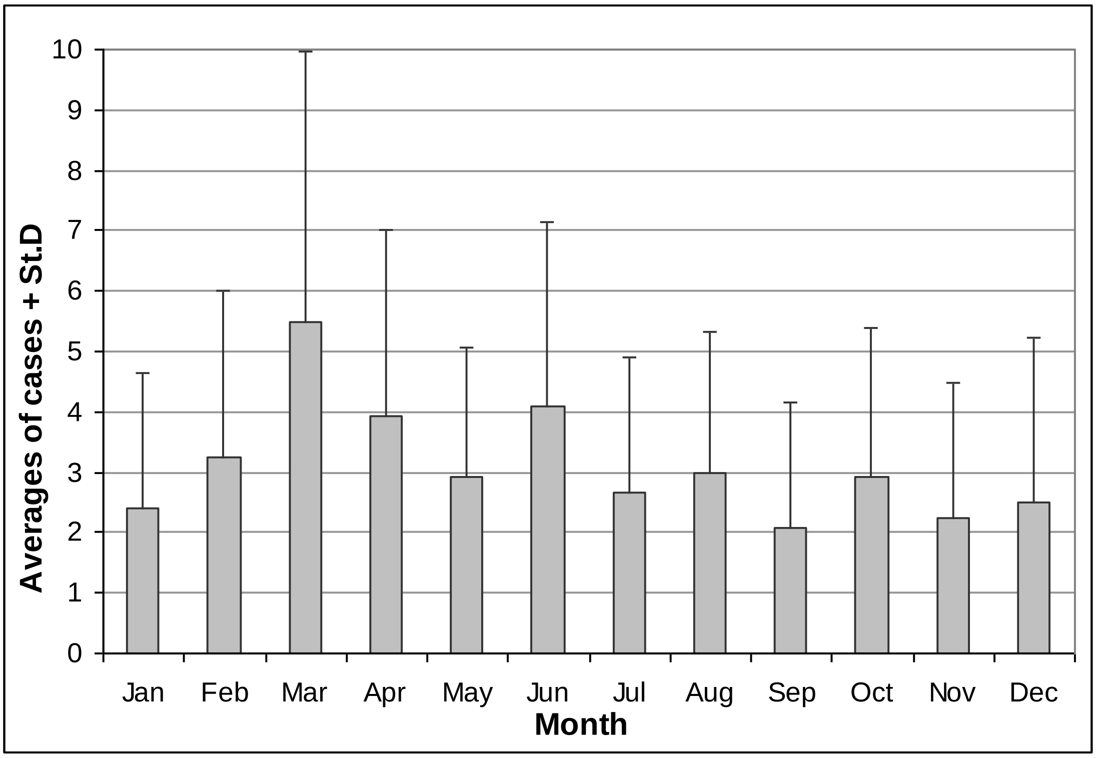


Figure 4.13*: Monthly averages of CL cases in the second group (Lowlands) of Asir Region (1996 - 2007)*

4.10.4 Temperature Data Description:

The temperature data for Khamise will be used in the analysis of cases across the whole of Asir Region as well as the first group (highlands). Descriptions of these data were presented in Section 3.11.3. Although this analysis is for a different year range (1996-2007 vs. 1995-2006) the seasonal trends in these data are similar to those presented previously.

The temperature in Majaredah will be used as representative of conditions in the lowlands group and these data were again presented previously for a slightly different range of years in Section 3.11.3.

4.10.5 Rainfall Data Description

Khamise rainfall will be assumed to be representative of all Asir and the highlands group. The monthly average rainfall in this city during the study period was presented in Section 3.11.4 for a slightly different yearly range.

Rejal-Alma is assumed to be representative of rainfall of the lowlands group, and data for this weather station was presented also in Section 3.11.4.

4.10.6 Relative Humidity Data Description

The relative humidity in Khamise will be assumed to be representative of all Asir and the highlands group. These data were presented previously in section 3.115.

4.10.7 Statistical Analysis Data Preparation

The analysis to examine the relationship between monthly cases of CL and the selected weather data proceeded in a number of stages;

A histogram of the number of CL cases each month in the whole of Asir shows a positively skewed distribution, with the majority of values between 7 and 35 cases. There are a few months with more than 40 cases and a few with less than 5 cases. This was confirmed through descriptive statistics. This may cause problems when performing regression analysis and so the natural logarithm of CL cases (adding 1 to zero values) was performed for the cases to produce Ln CL and this is illustrated in Figure 4.14. Descriptive statistics of this distribution are presented in Table 4.3 and demonstrated that taking the natural logarithm of CL produces a variable that is nearly normally distributed. For similar reasons the natural logarithm was taken of CL cases in highlands (Figures 4.15) (Table 4.4) and lowlands groups (Figures 4.16) (Table 4.5).

In terms of the independent variables, the rainfall data from Khamise also demonstrated a positively skewed distribution. Therefore, we took the natural logarithm of rainfall (adding 1 to zero values) to produce Ln rainfall. Figure 4.17 shows histograms of the rainfall after transformation, and Table 4.6 presents the descriptive statistics of this distribution.

The data were then adjusted for effects that could bias the results. Over time the number of CL cases in Asir has declined and this long term trend is shown in Figure 4.18. Since the 1990’s cases have declined from the peak of cases in 1998. The long term of trend in CL in each of the two groups is shown in Figures 4.19 and 4.20. All these groups indicate a decrease in cases since the late 1990’s.

In order to control for this effect, for the whole of Asir, the highlands and lowlands data, the natural logarithm of CL cases were put into a regression against time (each month numbered from 1 to 144). The unstandardised residual from this model represent the natural logarithm of CL cases with the long term trend in incidence removed.

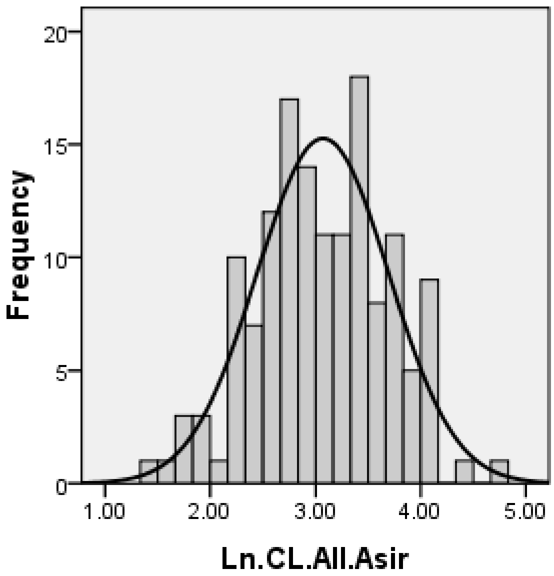


Figure 4.14: *Frequency of natural logarithm of CL (Ln. CL) in All Asir* Region (1996 – 2007)

Table 4.3: *Descriptive Statistics for Ln. CL Cases in Whole Air Region*

Ln. CL	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	1.39	4.68	3.07	0.627	- 0.09	0.202

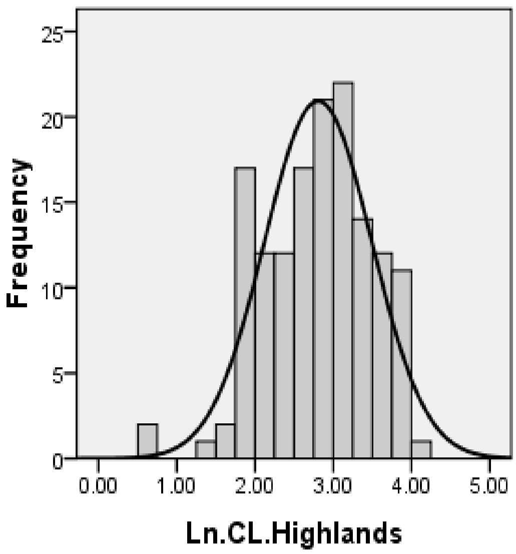


Figure 4.15: *Frequency of natural logarithm of CL (Ln. CL) in the highlands group (1996 – 2007)*

Table 4.4: *Descriptive Statistics for Ln. CL Cases in Highlands Group*

Ln. CL	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	0.69	4.25	2.81	0.686	- 0.380	.202

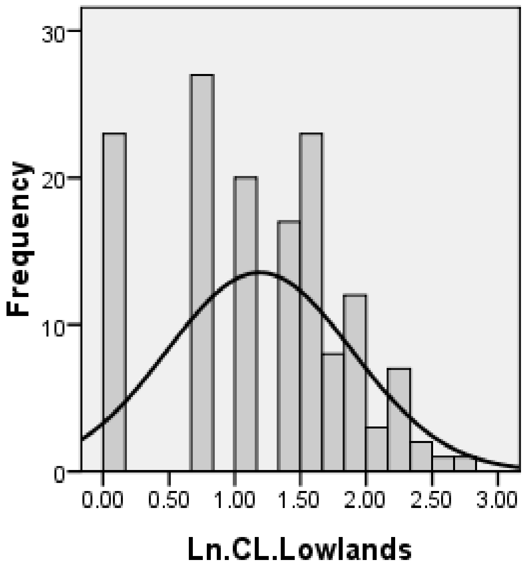


Figure 4.16: *Frequency of natural logarithm of CL (Ln. CL) in the lowlands group (1996 – 2007)*

Table 4.5: *Descriptive statistics for Ln. CL cases in the lowlands group*

L. CL	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	0.00.	2.83	1.189	0.707	-0.240	0.202

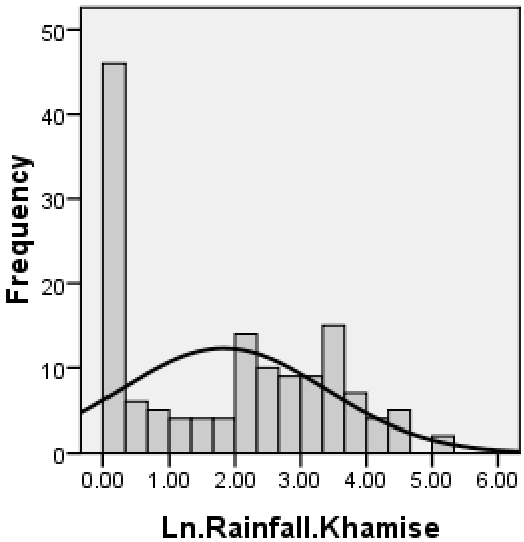


Figure 4.17: *Frequency of natural logarithm rainfall (Ln.R) in Khamise (1996 – 2007)*

Table 4.6: *Descriptive Statistics of Ln Rainfall in Khamise*

Ln Rainfall	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	0	5.27	1.826	1.557	0.145	0.202

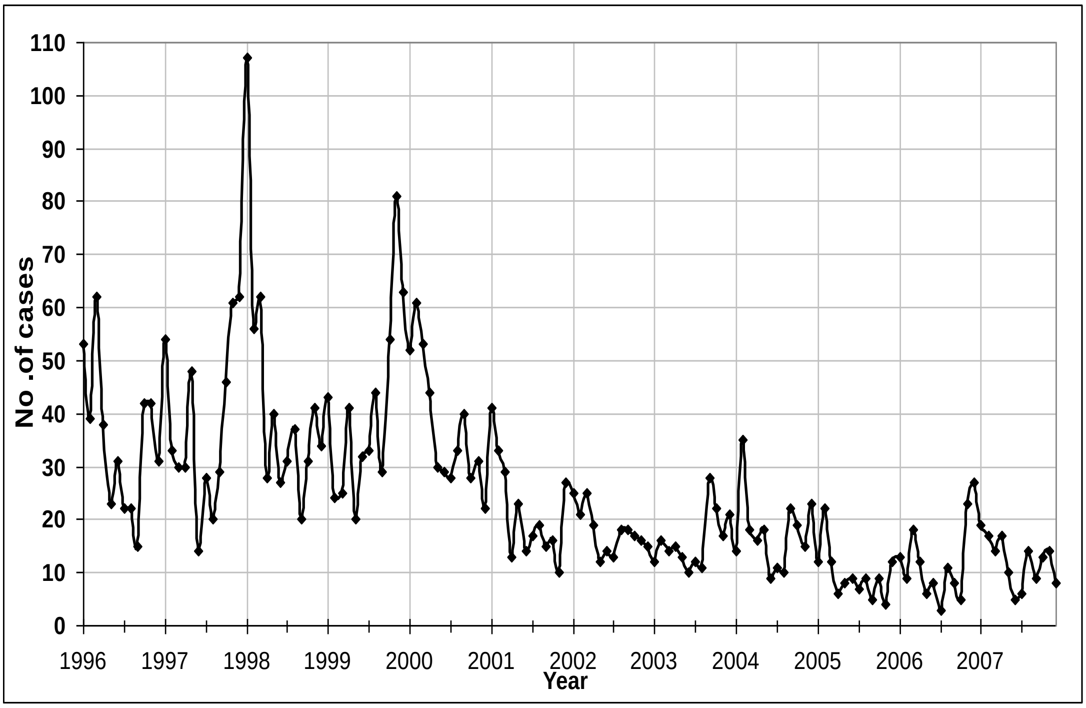


Figure 4.18: *Monthly CL cases in all Asir Region (1996 – 2007)*

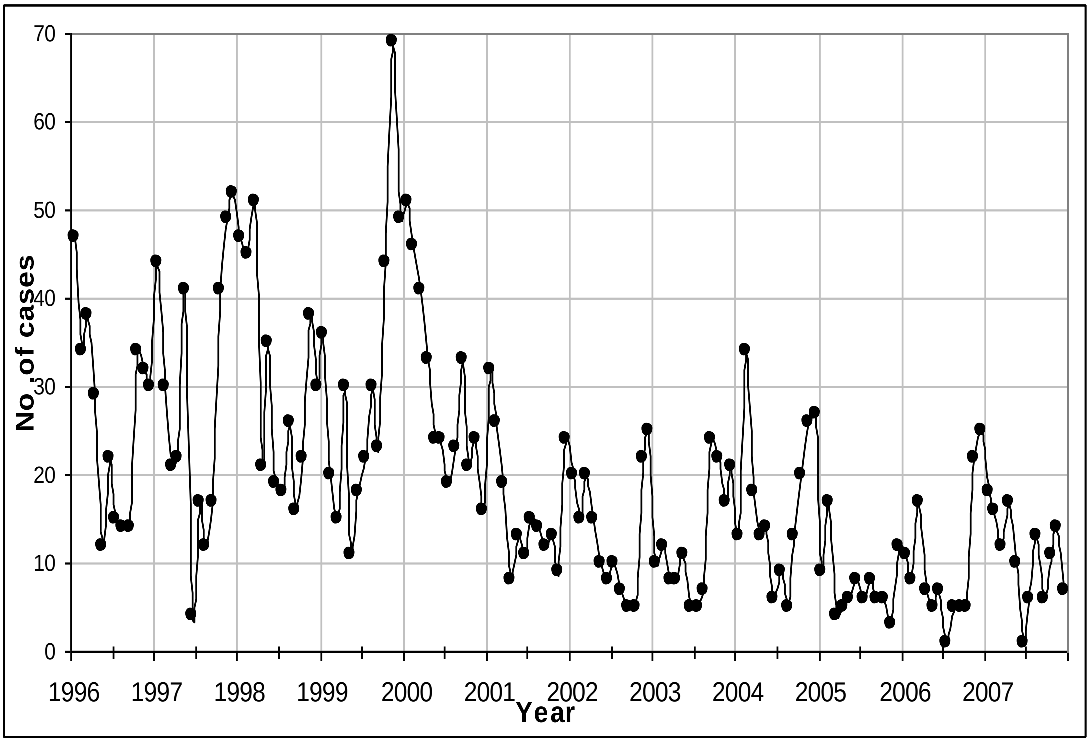


Figure 4.19*: Monthly CL cases in the highlands group in Asir Region (1996 – 2007)*

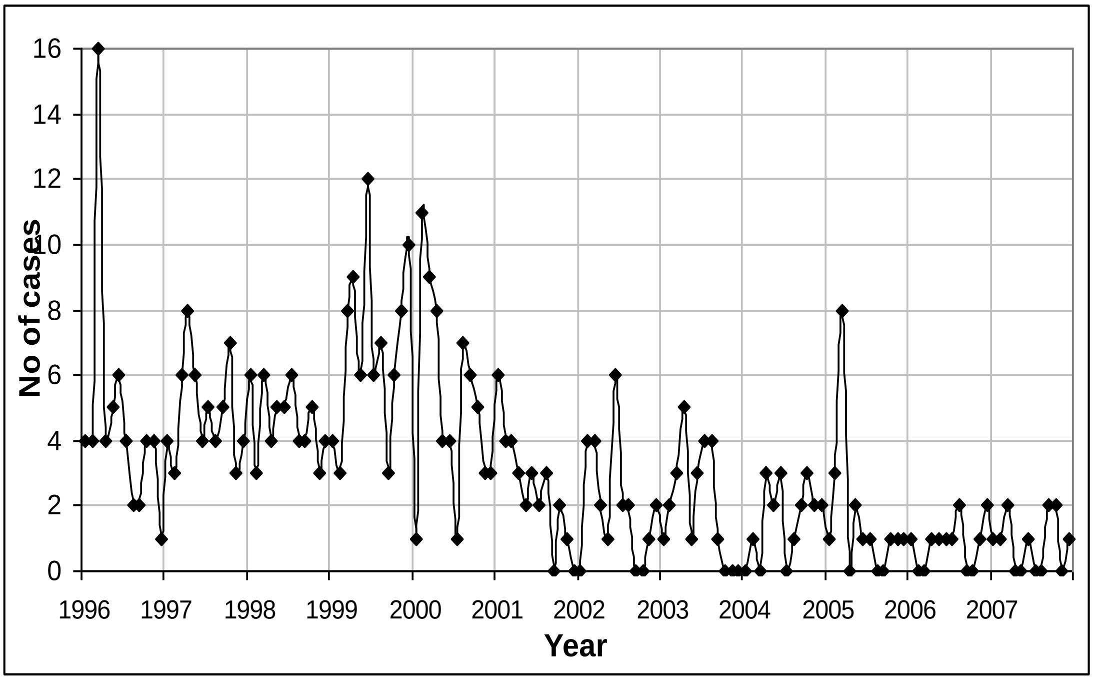


Figure 4.20: *Monthly CL cases in the lowlands group in Asir Region (1996 – 2007)*

4.10.8 Statistical Analysis

The literature review has demonstrated that the relationship between CL cases and weather may vary according to the time of the year. Therefore, the analysis proceeded in stages

1. Within each group (all Asir, highland, lowlands) months were grouped together. The models for all Asir and the highlands region consider three time periods; February to May, June to September and October to January (See Figure 4.11 for all Asir and Figure 4.12 for the highlands). The results for the lowlands region are presented for 2 time periods; March to November and December to February (See Figure 4.13). The grouping for all Asir, highlands and lowlands for each period was depended on the pattern of cases throughout the year.
2. To produce an analysis that is more robust to the distribution of the data an ordinal logistic of Ln CL cases for every month against each of the weather variables was produced as well. This was achieved by dividing Ln CL into five categories with equal numbers of months.
3. In the regular regression analysis it was not possible to assume that the CL rate in one month is unrelated to the CL rate in the next month (i.e. the data is autocorrelated). Therefore all models were analyzed in three ways. The first did

not control for seasonality or autocorrelation. The second controlled for seasonality by incorporating dummy variables for each of the individual months. The final controlled for autocorrelation by adding the CL cases in the previous months into these models.

4. The same actions were repeated for the ordinal logistic analysis.
5. The regressions were performed against the current month's weather data as well as the previous month's weather data up 6 previous months. The literature review indicated that lagged relationships may exist up to this period. We then examined these relationships and combined the weather from the three months with the strongest associations with CL.
6. In most cases the strongest relationships were between DT Ln CL and temperature in 2-4 previous months and between DT Ln CL and rainfall in 1-3 previous months. Therefore, for consistency these lags were used in all models.

All of the data were analyzed using SPSS v.16 / v.18 for Windows and Microsoft Excel 2003 / 2007.

4.11 Results

The analysis is presented by first looking at relationships between CL and temperature (maximum, mean and minimum) followed by rainfall and relative humidity. This is performed for all of the Asir region, the highlands and the lowlands separately.

4.11.1 CL with Maximum Temperature

Linear regressions and ordinal logistic of DT Ln CL cases against maximum temperature are presented for all Asir during June to September in Table 4.7, the highlands June to September in Table 4.8 and the lowlands during March to November in Table 4.9. Models for the rest of year for this variable and all similar variables which have a few significant relationships are not presented in this chapter but appear in Appendix B1. In these tables 0P represents the models where the independent variables are not lagged, 1P represents the independent variables lagged by 1 month and so on.

Table 4.7: *DT Ln CL and maximum temperature in Asir during June to September*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.030	.624	.130	.106	.130	.109	.270	.374	.940	.044	.890	.113
1 P	.070	.128	.070	.259	.080	.218	.360	.177	.430	.218	.640	.139
2 P	.065	.003	.161	.002	.164	.001	.207	.007	.730	.026	.909	.020
3 P	.041	.009	.119	.017	.146	.006	.090	.017	.060	.030	.360	.040
4 P	.050	.006	.130	.004	.130	.003	.080	.035	.040	.035	.350	.041
5 P	.040	.033	.070	.127	.070	.101	.050	.637	-.190	.455	-.060	.833
6 P	.080	.005	.090	.023	.100	.021	.080	.651	.010	.960	.630	.056
2-4 P	.055	.003	.221	.001	.247	.001	.323	.030	.432	.032	.851	.034

The results indicated that in Asir over June to September CL cases appear to be a positively significantly associated with average maximum temperature in the 2-4 previous months for linear regression and ordinal logistic regression.

Table 4.8*: DT Ln CL and maximum temperature in the highlands during June to September*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.020	.776	.190	.077	.200	.069	.210	.472	.940	.049	.670	.192
1 P	.080	.246	.030	.769	.040	.709	.410	.177	.330	.382	.260	.550
2 P	.082	.008	.170	.021	.169	.024	.290	.049	.783	.023	1.08	.007
3 P	.050	.012	.145	.040	.179	.018	.111	.025	.176	.036	.220	.044
4 P	.062	.007	.160	.009	.165	.008	.103	.038	.315	.031	.342	.041
5 P	.070	.010	.120	.046	.140	.029	.140	.251	.070	.773	.230	.392
6 P	.090	.028	.100	.084	.100	.079	.001	.985	-.010	.693	.040	.894
2-4 P	.073	.005	.262	.002	.278	.001	.164	.047	.512	.033	.718	.036

P: previous month. Cof.: Coefficients. P: ***P*** value (= or<).

The results indicated that in highlands over June to September CL cases appear to be a positively significantly associated with average maximum temperature in the 2-4 previous months for linear regression and ordinal logistic regression.

Table 4.9: *DT Ln CL and Maximum temperature in the lowlands during March to November*

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.010	.763	-.010	.853	-.020	.720	-.040	.590	-.010	.956	.030	.912
1 P	-.031	.065	.027	.540	.020	.642	-.110	.082	.069	.683	.081	.644
2 P	-.040	.006	.030	.557	.020	.714	-.120	.015	-.050	.749	-.040	.825
3 P	-.040	.001	-.015	.742	-.024	.591	-.120	.010	-.138	.426	-.123	.491
4 P	-.030	.005	.010	.805	.020	.709	-.100	.032	-.260	.200	-.150	.473
5 P	-.020	.069	.001	.955	.001	.933	-.060	.238	-.160	.339	-.080	.701
6 P	.001	.824	.030	.464	.030	.429	.010	.822	.001	.981	.090	.621

Temp. available for 132 out of 144 months for the whole of year model

In the lowlands sector CL cases over March to November are not consistently associated with maximum temperature for any of the previous months.

4.11.2 CL with Mean Temperature

Linear regressions and ordinal logistic of DT Ln CL cases against mean temperature are presented for all Asir during June to September in Table 4.10 and the highlands in Table 4.11. Mean temperature data was not available for the lowlands.

Table 4.10: *DT Ln CL and mean temperature in Asir during June to September*

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.010	.883	.190	.073	.190	.082	-.620	.158	-.660	.262	1.10	.165
1 P	.070	.222	.070	.358	.070	.358	-.130	.652	-.500	.246	.220	.702
2 P	.070	.005	.200	.003	.200	.004	.120	.384	.170	.043	1.10	.037
3 P	.040	.018	.120	.070	.150	.036	.070	.510	.250	.496	.180	.670
4 P	.050	.012	.160	.009	1.70	.007	.070	.494	.200	.573	.340	.409
5 P	.050	.043	.080	.277	.080	.251	.030	.783	-.800	.054	-.570	.212
6 P	.080	.017	.110	.117	.120	.108	.001	.998	-.750	.088	.360	.489

The results indicated that in Asir over June to September CL cases appear to be a positively significantly associated with mean temperature 2- 4 months previously but only in the linear regression. This effect mostly disappears in the ordinal logistic regression.

Table 4.11: *DT Ln CL and mean temperature in the highlands during June to September*

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.010	.917	.280	.059	.290	.057	-.740	.109	-.800	.215	-.030	.966
1 P	.090	.245	.050	.660	.060	.622	-.050	.877	-.560	.225	-.120	.826
2 P	.090	.011	.230	.024	.230	.027	.200	.090	.300	.056	1.30	.021
3 P	.060	.025	.180	.206	.150	.139	.080	.428	-.290	.422	-.450	.267
4 P	.060	.022	.140	.111	.150	.103	.100	.371	-.120	.742	.260	.501
5 P	.070	.023	.130	.169	.150	.143	.090	.478	-.440	.272	-.310	.445
6 P	.090	.054	.090	.374	.090	.358	-.020	.905	-.800	.055	-.400	.378

The results indicated that in the highlands between June and September CL cases appear to be positively and mostly significantly associated with mean temperature only in the 2 previous months for the linear regression and ordinal logistic regression.

4.11.3 CL with Minimum Temperature

Linear regressions and ordinal logistic of DT Ln CL cases against minimum temperature are presented for all Asir during June to September in Table 4.12, the highlands in Table 4.13 and the lowlands during March to November in Table 4.14.

Table 4.12: *DT Ln CL and minimum temperature in All Asir during June to September*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.030	.647	.100	.372	.100	.384	-.400	.216	-.760	.212	.440	.542
1 P	.060	.259	-.020	.845	-.020	.856	-.200	.499	-1.20	.029	-.480	.445
2 P	.070	.014	.200	.032	.190	.037	.120	.428	.189	.039	.910	.035
3 P	.040	.041	.060	.483	.080	.395	.080	.493	-.330	.486	-.130	.810
4 P	.040	.049	.070	.358	.070	.369	.090	.434	-.130	.768	.070	.882
5 P	.040	.092	-.010	.869	-.010	.883	.080	.497	-.170	.640	-.350	.381
6 P	.040	.195	-.030	.574	-.030	.596	.030	.835	-.450	.170	-.410	.253

The results indicated that in all Asir over June to September CL cases appear to be a positively significantly associated with minimum temperature only in the 2 previous months for both linear and ordinal logistic regression.

Table 4.13: *DT Ln CL and minimum temperature in the highlands during June to September*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.090	.001	-.150	.120	-.150	.120	-.280	.017	-.700	.099	-.420	.349
1 P	-.100	.001	-.130	.120	-.100	.222	-.270	.260	-.300	.392	-.170	.661
2 P	.040	.182	.120	.018	.150	.034	.210	.194	.100	.769	.660	.058
3 P	.080	.152	.100	.176	.080	.254	.001	.996	-.120	.686	-.030	.924
4 P	.090	.004	.060	.412	.020	.789	.190	.137	-.180	.574	-.290	.399
5 P	.060	.008	.070	.428	.060	.493	.130	.155	-.480	.221	-.030	.941
6 P	.060	.014	.800	.491	.090	.414	.140	.150	-.500	.329	.090	.394

The results indicated that in the highlands over June to September CL cases appear to be a positively significantly associated with mean temperature only in the 2 previous months. The effect is only seen in the linear regression.

Table 4.14: *DT Ln CL and minimum temperature in the lowlands during March to November*

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.020	.396	.040	.362	-.040	.412	.030	.628	.230	.257	.220	.244
1 P	-.040	.030	-.040	.315	-.060	.187	-.120	.079	.010	.946	-.160	.372
2 P	-.050	.002	-.050	.270	-.040	.341	-.120	.030	.070	.706	.040	.797
3 P	-.050	.001	.001	.980	.001	.966	-.110	.045	.030	.164	.230	.264
4 P	.040	.015	.080	.165	.090	.152	-.070	.200	-.470	.049	.420	.096
5 P	-.040	.029	.010	.842	.001	.968	.060	.311	.430	.151	.190	.543
6 P	-.010	.563	-.030	.614	.001	.936	.010	.854	.190	.402	.120	.568

Minimum temperature data: available for 132 out of 144 months for the whole of year model

In the lowlands sector CL cases over March to November are not consistently associated with minimum temperature for any of the previous months.

4.11.4 CL with Rainfall

Linear regressions and ordinal logistic of DT Ln CL cases against rainfall are presented for all Asir during June to September in Table 4.15, the highlands June to September in Table 4.16 and the lowlands during March to November in Table 4.17.

Table 4.15: *DT Ln CL and rainfall in All Asir during June to September*

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.030	.331	-.050	.189	-.050	.214	-.090	.587	-.010	.642	-.420	.120
1 P	.040	.342	-.020	.686	.140	.754	.140	.507	.130	.578	-.010	.973
2 P	-.084	.014	-.075	.059	-.074	.063	-.170	.393	-.197	.365	-.402	.122
3 P	-.053	.099	-.059	.093	-.061	.089	-.210	.243	-.220	.287	-.430	.067
4 P	.020	.417	-.030	.472	-.040	.423	-.020	.891	-.230	.336	.120	.670
5 P	.020	.536	-.030	.448	-.030	.458	-.010	.941	-.180	.430	-.100	.693
6 P	-.030	.498	-.030	.426	-.040	.397	.020	.909	-.060	.799	-.160	.564

In the whole of Asir CL cases over June to September are not consistently associated with rainfall for any of the previous months.

Table 4.16: *DT Ln CL and rainfall in the highlands during June to September*

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.080	.056	-.140	.015	-.140	.018	-.110	.538	-.190	.428	-.490	.083
1 P	.050	.297	.050	.391	.050	.446	.120	.552	.170	.467	.060	.818
2 P	-.056	.252	-.041	.469	-.040	.498	-.092	.649	-.099	.659	-.347	.173
3 P	-.074	.094	-.081	.103	-.082	.103	-.140	.439	-.070	.408	-.180	.409
4 P	.043	.295	-.023	.702	-.027	.656	.110	.515	-.040	.868	.230	.351
5 P	.010	.901	-.070	.231	-.070	.232	-.110	.506	-.320	.159	-.420	.077
6 P	-.010	.873	-.040	.538	-.040	.493	.020	.915	-.120	.607	.130	.637

In the highlands sector CL cases over June to September are not consistently associated with rainfall for any of the previous months.

Table 4.17: *DT Ln CL and rainfall in the lowlands during March to November*

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.070	.020	.050	.082	.070	.110	.420	.001	.420	.001	.270	.036
1 P	.075	.008	.076	.005	.070	.009	.460	.001	.531	.001	.355	.010
2 P	.009	.001	.020	.548	.030	.314	.300	.005	.300	.007	.040	.744
3 P	.079	.003	.076	.004	.076	.003	.535	.001	.559	.001	.409	.002
4 P	.030	.219	.040	.168	.020	.395	.400	.001	.490	.001	.050	.726
5 P	.020	.539	.020	.384	.020	.568	.410	.001	.490	.001	.210	.115
6 P	.010	.742	.030	.244	.030	.259	.460	.001	.620	.001	.450	.001
1-3 P	.099	.004	.085	.012	.078	.022	.800	.001	.829	.001	.492	.008

Rainfall data: available for 132 out of 144 months for the whole of year model

The results indicated that in the lowlands over March to November CL cases appear to be positively and significantly associated with average rainfall of 1-3 months previously for both the linear and ordinal logistic regression.

4.11.5 CL with Relative Humidity

Linear regressions and ordinal logistic of detrended logarithm CL cases against humidity are presented for all Asir June to September in Table 4.18 and the highlands June to September Table 4.19. No humidity data was available for the lowlands.

Table 4.18: *DT Ln CL and relative humidity in All Asir during June to September*

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.001	.987	.001	.803	.001	.832	-.020	.646	-.020	.690	-.040	.573
1 P	.010	.211	.010	.483	.010	.479	.030	.530	.020	.649	.001	.950
2 P	-.015	.021	-.013	.132	-.013	.151	-.027	.464	-.026	.587	-.093	.094
3 P	.013	.015	.013	.120	.015	.091	-.020	.422	.010	.867	.060	.248
4 P	.020	.001	.030	.073	.030	.082	.070	.058	.090	.066	.140	.021
5 P	-.010	.038	-.010	.198	-.010	.152	-.060	.125	-.070	.191	-.010	.885
6 P	.015	.021	.020	.132	.020	.110	.090	.032	.100	.037	.140	.016

Table 4.19: *DT Ln CL and relative humidity in the highlands during June to September*

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.001	.080	-.010	.756	-.010	.760	.001	.958	.010	.936	.001	.961
1 P	.010	.262	.010	.429	.010	.431	.010	.790	.010	.784	-.030	.587
2 P	-.013	.145	-.008	.529	-.007	.588	-.036	.344	-.028	.548	-.077	.144
3 P	-.011	.159	.001	.907	.001	.941	-.010	.784	.040	.373	.040	.418
4 P	-.024	.007	-.024	.057	-.023	.063	.110	.060	.060	.071	.100	.054
5 P	-.020	.031	-.020	.237	-.020	.202	-.090	.049	-.090	.107	-.090	.146
6 P	-.020	.033	-.020	.129	-.020	.131	-.060	.188	-.060	.229	-.070	.221

In the all Asir and highlands sector CL cases over June to September are not consistently associated with relative humidity for any of the previous months.

4.11.6 Multiple Regressions

In this section we will present the results from the normal and multiple regressions for the coefficient of DT Ln CL cases against averages of three main variables of weather data (Maximum Temperature, Rainfall and Relative Humidity). For temperature, we will present maximum temperate only as it has a similar seasonality to minimum and mean temperature and appeared to have the strongest associations with CL. In the multiple regressions we have presented only models for times of the year when one of the independent variables was significant.

A- Multiple Regression of CL in All Asir

The strongest results from the univariable linear and ordinal logistic regression for CL in all Asir against maximum temperature, rainfall and relative humidity, for average of 2, 3 and 4 previous months during June to September period are illustrated in Table 4.20. Table 4.21 presents the multiple regressions for all combination of these variables.

Table 4.20: *Regressions of DT Ln CL cases of Asir for maximum temperature, rainfall and relative humidity during June to September for average of 2 to 4 previous months*

Average of 2-4 previous months	Linear regression									Ordinal logistic								
	Variables Only			With seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P		Cof.	P		Cof.	P	Adj. R^2	Cof.	P		Cof.	P		Cof.	P	
Max.Tem. Only	.055	.003	.155	.221	.001	.291	.247	.001	.319	.323	.030	-58.1	.432	.032	-56.4	.851	.034	-51.1
Rainfall Only	-.130	.043	.066	-.158	.056	.175	-.162	.055	.171	-.512	.166	-68.5	-.777	.068	-67.4	-.845	.061	-51.3
Humidity Only	-.024	.031	.201	-.030	.080	.121	-.030	.089	.123	-.056	.169	-68.6	-.069	.271	-68.5	-.168	-.168	-52.5

Table 4.21: *Regressions of DT Ln CL cases of Asir with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) during June to September for average of 2 to 4 previous months*

Average of 2-4 previous months	Linear regression									Ordinal logistic								
	Variables Only			with seasonality			With auto Correlation & Seasonality			Variables Only			With Seasonality			With auto correlation & Seasonality		
Variables In Multiple Method	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	.059	.001	.257	.183	.005	.300	.207	.002	.332	.153	.049	-61.48	.169	.044	-58.41	.600	.024	-50.53
Rainfall	-.151	.010		-.088	.214		-.091	.192		-.605	.107		-.638	.248		-.554	.283	
Max.Tem	.008	.016	.184	.183	.009	.289	.217	.003	.312	.019	.050	-68.29	.303	.048	-68.29	.411	.041	-50.16
Humidity	-.021	.113		-.012	.344		-.009	.477		-.053	.478		-.040	.602		-.127	.167	
Rainfall	-.022	.002	..238	-.114	.173	.199	-.124	.144	.192	-.457	.217	-67.80	-.792	.138	-67.39	-.357	.532	-50.25
Humidity	-.103	.078		-.020	.138		-.020	.156		-.049	.224		.004	.963		-.133	.158	
Max.Tem	.083	.045	.244	.170	.018	.287	.204	.006	.315	.178	.027	-67.48	.201	.039	-67.29	.361	.031	-50.03
Rainfall	-.136	.038		-.072	.365		.086	.277		-.633	.144		-.752	.640		-.291	.618	
Humidity	-.007	.607		-.006	.667		-.002	.901		.011	.898		.020	.819		-.103	.323	

The results of multiple regressions for CL in Asir during June to September demonstrated that in no models were more than one weather variable significant. We conclude therefore that the best model for period is that of DT Ln CL against maximum temperature in the previous 2-4 months. This temperature variable was positively significant in all variants of the normal and ordinal logistic regression. In all cases models including this variable had a better fit (adjusted R^2 and log likelihood ratio) and a stronger significance than any of the other weather variables. Higher maximum temperature was associated with elevated CL cases.

B- Multiple Regression of CL in Highlands Group

The strongest results from the univariable linear and ordinal logistic regression for CL in the highlands against maximum temperature, rainfall and relative humidity, for the average of the previous 2-4 months during June to September are illustrated in Table 4.22. Table 4.23 presents the multiple regressions for all combinations of these variables.

Table 4.22: *Regressions of DT Ln CL cases of the highlands for maximum temperature, rainfall and relative humidity during June to September, for average of 2 to 4 previous months*

Average of 2-4 previous months	Linear regression									Ordinal logistic								
	Variables Only			with seasonality			With auto correlation & Seasonality			Variables Only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	.073	.005	.140	.262	.002	.194	.278	.001	.198	.164	.047	-64.8	.512	.033	-64.1	.718	.036	-54.3
Rainfall Only	-.096	.289	.030	-.175	.080	.066	-.178	.079	.050	-.110	.765	-65.8	-.411	.339	-64.6	-.345	.427	-55.5
Humidity Only	-.022	.026	.083	-.018	.288	.022	-.017	.309	.002	-.048	.266	-65.2	-.029	.663	-64.9	-.084	.249	-55.1

Table 4.23: *Regressions of DT Ln CL cases of the highlands with multiple weather (maximum temperature with rainfall and maximum temperature with relative humidity and for all of them together) during June to September for average of 2 to 4 previous months*

Average of 2-4 previous months / Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	.077	.003	.162	.245	.012	.178	.263	.008	.180	.177	.024	-64.57	.440	.039	-63.09	.740	.042	-53.16
Rainfall	-.123	.143		-.040	.706		-.034	.747		-.222	.554		.176	.714		.046	.927	
Max.Tem	.085	.036	.123	.314	.003	.190	.355	.001	.207	.206	.030	-63.20	.632	.035	-64.03	.676	.040	-54.24
Humidity	.006	.764		.016	.381		.023	.235		.019	.814		.037	.652		-.012	.891	
Rainfall	-.069	.430	.076	-.175	.168	.044	-.183	.156	.027	-.083	.823	-65.17	-.461	.385	-64.61	-.080	.881	-55.10
Humidity	-.021	.037		.001	.994		.001	.944		-.047	.174		.014	.871		-.076	.393	
Max.Tem	.129	.019	.167	.295	.006	.186	.336	.003	.206	.297	.020	-64.41	.579	.019	-63.83	.697	.040	-54.23
Rainfall	-.170	.073		-.104	.384		-.116	.237		-.330	.433		-.344	.524		.091	.869	
Humidity	.023	.271		.025	.242		.032	.135		.052	.572		.064	.409		.019	.847	

The results of the multiple regressions for CL in the highlands during June to September demonstrated that in no models with more than one weather variable was positively significant. We conclude therefore that the best model for this period is that of DT Ln CL against maximum temperature in the previous 2-4 months. This weather variable was positively significant in all variants of the normal linear and ordinal logistic regressions and in all cases had a better fit (adjusted R^2 and log likelihood ratio) and a stronger significance than any of the other weather variables. Higher maximum temperature was associated with elevated CL cases.

C- Multiple Regression of CL in Lowlands Group

The strongest results from the univariable linear and ordinal logistic regression for CL in the lowlands against maximum temperature, and rainfall in the previous 1-3 months are illustrated in Table 4.24. Table 4.25 presents the multiple regressions for all combinations of these variables.

Table 4.24: *Regressions of DT Ln CL cases of the lowlands for maximum temperature and rainfall during March to November for average of 1 to 3 previous months*

Average of 1-3 previous months	Linear regression									Ordinal logistic								
	Variables Only			with seasonality			With auto correlation & Seasonality			Variables Only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max. Only	-.038	.010	.058	.048	.426	.091	.032	.587	.122	-.137	.019	-127.1	-.045	.843	-124.2	-.018	.939	-103.1
Rainfall. Only	.099	.004	.080	.085	.012	.142	.078	.022	.152	.800	.001	-105.2	.829	.001	-101.6	.492	.008	-85.01

Table 4.25: *Regressions of DT Ln CL cases of the lowlands with multiple weather (maximum temperature and rainfall) during March to November for average of 1 to 3 previous months*

Average of 1-3 previous months	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables Only			With seasonality			With auto correlation & Seasonality		
------------- Multiple Method	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem	-.028	.070	.130	.035	.567	.189	.023	.710	.195	-.067	.322	-90.09	.213	.443	-86.79	.120	.665	-75.58
Rainfall	.097	.006		.086	.012		.080	.022		.853	.001		.893	.001		.565	.005	

The results of multiple regressions for CL in the lowlands group during March to November demonstrated that in no models was more than one weather variable significant. We conclude therefore that the best model for this period is that of DT Ln CL against rainfall. Average rainfall in the previous 1-3 months between March and November was positively significant in all variants of the normal linear and ordinal logistic regression and in all cases had a better fit (adjusted R^2 and log likelihood ratio) and a stronger significance than maximum temperature. Higher rainfall was associated with elevated CL.

4.12 Discussion and Conclusion

There are two main species of leishmaniasis cases in Saudi Arabia; VL and CL (Al-Amru, 2002). This study focuses on CL in Asir Region as this form of illness is endemic and spread over the foothills and highlands of this region (Ibrahim et al., 2005). Al-Zahrani et al., (1989) state that the distribution of this disease in Asir region is influenced by some little known climate factors and geographical situation.

There were some difficulties during this study, as we only had limited data for weather in the selected areas in Asir. For example, the weather in Khamise City is not representative of the whole of Asir as the elevation in this region varies from 0 to 3000m. Weather and hence sandfly distributions and leishmaniasis cases are almost certain to vary across Asir. Also it was not possible to analyse the data for some sectors due to lack of weather data and the low number of cases. For example no weather data was available for the Different Lands Group and the numbers of cases reported for this sector was low. Finally, some of the Leishmaniasis cases were unclassified and so could not be assigned to a sector.

Overall the CL cases show that the total number of yearly cases is declining from a peak (outbreak) in 1998. This outbreak may have been due to the heavy rainfall throughout this region during some months of year 1997 and 1998 (Dr A. Abdoon 2007 pers. Comm.). However, our results indicated that rainfall is not associated with CL cases in the highlands area where most cases occur. Vector control is a likely explanation for this reduction in cases.

The statistical analysis presented in this chapter was based on the hypothesis that there is a relationship between weather and CL. This was assumed because the distribution of leishmaniasis is tightly linked to geography and may be sensitive to weather and climate influences (Reithinger et al., 2007). There is also evidence that climate affects sandfly numbers which has an impact upon leishmaniasis cases. Cross et al., (1996) noted that the vector is affected by environmental conditions especially temperature and rainfall. In Argentina Salomon et al., (2008) showed that the activity season of one sandfly species sharply increased during the rainy season and decreased during the months of lower rainfall or higher temperatures. Hunter, (2003) mentioned that the increased rainfall can lead to an increase in vegetation, allowing expansion in the population of vertebrate host. An increase in sandfly populations can lead to an increase in the occurrence of leishmaniasis (Gage et al., 2008). There is therefore, much evidence that weather is important for leishmaniasis.

Monthly averages of CL cases in all Asir Region during the study period show transmission throughout the year. However, there is a clear seasonality with peak incidence between October and March, with the highest average number of cases in January. The average number of cases during the summer is lower, with the lowest number of cases in June. There was a high standard deviation in most months which indicates that there is a large variability from year to year in monthly CL cases. Most of the CL cases in Asir are in the first group (highlands) and so the monthly patterns of cases are similar between the two. There is much less seasonality in the lowlands than in the highlands group with the peak cases occurring between February and June, with the highest cases in March. Cases numbers in the rest of the year are little lower, with the lowest cases in September.

In the results, CL incidence was compared to temperature across Asir. The results presented evidence that temperature is an important factor affecting variation in CL cases but only during the summer (June to September). Elevated maximum temperature in the 2-4 previous months was highly significantly associated with leishmaniasis cases ($P<0.001$). This result was nearly identical in the highlands group, which is unsurprising as most cases in Asir occur in the highlands. This result is plausible as the lags indicate that temperature during the end of winter and early spring affects leishmaniasis cases in the summer. During the end of winter and early spring temperatures are generally low (around 10 to 20^{0}C) and so elevated temperature may have positive effects upon the vector. There was no effect in the lowlands indicating that temperatures are never a limiting factor for Leishmaniasis. In the lowlands winter temperatures are usually higher (20 to 25^{0}C). The influence of temperature is supported in the literature and Cross et al, (1996) state that the vector is affected by environmental conditions, especially temperature. Hunter, (2003) and Gubler et al., (2001) state that there are some possible mechanism changes in the influence of temperature on the transmission of vector borne disease. Most of the CL cases in this study are from highland areas, and the highest average maximum temperature in the representative area occurs in June (32.26). In some parts of India one of the studies revealed that the sandfly were found only at temperatures between 17 and 36°C (Singh, 1999). Therefore the highlands might provide the optimum temperature for the vector during summer and then the activity of sandfly is likely to increase with this temperature.

The study shows that the increase of temperature during summer can lead to an increase of CL cases in the whole of the Asir Region and also in highlands group. However, there was no evidence for a relationship between maximum temperature and CL cases in the lowlands group. This is slightly unexpected as the highest average maximum temperature occurs in June which reaches over 40^{0}C. Adults and larvae are sensitive to high temperature and in laboratory experiments, all adult sandflies died within two hours at temperatures above 40°C (Cross and Hyams, 1996). A negative association with maximum temperature in the summer might therefore be expected. The lack of a result suggests that sandflies find mechanisms to avoid these high temperatures

Maximum, mean and minimum temperatures in Asir are highly correlated. However, maximum temperature in Asir was most strongly associated with leishmaniasis cases. This suggests that maximum temperature is most related to the temperatures experienced by the sandflies but the reasons for this are unclear.

Within the whole of Asir and in the highlands there was no evidence that rainfall impacted on CL cases. This may indicate that rainfall has no impact or influence on the species of sandflies in the highlands. In the lowlands group, there was evidence that increased rainfall can lead to increased cases of Leishmaniasis.

There is a highly positive significant relationship between the average rainfall in the 1-3 previous months and CL cases between (March and November). This indicates that rainfall provides suitable conditions for the vector but in the lowlands only. Hunter, (2003) noted that increased rainfall can increase vegetation growth and allow expansion in the population of vertebrate hosts, therefore this can increase the infected sandfly numbers and thus the possibility of CL cases. MOH in Saudi Arabia, 2000 has mentioned that there is a highly significant correlation between the density of sandfly and positive cases. This is because after rainfall it takes time for increases in sandflies to occur.

In Pondicherry, India, summer rainfall is followed by an increase in the population of sandflies (Sirnivasan et al., 1993). Also some studies in Colombia stated that drought followed by rainfall increases the occurrence of CL (Cardenas et al., 2006; Gage et al, 2008). Cross et al., (1996) noted that the vector is affected by rainfall. Therefore, these conditions can lead to increase the vector, thus the occurrence of CL. Our results suggest that in the lowlands area of Asir there is no enough rainfall for vegetation. This means that when there is rainfall there is more sandflies and hence leishmaniasis. The weather in these areas is drier. It is therefore not surprising that more rainfall may lead to more vegetation and hence more sandflies and leishmaniasis.

Some studies note that humidity is one of the most important weather factors for sandfly survival, development and activity (Cross and Hyams, 1996; Sirnivasan et al., 1993; Kasap et al., 2009), but the results of this study do not show evidence that there was a significant relationship between relative humidity and CL cases for Asir or any of the endemic areas. This interpretation is slightly limited by the absence of humidity data in the lowlands. This contradiction could be due to the different location of this study. It also could be due to the increase in humidity which is associated with other weather factors, such as high temperature, which have shown themselves to be significant in the model.

In summary, this study showed that weather factors play an important role in affecting CL cases. Temperature was the most important factor associated with CL in all Asir and in the highlands area during the summer and beginning of autumn. If the maximum temperature in the previous 2 to 4 months was elevated there were more cases. Rainfall plays an important role in CL transmission in the lowlands with greater cases if rainfall is elevated in the previous 1 to 3 months. This occurs in all months except during the winter season. Although this study shows that weather has an influence upon CL in Asir, it is important to recognize that leishmaniasis cases are becoming less of a problem in this Region. Overall, the study shows that the total number of yearly CL cases has declined to one third of cases in the nineties by the end of the study period. The reasons for this were provided in the literature review.

Chapter 5

Influence of Climate Variables upon Schistosomiasis Cases in Asir Region, Saudi Arabia

5.1 Introduction

Schistosomiasis, also known as Bilharzia, is a parasitic disease caused by parasitic worms called schistosomes that leads to chronic ill health in humans and is second only to malaria in terms of public health importance (WHO, 2005). Over one billion humans are at risk worldwide, and it is estimated that 200 million people worldwide are infected with the snail-transmitted, water-borne parasite leading to 1.53 million disability-adjusted life year (Gryseels et al., 2006). Also 20,000 deaths are associated with the severe consequences of infection, including bladder cancer or renal failure (Schistosoma *haematobium*) and liver fibrosis and portal hypertension (S. *mansoni*) (CDC, 2010). It is also easily transmitted from developing countries to developed countries (Hussein et al., 2008).

Schistosoma (Figure 5.1), are blood-flukes, including flatworms which are responsible for the parasitic infection which causes schistosomiasis (WHO, 2007). The worms responsible for the disease were discovered in 1851 by Theodor Bilharz, a German pathologist, from whom this disease took its name, Bilharziasis (Appleton et al., 1977).

Schistosoma needs fresh water to survive, so it can be found in and around water, i.e. rivers, streams, dams and lakes in endemic areas. Wherever people are in contact with water during their normal daily activities, such as recreation and irrigation, they are at risk. Children are nearly always the most heavily infected since they spend some of their time playing and swimming in water, and also because their natural immunity is less than in adults (Amin et al., 1995). Therefore, this disease has an especially detrimental effect on the growth and development of children (Hussein et al., 2008).

Adult worms can lay hundreds of eggs (Figure 5.2) each day while they are inside humans, and these eggs are excreted in human faeces or urine. This leads to the water becoming contaminated by Schistosoma. The parasite lifecycle is completed when these hatch into miracidia which then infect the intermediate snail host (Figure 5.3) (WHO, 2007).The snails release cercaria into the water which may infect other people who come into contact with this water.

Figure 5.1*: Different single parasites of schistosoma (WHO, 2009)*

Figure 5.2: *Single egg of schistosoma (CDC, 2010)*

Figure 5.3: *Schistosoma snail host (CDC, 2010)*

5.2 Species of Schistosomes and Geographical Distribution

Schistosomiasis is found in tropical countries in Africa, Caribbean, eastern South America, East Asia and in the Middle East (**F**igure.5.4) (WHO, 2004). There are five species of water-borne flatworm, or blood flukes, called schistosomes (WHO, 2007; CDC, 2010):

- Schistosoma *mansoni* which cause intestinal schistosomiasis, occurs in Africa, the Eastern Mediterranean, the Caribbean and South America,
- S. *Japonicum* group of parasites, which cause Oriental or Asiatic intestinal schistosomiasis. It is endemic in South-East Asia and in the Western Pacific region.
- S. *mekongi* in the Mekong river basin which cause Oriental or Asiatic intestinal schistosomiasis. It is endemic also in South-East Asia and in the Western Pacific region.
- S. *intercalatum* has been reported from central African countries. It causes another Intestinal schistosomiasis.

• S. *haematobium* is endemic in Africa and the Eastern Mediterranean. It causes Urinary schistosomiasis.

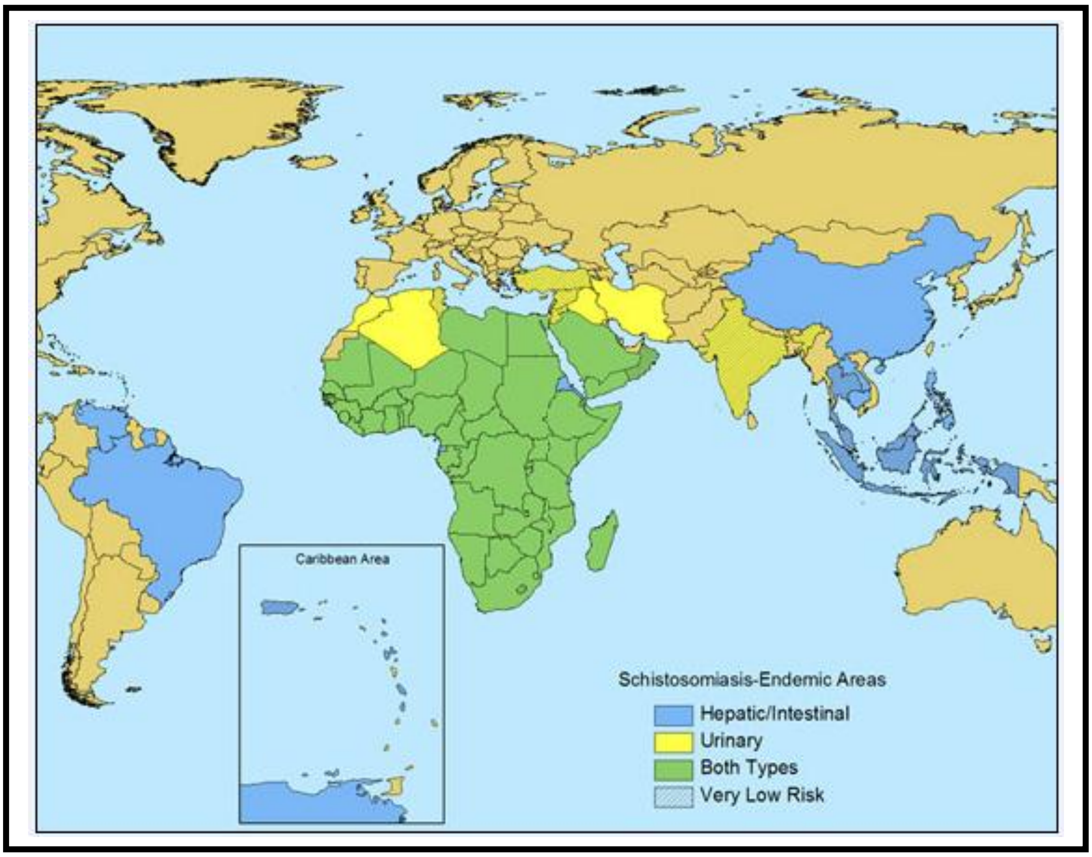


Figure 5.4: *Distribution of schistosomiasis*

5.3 Infection and Life Cycle of Schistosomiasis

Infection occurs when people come into contact with contaminated fresh water including infected snails (which carry schistosomes). The life cycle of the human schistosomes are generally similar, and involves many steps (CDC, 2010; Amin et al., 1995).

Figure 5.5 (CDC, 2010) shows the life cycle of schistosomiasis. The cycle begins when infected people urinate or defecate in fresh water. This water becomes contaminated by Schistosoma eggs. The eggs hatch releasing larva (miracidium), and this larva searches for appropriate snails in the water. The miracidium penetrate into snails, grow and develop inside the snails and transform into a mother sporocyst. About a week later this mother will give rise to many daughters which after 3-4 weeks will produce cercarae. These are sexually differentiated, into male and female. The cercaria of schistosomes is usually released 25 to 30 days after the snail has been infected. It can penetrate the skin of people who come into contact with contaminated water. During penetration the cercarae lose their tails and become schistosomes. Within several weeks, the worms grow, multiply and develop inside the blood stream. They then pass to the right side of the heart and the lung and produce eggs when they reach the liver. Some of the eggs go to the bladder or intestines and are passed into urine or stools. This human cycle is usually completed in 30 to 45 days.

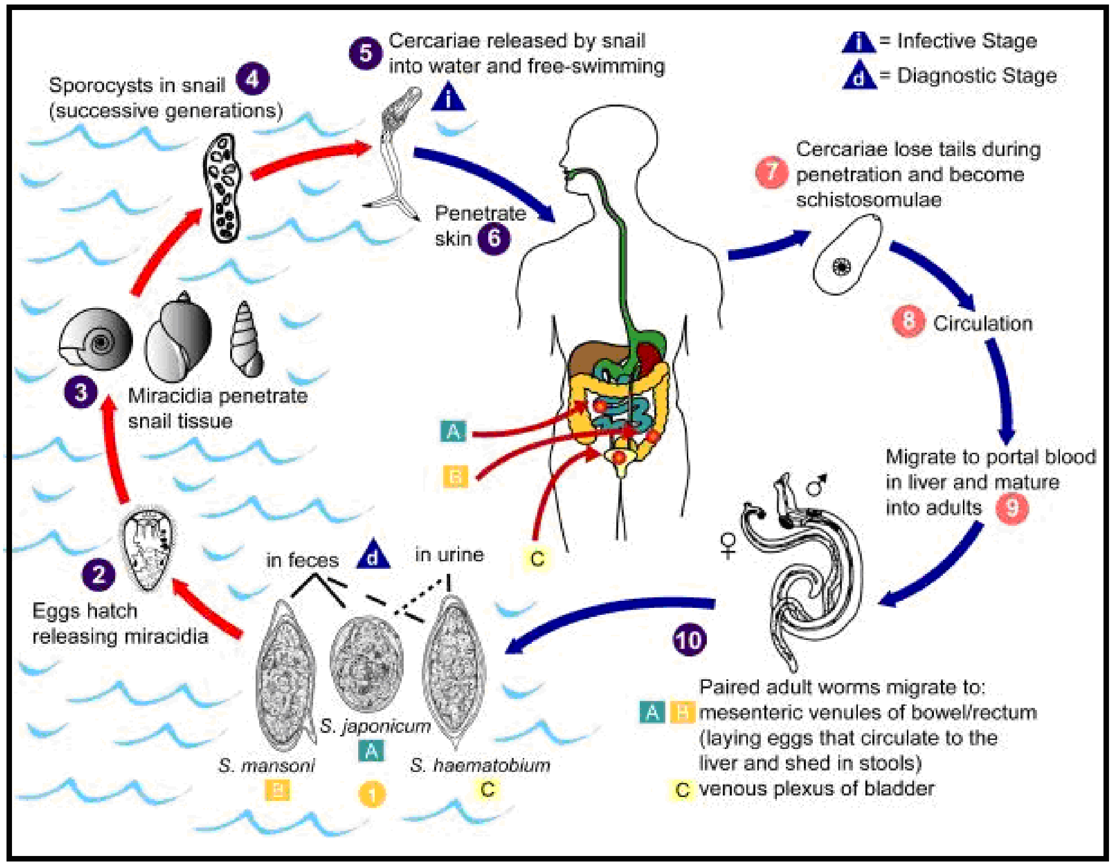


Figure 5.5: Life cycle of schistosomiasis (CDC, 2010)

5.4 Symptoms and Diagnosis of Schistosomiasis

Many infections are sub clinically symptomatic (CDC, 2010; WHO, 2005), with mild anaemia and malnutrition being common in endemic areas. Acute schistosomiasis may occur 7-14 weeks after the initial infection depending on the species of snail, parasite, climate variables, environment and source of water (Amin at al., 1995). There are two main stages of schistosomiasis; the early stage of schistosomiasis includes itchiness of the skin, bloody mucous stools, fever, cough, diarrhoea, abdominal pain and dysenteric attacks. The late stage of schistosomiasis includes; Hepatosplenomegaly (the enlargement of both the liver and the spleen) (Figure 5.6), weight loss, severe liver disease, anaemia and jaundice. It can also cause bladder cancer, kidney problems or complications of the liver and spleen.

Microscopic identification of eggs in the stool or urine is the most practical method for diagnosis. The stool examination is the more common of the two (Amin et al., 1995).

Figure 5.6: *The enlargement of the liver and the spleen (Medical Ecology, 2004)*

5.5 Control of Schistosomiasis

WHO state that there are three main methods that may be used to control schistosomiasis (CDC, 2010; WHO, 2005; Amin at al., 1995): Parasite control (Treatment), control of transmission and health education.

5.5.1 Parasite Control (Treatment)

The main schistosomiasis treatment drug is praziquantel using a single oral dose annually. When outbreaks of schistosomiasis occur it is often not practical to test all individuals for schistosomiasis especially as some individuals may show few symptoms. Therefore WHO, 2005 has developed guidelines for community treatment of schistosomiasis based on the impact of the illness on children (children being more susceptible) in endemic villages:

1. If more than 50% of children have blood in their urine (a symptom of schistosomiasis) then everyone in the village should receive a treatment.

2. If 20 to 50% of children have blood in their urine, only school-age children are treated
3. But if less 20% of children have these symptoms, mass treatment is not implemented.

5.5.2 Control of Transmission

Methods of control of transmission include snail control and prevention of human water contact.

Control of snail:

- Molluscicides: Snails can be controlled through the spraying of molluscicides in locations where snails breed. Examples include valleys, wells, dams, streams, vegetation, algae and any areas where individuals may be exposed to snails (Figure 5.7) (Amin at al., 1995). Hand or power spraying is the recommended method for stagnant or slow running water in ponds, marshes, lake shores and wells where the parasite and snails may be present. For flowing water in small rivers, streams, irrigation canals, the application of molluscicide through drip-feed methods in recommended. In these the chemical is applied continuously at one dispensing point upstream of any stretch of water to be treated and is carried downstream killing snails along the length of water course.
- Environmental management: This includes the elimination of snails and changing their habitats by removing vegetation, filling rain pools and removing snails (Figure 5.8) (Medical Ecology.org., 2004). Secondly, improving water supply and sanitation for communities, as the provision of safe water for drinking and domestic activities and adequate sanitation systems have been proved to be effective in reducing human water contact. This is the top intervention priority for the control of transmission (Medical Ecology.org., 2004). Safe drinking water can be provided through the use of deep and surface wells, and the filtration and treatment of stream water. Prevention of human water contact can also be effected by fencing off stretches of water, bridging streams and providing safe laundry facilities. Also improving sanitation facilities can also be effected (Amin at al., 1995).

Figure 5.7*: Spraying of molluscicides in locations where snails breed in Asir, Saudi Arabia (The Vector Control Administration in Asir Region, 2007)*

Figure 5.8: *Removing vegetation, filling rain pools and removing snails in Asir (The Vector Control Administration in Asir Region, 2007)*

5.5.3 Health Education

Co-operation among related agencies is required to communicate to people that this illness is dangerous to their health. People should be urged co-operate with the health team, avoid contact with water at high risk sites, and avoid urination or defecation in or beside water. The message can be spread through schools, gatherings e.g. religious gathering, or through face to face contacts in primary health care centres or any health point. Leaflets and posters at water contact points or schools are other methods through which such information can be spread. As children are most at risk education can be challenging because children love playing in water (Amin at al., 1995).

5.6 Seasonal Influences on the Transmission of Schistosomiasis.

Snails play a very important role in the transmission of schistosomiasis, and snail population sizes, rates of infection, and the production of cercaria are strongly influenced by climate. This therefore affects the rates of transmission of the disease. There are several environmental factors that can affect the density and viability of snail populations (Medical Ecology, 2004; Davis et al., 2002):

- Water levels, affected by rainfall, are critical as the optimal snail habitat occurs in a narrow zone of elevation above mean low water. In arid areas rainfall is required to provide suitable snail habitat. Annual floods in some environments can drown many, if not the majority of the adult snails. In areas where there is continuous flooding some species of snail live for about one year. Where there is no flooding, the species can live twice as long, and often longer.
- Temperature can also have an impact on the snail population as when temperatures in the water fall below 10°C or exceed 30°C both adult snails and their eggs may die.
- Elevation also plays an important role in the density of snail populations. The optimum habitats for the snails are flat, mid-level land with some dry-season ponds, and also thick grass.

5.7 Previous Studies

There are very few studies that look at the direct influence of weather upon schistosomiasis cases. Therefore this section will try to present the available studies which examine the relationship of weather conditions to snail populations followed by the parasite. The few studies on weather and schistosomiasis cases will then be presented. We will present studies from around the world before focussing upon those conducted in the Middle East and finally in Saudi Arabia and the study area Asir Region.

5.7.1 The Influence of Weather on the Snails Hosts

One study in Senegal examined seasonality in the transmission of schistosomiasis (Sturrock et al., 2001). Quantitative snail surveys were conducted over 3 years from 1992 at sites representing different habitats in and around an irrigation scheme. Water temperature affected snail survival and reproduction and this concurred with Appleton’s research (1977). All snail populations grew rapidly and numbers peaked in late spring and early summer depending on the habitat. They then dropped sharply in the heat of the summer as water temperatures reached their peak. Numbers remained relatively low until the following spring, with most transmission between May and August each year.

Pimentel-Souza, et al (1988) studied the influence of experimental illumination and seasonal variation on the snail Biomphalaria Glabrata, a snail vector of schistosomiasis in Brazil. The data were counted throughout the year under two regimes (12h light and 12h dark from 7am to 10pm). The researchers state that, as found in some previous studies, water temperature has an influence on egg-laying, hatching and survival for the schistosomiasis vector snails. An increase of temperature during winter and autumn leads to more mating activity, but when the temperature starts to decrease the mating count decreased. Another study in Brazil (Pimentel-Souza et al., 1990) stated that a higher rate of egg production was observed at water temperatures between 20.0 and 27.5°C, and the number of eggs / snails / day reached a maximum within this temperature range. A statistically significant lower number of all these was observed at lower temperatures around 17.5°C.

Barbosa et al., (1987) studied the effect of temperature on the reproductive rate in snails as these are a vector of schistosoma manisoni. The snail data were collected between summer 1981 and spring 1982 and the experiments were in the middle of each season. Reproduction was measured by egg production, number of clutches and hatching, and the highest rates occurred during winter and low rates during the_summer. Although there was not a high correlation between the rates of reproduction and temperature, the highest mean number of hatching, clutches, and number of snails per day were recorded in winter. Following this lower numbers occurred during the autumn then spring with the lowest occurring during the summer. The variation in temperature for this study during the year was from 19.5 to 26.3°C.

This study confirmed that during winter the density of snails increases in tropical zones such as Egypt (El-Hassan, 1974), and Brazil (Barbosa, 1970). However it increases during summer in temperate zones such as South Africa. This is probably due to the optimum temperature for snails, as in temperate zones temperatures are most suitable in the summer (Appleton, 1977).

Michelson, (1960) studied the effects of temperature on the growth and reproduction of australorbis glabratus (a genus of planorbid freshwater snails) in the laboratory. Michelson mentioned that temperature may influence the ability of miracidia to infect snails and also the development of the schistosoma larvae within snails. It may also affect cercarial emergence and thus the infectivity of cercaria for the mammalian host. He states that the optimal temperature for rapid growth was at 30°C. However this range is different to that found in Brazil (Pimentel-Souza et al., 1990) which stated that a higher rate of egg production was observed at temperatures between 20.0 and 27.5°C.

A study of infections with larval stages in snails was carried out in Qena Upper Egypt (Hussein et al., 2008). The result of this study showed that the highest numbers of infected snails collected were during January followed by September, whereas the lowest number appeared in June as this is the hottest month in Egypt. The influence of climate was clearly shown and the number of snails peak in winter and autumn, and decrease in summer and spring.

In the Jequitinhonha Valley, Brazil, Kloos et al., (2004) studied the schistosoma in all aquatic snail habitats in a rural area. Snail and environmental surveys were carried out from July 2001 to November 2002. One of the major objectives of this study was to examine the seasonal distribution of schistosoma *mansoni* infections in this area. Larger snail numbers were found in standing waters from October to March during the rainy and hot season, but the densities were higher in streams and canals from April to September during the dry season. Also a significantly larger mean number of one of the snail species (*B. glabrata*) was found in the rainy season $P<0.001$.

In a study in the Jos metropolis area of Nigeria, Agi (1995) noted that the population of *Bulinus sp.* snail increased during the summer with the peak occurring in June and that the number of these snails decreased during March. The researcher mentioned that the seasonality of the snail population was attributed to changes in the rainfall pattern. The rainy season in this part of the country occurs during summer when more snails were found.

5.7.2 The Influence of Weather on the Parasite of Schistosoma

Adult infection-free schistosoma japonicum harboured in Oncomelania hupensis were collected from Jiangsu province in eastern China by Yang et al., (2007). In one of the experiments carried out under laboratory conditions, they investigated the effect of temperature on the development of *S. japonicum*, and have also tried to determine the lowest temperature at which the hibernation of *O. hupensis* occurs.

The findings state that a positive relationship exists between temperature and the development of *S. japonicum*. The effect of temperature on the prepatent (early stage) periods was highly statistically significant ($P<0.001$) as the average development rate / day of the snails increased with rising of temperature. At 21°C, 24°C, 27°C and 30°C the development rates were 0.008, 0.011, 0.014 and 0.016, respectively. The lowest thermal temperature derived from this regression is 15.3°C (lowest temperature at which development occurs). These findings indicate that the transmission of schistosomiasis will be increased if climate change leads to a warmer China.

Coelho et al., (2006) evaluated the influence of temperature on schistosoma *mansoni* infection in Biomphalaria glabrata. Lower temperatures led to the lowest infection level. The influence of temperature upon infection at 15°C was significantly less than it was at 20°C ($P < 0.01$). At 20°C it was significantly less than it was at 30°C ($P<0.01$).

5.7.3 The influence of weather upon schistosomiasis illness

A recent epidemiological study for schistosomiasis disease was carried out in two local areas of Benue State in Nigeria (Houmsou et al., 2009). Seven hundred and fifty urine samples were obtained from different parts of the community between November 2008 and March 2009. The greatest risk and prevalence of infection was during the dry season (P<0.01), but there was no significant difference in infection rates between one month and another. The highest incidence of schistosoma infection was recorded during February and March (52%) for each. The paper suggests that this may be due to the hot season in this area during these months.

In Morocco climate variability may have contributed to the prevalence of schistosomiasis during the 1980's. The severe drought in that period led to a lack of water, and a reduction in the number of intermediate snail hosts of the parasite of this illness. Also the lack of rainfall especially in the Ouarzazate area of Morocco, led to the drying out of the breeding sites of Bulinus truncatus, hence stopping the transmission cycle of the schistosomiasis (Laamrani et al., 2000).

5.7.4 Studies in Saudi Arabia

Several studies on schistosomiasis in Saudi Arabia have been carried out, but most of them do not examine the influence of weather in detail. Problems in the control of schistosomiasis in Asir Region have been studied by (Al-Madani, 1991). This study discussed some factors of this region such as geography, climate, hydrographical conditions, sources and spread of infection, and the role of primary health care centres. This information is used to establish appropriate plans for the control of this disease.

This study mentioned that rainfall and streams are the major sources of water in Asir region and that vector snail habitats are found in streams in the highlands. After heavy rainfall these streams carry the snails from the highlands down to the lowlands where the flood water accumulates and the snails exist in pools and dams. Sources of the infection of this illness are also mentioned, for example when expatriates from endemic countries come to work in this region and become an important source of infection. Also in the past there were not enough specialists and field technicians in the region to implement an appropriate program to control schistosomiasis. The paper makes many suggestions to improve the control program including; Activate the cooperation and coordination between different ministries and agencies involved in the control program and joint committee meetings with related department in this region (e.g. Water & Electricity Department, Agriculture and Municipality). Also provide safe drinking water supplies, an adequate sanitation system and provide health education to the residents. Furthermore specialized training programs should be established such as health education programmes and training for the professionals of the primary health care centres. Routine population check-ups for this disease should be carried out by these centres thus giving them a more active role in schistosomiasis prevention.

A recent study in Asir region, Saudi Arabia, has been carried out and considers the factors affecting the prevalence of schistosomiasis (Shati, 2009). He compared two sectors in Asir; Abha (highlands) and Tehama (lowlands), over eight years (2000-2007). Over the period a decline in the number of cases was noted and there were significantly more cases in the highlands in comparison to the lowlands. The infection rate in the highlands during summer was high, but there were no significant differences in infection rates between seasons in the lowlands. So the prevalence of the illness was significantly affected by season (summer) in the highlands only. The study mentioned that many biotic factors can play an important role in schistosomiasis prevalence such as rainfall which usually increases during summer in some parts of the highlands. This increase can be followed by a rise in schistosomiasis cases in the highlands area. As was found in other studies, the researcher noted that the increase of schistosomiasis prevalence in this area usually peaks during the wet season. In the highlands the temperature during winter can drop to less than ten degrees, and the literature review has demonstrated that such temperatures are unsuitable for schistosomiasis transmission. However in the lowlands temperatures during winter season are more suitable. In the summer temperatures are very high in the lowlands which may provide unsuitable conditions for schistosomiasis transmission. Thus temperature can affect schistosomiasis transmission. The study showed that there was a decrease in the prevalence during the study period, and this may be due to Ministry of Health control program.

5.7.5 Literature Review Summary

Table 5.1 summarises the main studies (statistically) of the correlation between schistosomiasis or snails and climate variables.

__Table 5.1__: Summary of the main studies relating to schistosomiasis

No	The author	Place	Dependent Variable	Independent Variable	The relationship & Lag time (month)
1	Appleton, 1977	Senegal	Number of snails	Water Temperature	Negative
2	Pimentel-Souza, et al 1988	Brazil	The mating count of snail	Water Temperature	Positive
3	Barbosa et al., 1987	Tropical. South Africa	density of snails	Water Temperature	Negative in tropical Positive in South Africa
4	Hussein et al., 2008	Qena Upper Egypt	numbers of infected snails	Water Temperature	Negative
5	Kloos et al., 2004	Jequitinhonha Valley, Brazil,	numbers of snails	Water Temperature Rainfall	Positive Positive
6	Agi, 1995	Nigeria	numbers of snails	Water Temperature Rainfall	Positive Positive
7	Yang et al., 2007	Eastern China	Snails (*S. japonicum*)	Temperature	Positive
8	Coelho et al., 2006	laboratory conditions	schistosoma *mansoni*	Temperature	Positive
9	Houmsou et al., 2009	Benue State, Nigeria	infection rates	Temperature Rainfall	Positive Negative
10	Laamrani et al., 2000	Morocco	Transmission of schistosomiasis	Rainfall	Positive
11	Al-Madani, 1991	Asir Region, Saudi Arabia	abundance of snails	Rainfall	Positive
12	Shati, 2009	Asir Region, Saudi Arabia	schistosomiasis infection	Temperature	Positive in highlands Not significant in Lowland

The literature review highlights a number of important points:

1. There are few studies which look at the influence of weather upon schistosomiasis cases.
2. The weather influences vary by location.
3. Time lags between weather and infection are likely to be between 3 and 9 months depending on the location and type of schistosomiasis, weather variables and other factors.
4. Different climate variables such as temperature and rainfall may influence schistosomiasis.
5. Some studies investigated the influence of weather upon the populations, survival and reproduction of the schistosomiasis host (snail). Others found that the host abundance has an effect upon the incidence of the illness.

6. Some studies showed that climate variables have an impact upon schistosomiasis incidence. However, the impact of specific weather variables can be either positive or negative depending upon the geographical setting and season.

Based on the findings of the previous studies, it is clear that there is an urgent need to research the influence of weather upon the host (snail) and parasite of schistosomiasis in the endemic areas of Saudi Arabia such as Asir Region. Building upon the literature review such a study should examine a wide range of weather variables and also consider that any relationships with the weather may vary seasonally. A statistical analysis for this disease seems the most appropriate study design and this may need to consider factors such as autocorrelation in the data.

5.8 Schistosomiasis in Saudi Arabia

There are three main species of schistosomiasis in this country; urinary, intestinal and combined schistosomiasis. The geographical distribution during 2007 for urinary schistosomiasis (MOH, 2008), shows that this illness is endemic in Makkah, Madinah, Jazan, Asir and Lithe Region. However intestinal schistosomiasis is endemic in Taif, Albahah, Asir, Bishah, Najran, Makkah, Madinah, Hail, Jeddah and Jazan Regions. The snail responsible for both types of schistosomiasis exists only in Jazan, Makkah, Asir and Madinah Region. Combined schistosomiasis has been recorded in Asir Region (MOH, 2008).

Schistosomiasis used to be one of the most important public health problems in Saudi Arabia, especially in southern regions. In terms of trends over time Figure 5.9 presents the number of schistosomiasis cases in Saudi Arabia from 1980 to 2009. This figure shows a sharp decrease of cases throughout this period, with the highest number of cases occurring in 1983 (25985 cases). There was a dramatic increase from 1980 (9880 cases) to 1983. The number of cases in 2009 is less than 3% of the level in 1980.

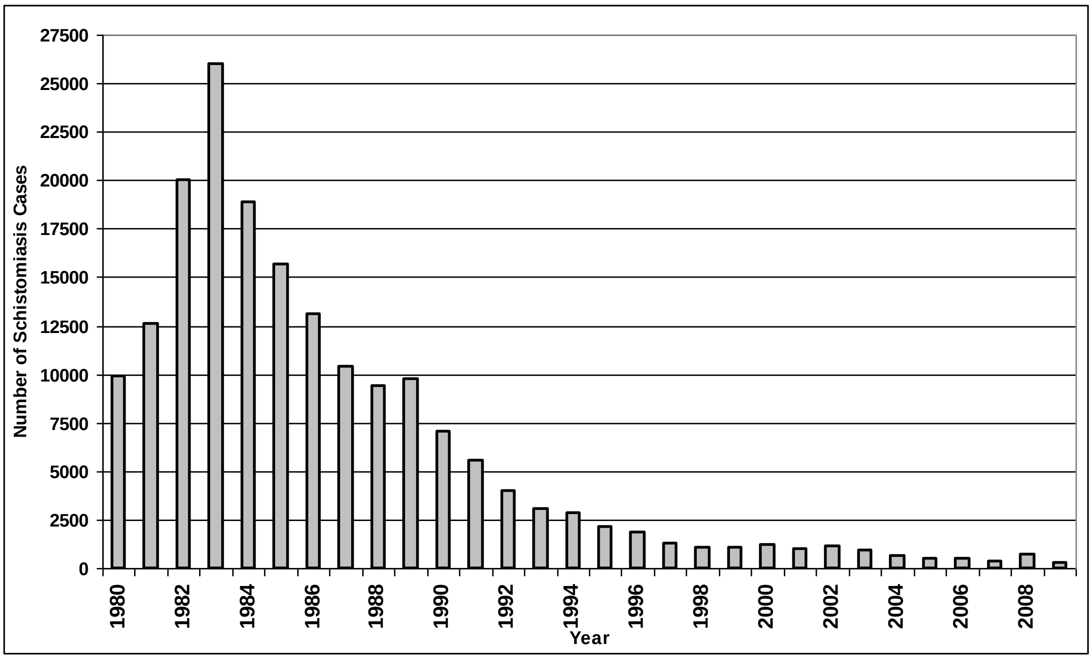


Figure 5.9: *The number of (schist) cases in Saudi Arabia (1980- 2009)*

The prevalence rates of this illness in 2007, 2008 and 2009 were 1.52/100,000, 2.80/100,000 and 1.14/100,000 respectively. Urinary schistosomiasis in all of Saudi Arabia in 2007 was 24.6% of all cases while intestinal schistosomiasis was 75% and the combined illness represented just 0.4% (MOH, 2010).

The statistical year book (MOH, 2006) states that the highest percentage of all cases types in 2005 was found in Asir Region (39%), followed by Jazan, Bishah and Albahah Regions (27.6%, 16.3% and 9.9% respectively) (Figure 5.10). All these regions are located in the south of Saudi Arabia.

One study in Asir Region (AI-Madani, 1991), reports that both intestinal and urinary schistosomiasis have been reported. The topography of Asir region and different weather conditions between sectors create difficulties for schistosomiasis control in the Region. However, improvements to primary health care centres are the most important factor for better control of this disease (AI-Madani, 1991).

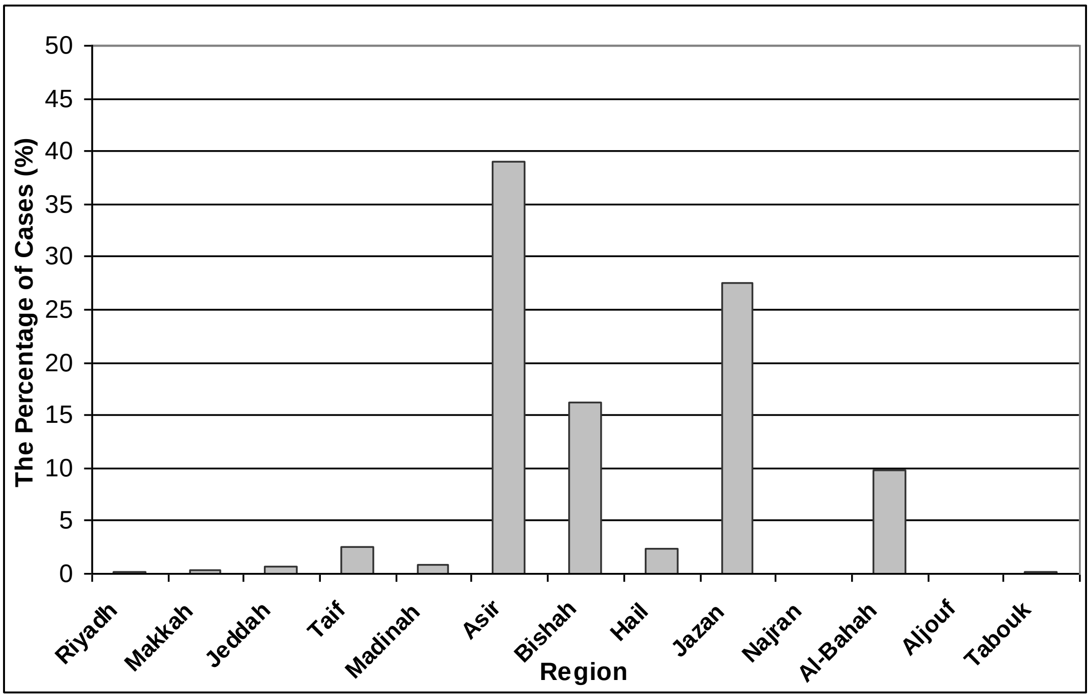


Figure 5.10: *Comparison of schistosomiasis among regions of Saudi Arabia 2005 (MOH, 2006)*

5.9 Schistosomiasis in Asir Region (Study Area)

This study will focus on schistosomiasis cases in Asir Region and its subsectors. The prevalence of this illness and its transmission is influenced by little known geographical and climate factors such as temperature, rainfall and humidity (AI-Madani, 1991; Amin et al., 1995; Shati, 2009).

The topography of Asir Region may be one of the main factors which contribute to the difficulty in controlling of schistosomiasis. This topography helps in disseminating the snails from the highlands to lower areas thus repopulating free habitats in the lowlands with the intermediate hosts (Al-Madani, 1991). Also the presence of many inaccessible water sources in the highlands which are infested with snails makes control difficult. Additionally some parts of this region are inhabited by bedouins who move from one area to another searching for water. These people use water in the valleys as the main source for their daily activities. It is therefore difficult to stop schistosomiasis transmission as valley water is part of their everyday live. Education may also be problematic. Within Bedouin tribes it is also difficult to locate the infected individuals and provide them proper treatment. Without treatment these individuals become part of the life cycle of schistosomiasis (Almadini, 1991; Shati, 2009).

5.10 Topographical Classification of Asir Region and Endemic Areas

Topographically, climatically and endemically this region can be divided into three main sectors in terms of schistosomiasis transmission (Dr A. Abdoon 2007 pers. Comm.) (Figures 5.11 and 5.12):

1. Highlands Areas: a series of high lands which extend from the north of Asir Region to the south along the coastal plains of the Red Sea (2000 -~3000m above sea level). It is one of the coldest areas in Saudi Arabia and has the highist annual rainfall (500mm), raining almost every month, in spring and summer (MEPS, 2007; Subyani, 2000). This area covers districts such as Abha, Khamise, Tanoma, and Dhahran. The annual average temperature for this sector is 17.7^{0}C, and the annual average relative humidity 53.1%. These areas have the highest occurrence of schistosomiasis in and it can be divided into two sections depending on the endemicity:
    a. Southern Asir Sarawat Mountains and their sectors
    b. Sabt-Alalaya Sector (North)

2. Asir Plateau (a part of Highlands); is in the east of Asir region with an elevation range between 1000 and 2000m decreasing to the east. This area covers the districts such as Tathlith, Almadha and Bishah. The annual average temperature for this sector is 19.5^{0}C, with 250mm annual rainfall and annual average relative humidity of 44.4%. This sector has many wadies all flowing eastward. According to local sources (Dr A. Abdoon 2007 pers. Comm.) there are few cases of schistosomiasis in this area as a result of a low amount of rainfall during the last two decades in this sector.
3. Tehama (Lowlands): This area receives an annual rainfall of more than 350mm, and temperature ranging between 25^{0}C and 49^{0}C, with relative humidity varying from 55% in summer to 70% in winter. Depending on the altitude this area can be divided into two areas: foothills between 300 and 900m such as Al-Majaredah, Muhail and Rejal-Alma. This area has a moderate occurrence of schistosomiasis. However the coastal area which is between 0 and 200m (Costal Plain Red Sea)

has the fewest cases of schistosomiasis in the region such as Al-Gahma and Al-Berk.

5.11 Rationale and Hypotheses

The influence of weather upon schistosomiasis cases is important to understand for a number of reasons:

1. Based on the findings of this study and an understanding of how schistosomiasis is affected by weather it should be possible to design an early warning system to predict schistosomiasis cases. This would also be useful for health service planning and hence to develop good and effective control programmes, for example identifying periods when enhanced molluscicides spraying is required.
2. If weather alters under climate change then this data could help predict the impact of this change on schistosomiasis in Asir Region.
3. It can help clarify the important modes of transmission in the region.
4. It improves our understanding of disease transmission dynamics.

This study tests the hypotheses that there are relationships between weather (maximum, mean and minimum temperature, rainfall and relative humidity) and schistosomiasis cases in Asir Region. In addition this study was also able to make use of a dataset of snail abundance to examine how numbers of the host in Asir Region are affected by the same weather factors. It also enabled us to examine the relationships between schistosomiasis cases and snail numbers.

5.12 Data and Method

5.12.1 Sources of Data

Official letters were issued, instructing authorized personal to collect health and weather data. The numbers of schistosomiasis cases and snails in each month from the first of Jan 1998 to the end of Dec 2009 for the whole of Asir Region were obtained from the Vector Control Administration, Health Affairs Directorate in Asir. The data represents all reported cases of schistosomiasis in Asir region and have been collected from all hospitals and primary health care centres (public or private) and the Main Parasitology Laboratory in Abha (Annual reports, 1998- 2009). The reported schistosomiasis cases were confirmed in different ways depending on the type of this disease. Urinary schistosomiasis cases were confirmed by a person with visible haematuria or with a positive reagent strip for haematuria or with the eggs of S. *haematobium* in urine (microscope). Intestinal schistosomiasis were confirmed by a person with eggs of S. *mansoni*, or S. *japonicum* / *mekongi* in stools (microscope) whether chronic or recurrent intestinal cases. This study will not consider each type of this disease separately but will consider both types together for the statistical analysis. The snail data were collected by teams from the Vector Control Administration and Primary Health Care Centres in different endemic areas across Asir region. The control program for Schistosomiasis in Asir consists of collecting and removing snails from areas where they are likely to occur. These include valleys, wells, streams, water pools and dams. It is acknowledged that these methods of control have not been very effective (Al-Madani, 1991). As part of this process the removed snails are counted and typed. These counts are the input data used in this study. The professionals and experts of this disease with their field teams collect snails throughout the year particularly during the seasons when snails are anticipated (Dr A. Abdoon 2007 pers. Comm.; Annual reports, 1998- 2009).

Weather data for Khamise, the lowlands and Sabt-Alalaya sector were obtained from sources mentioned in the last 2 chapters. All the locations of weather stations in Asir Region are illustrated in Figure 5.12. The aim of this collection was to obtain corresponding weather data for each sector within Asir. However, this proved impossible due to the limited availability of data for many sector within Asir.

5.12.2 Classification of Data:

As a consequence of wide differences in topology and weather within Asir, there are likely to be differences in schistosomiasis between sectors. There are fourteen sectors in Asir (Figure 5.11): Abha, Khamise, Ahad-Rifadah, Al-Madhah, Tathlith, Sarat-Abedah, Dhahran-Aljanoub, Tanoma, Rejal-Alma, Majaredah, Muhail, Al-Berk, Al-Gahma and Sabt-Alalaya.

The limited weather data available across Asir imply that it is not possible to examine the associations between schistosomiasis cases and weather for each endemic sector in Asir individually. It is therefore, necessary to group sectors together. Differences in incidence between sectors may be due to differences in reporting.

However, varying seasonalities are more likely to be due to transmission differences between sectors. To group sectors together graphs of schistosomiasis seasonality in each sector were produced Figure 5.11. However, these did not reveal consistent seasonality between groups of sectors partly due to the low numbers of cases in subsectors. This made the grouping of sectors, using the method used in previous chapters impossible.

Therefore, sectors were grouped depending on the topography of this region, and also according to the classifications of the Vector Control Administration, Health Affairs Directorate in Asir. Shati, (2009) uses similar classification of Asir Region. Groupings were created which were highlands, lowlands, Sabt-Alalaya. Using these three groups four models were constructed. The first was an analysis of schistosomiasis in the whole of Asir. Then three models of schistosomiasis cases of the sectors; the highlands, the lowlands and in Sabt-Alalaya sector. Further details are provided below:

1. Schistosomiasis cases in overall Asir Region against Khamise weather data (Maximum, mean and minimum temperature, rainfall and relative humidity, Station 1 Figure 5.12). Khamise is the second main city in the region, and covers the largest occupied sector in the middle of this region (MOH, 2006). Weather data was available for all months.
2. Schistosomiasis cases in the highlands group (eight sectors): Abha, Khamise, Ahad-Rifadah, Al-Madhah, Tathlith, Sarat-Abedah, Dhahran-Aljanoub, and Tanoma. Khamise weather data will represent this group as well (See station 1 Figure 5.12).
3. Schistosomiasis cases in the lowlands group (five sectors): Rejal-Alma, Majaredah, Muhail, Al-Berk and Al-Gahma. Majaredah temperature (See station 2 Figure 5.12) and rainfall of Rejal-Alma (See station 3 Figure 5.12, data available for 132 out of 144 months) will represent this group. No humidity data was available for this area.
4. Schistosomiasis cases in Sabt-Alalaya Sector, Sabt-Alalaya station weather data will represent this sector. (See station 4 Figure 5.12). No humidity data was available for this area.

Monthly snail numbers are available for the whole of Asir only, Therefore in the final model these data will be analysed against Khamise weather data (Maximum, mean and minimum temperature, rainfall and relative humidity, Station 1 Figure 5.12).

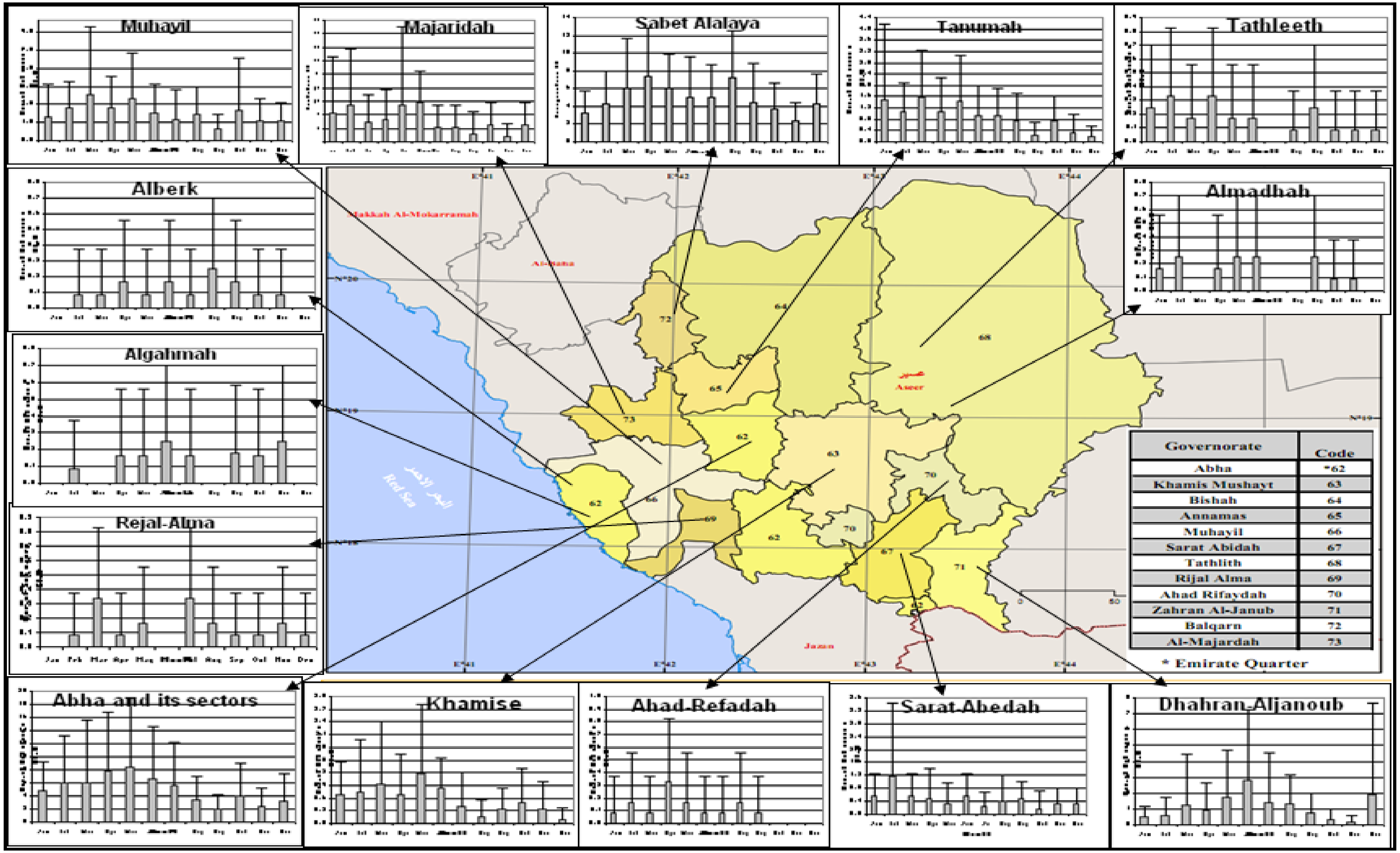


Figure 5.11: *Monthly Average of Schistosomiasis Cases in Sectors of Asir Region (1998-2009) Adapted from (CDSI, 2005)*

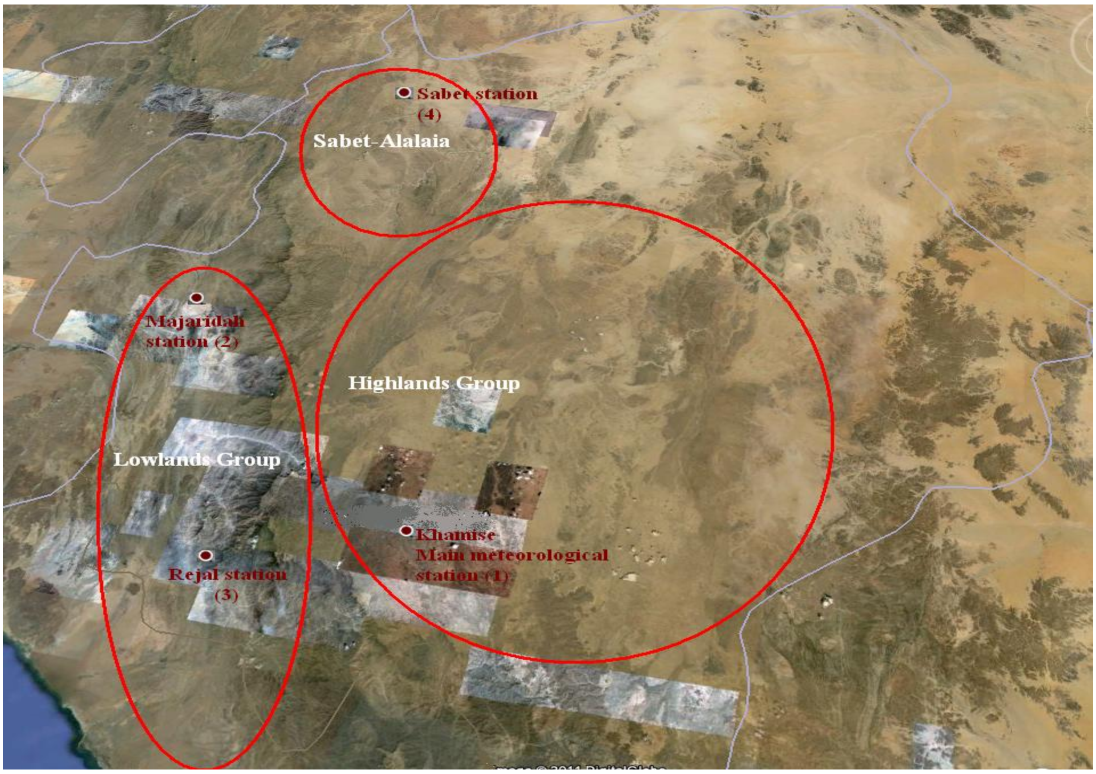


Figure 5.12: *Topographic map for Asir Region including the weather stations*

5.12.3 Schistosomiasis Data Description

The monthly averages of schistosomiasis cases in the whole of Asir Region during the study period are presented in Figure 5.13 and show transmission of the parasite throughout the year. However, there is some seasonality with peak incidence between March and June, with the highest average number of cases in May (24.83) followed by April (24.75). The average number of cases during the autumn and winter are lower, with the lowest number occurring in November (9.83). The standard deviation bars on the graph indicate that there is a large variability from year to year in monthly cases of schistosomiasis.

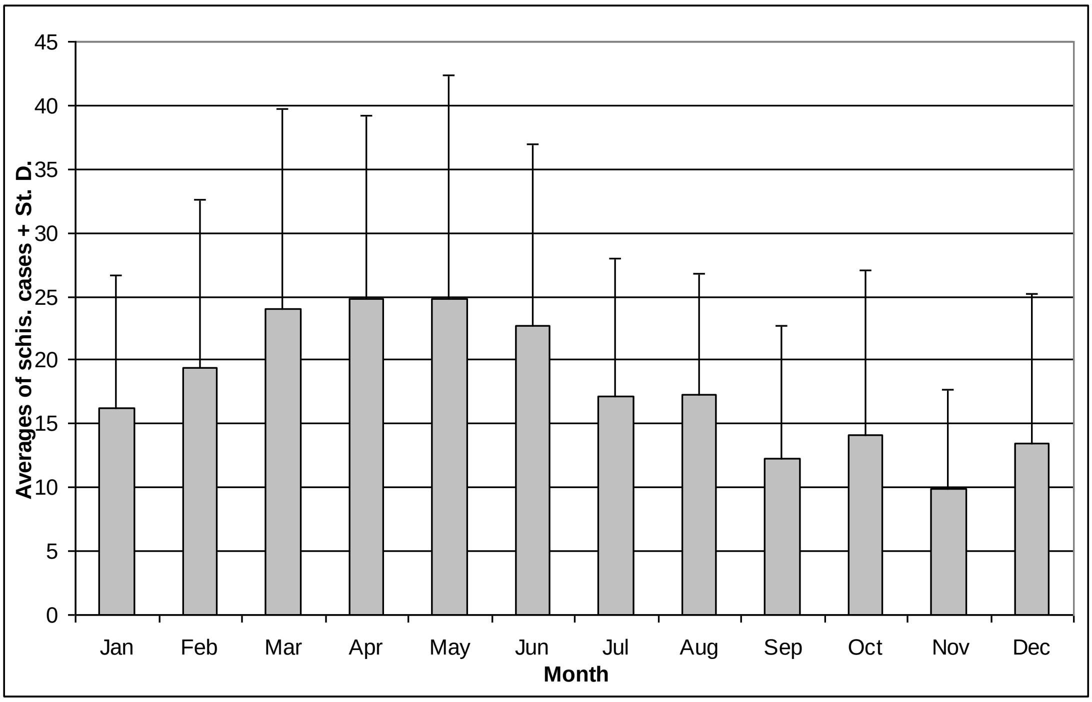


Figure 5.13: *Monthly Averages of schistosomiasis Cases in All Asir Region (1998 - 2009)*

Figure 5.14 shows the monthly averages of schistosomiasis cases in the highlands group during the study period. There is a clear seasonality with peak averages of cases between February and June, with the highest average cases in May (13.83) followed by June (13.58). The average numbers of cases during the late summer and autumn and early winter are lower, with the lowest number of cases in November (5.17). The standard deviation bars on the graph indicate that there is a large variability from year to year.

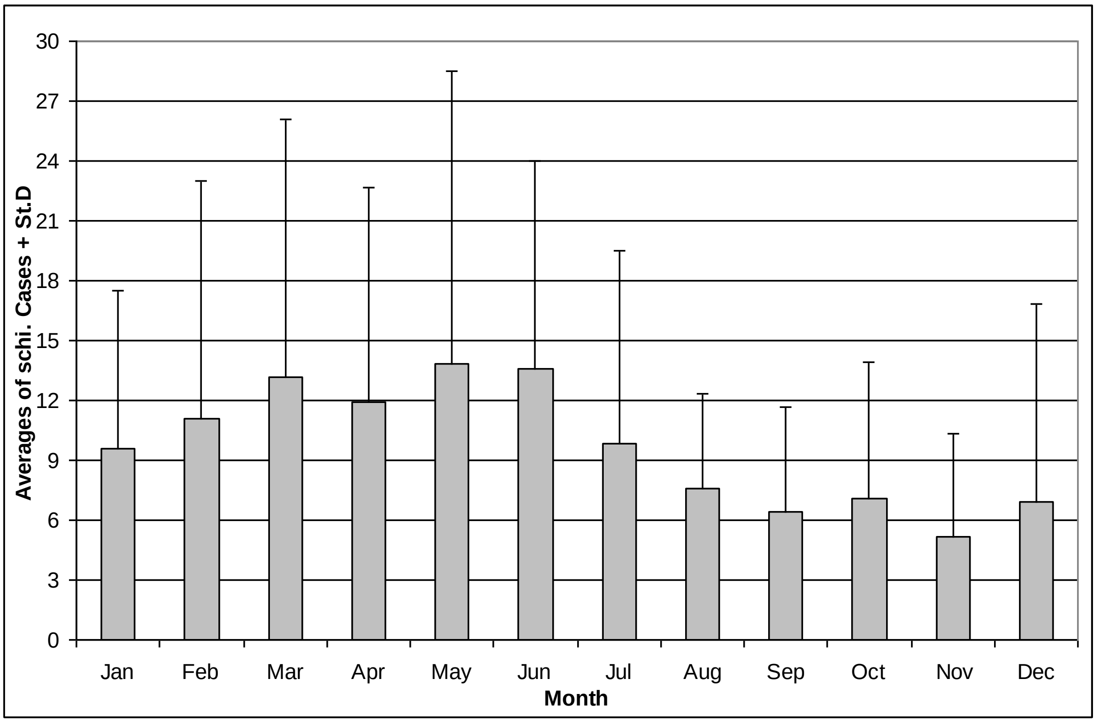


Figure 5.14: *Monthly averages of schistosomiasis cases of the highlands group (1998 - 2009)*

Figure 5.15 shows monthly averages of schistosomiasis cases in the lowlands group in Asir Region during study period. There is less seasonality that in the highlands group with the peak averages of cases occurring between February and June, with the highest average cases in May (4.92) followed by March (4.83). The average number cases in the rest of the year were a little lower with a small peak in October (but this may simply be random variation), and the lowest averages of cases was in September (1.5). The standard deviation bars on the graph indicates that there is a large variability from year to year.

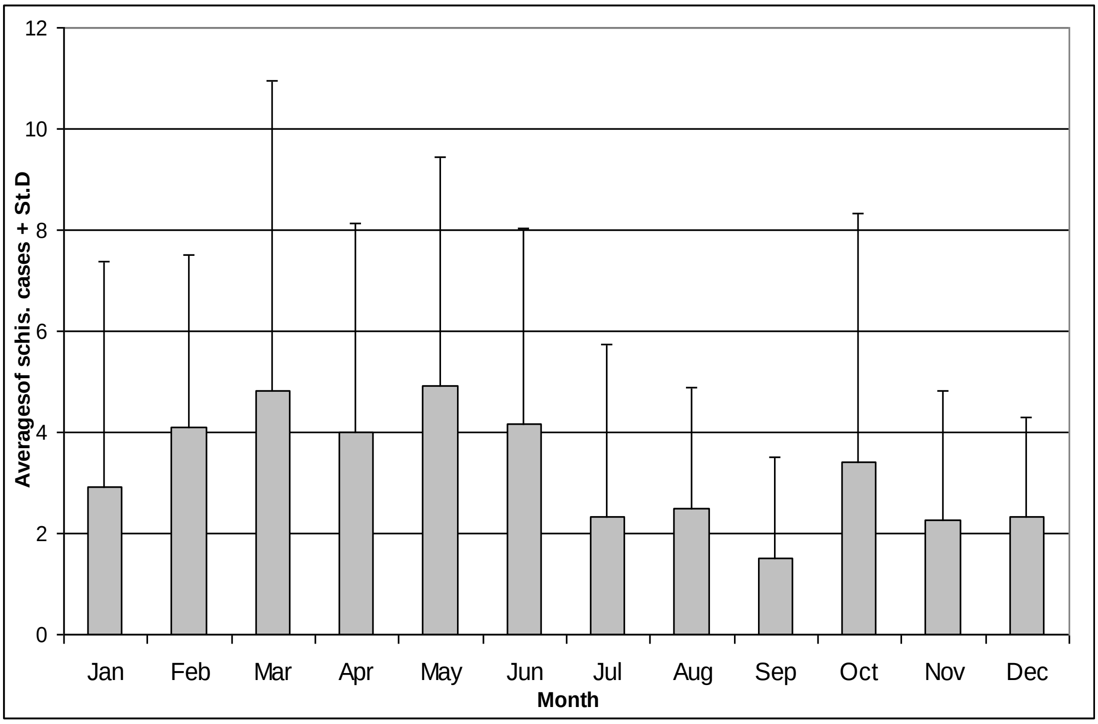


Figure 5.15: *Monthly averages of schistosomiasis cases in the lowlands group (1998 - 2009)*

Figure 5.16 shows monthly average number of schistosomiasis cases in Sabt-Alalaya sector, which is in the north of the highlands in Asir Region, during the study period. There is a little seasonality in this sector, with the peak averages of cases occurring between March and August, with the highest average cases in April (7.33) followed by August (7.17). The lowest average of cases was in November (2.42). The standard deviation bars on the graph indicates that there is a large variability from year to year.

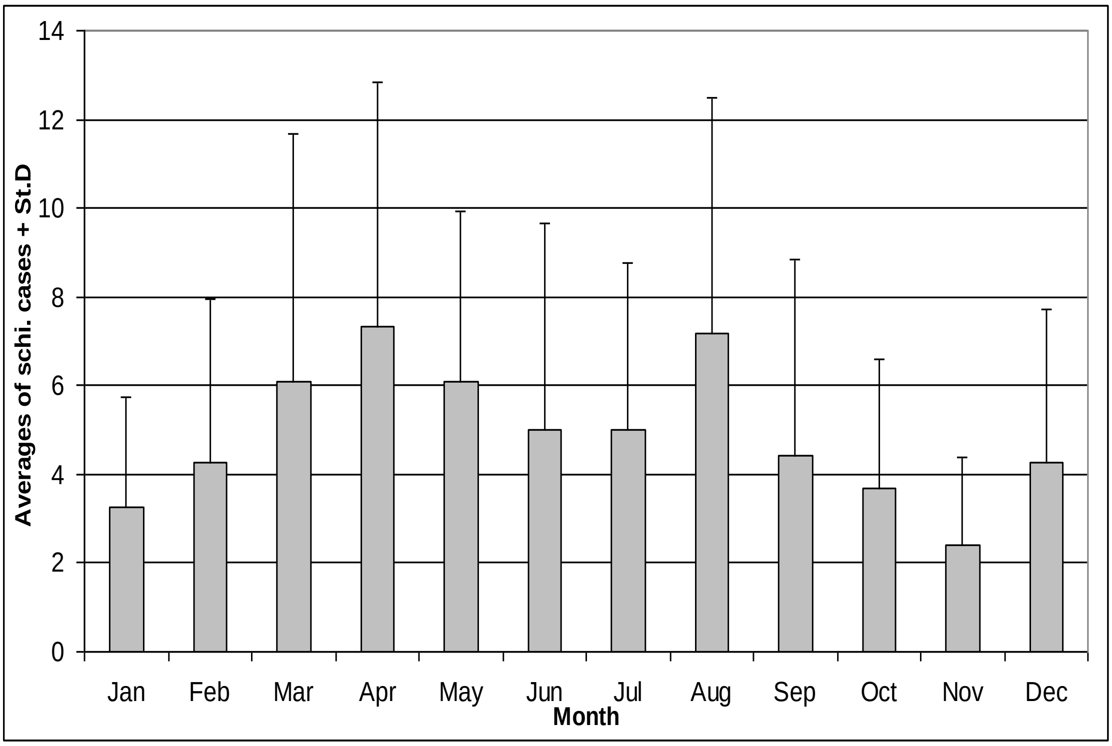


Figure 5.16: *Monthly averages of schistosomiasis cases in Sabt-Alalaya, Asir Region (1998 - 2009)*

5.12.4 Snail Data Description

The monthly average number of snails in all Asir Region during the study period is presented in Figure 5.17. There is a clear seasonality with peak incidence between January and June, with the highest average number in May (117.5) followed by April (114.8). The average number in the next half of the year is lower, with the lowest number occurring in December (68.9). The standard deviation bars indicate that there is variability from year to year in the monthly number of snails.

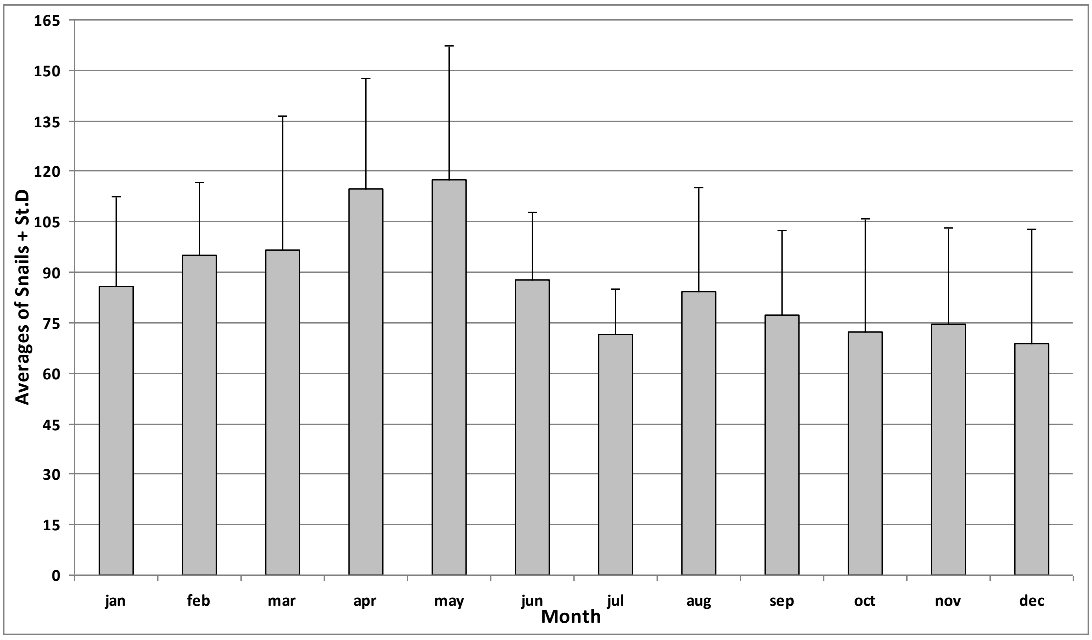


Figure 5.17: *Monthly averages of snail numbers in all Asir Region (1998 - 2009)*

5.12.5 Temperature Data Description

The temperature data for Khamise City will be used in the analysis of cases across the whole of Asir Region as well as the highlands group. It will also be used for the snail data. Descriptions of these data were presented in Section 3.11.3. Although this analysis is for a different year range (1998-2009 vs. 1995-2006) the seasonal trends in these data are similar to those presented previously.

The temperature in Majaredah will be used as representative of conditions in the lowlands group and these data were again presented previously for a slightly different range of years in Section 3.11.3.

The temperature in Sabt-Alalaya station will be used as representative of conditions in this area. These data have not been used in previous chapters. From this station only maximum and minimum temperature are available and the data are shown in Figure 5.18. The highest average maximum temperature occurs in June (30.6^{0}C) and the highest minimum in July (18.1^{0}C). The lowest average maximum and minimum temperature occurs in January (17.4 and 8.7^{0}C respectively).

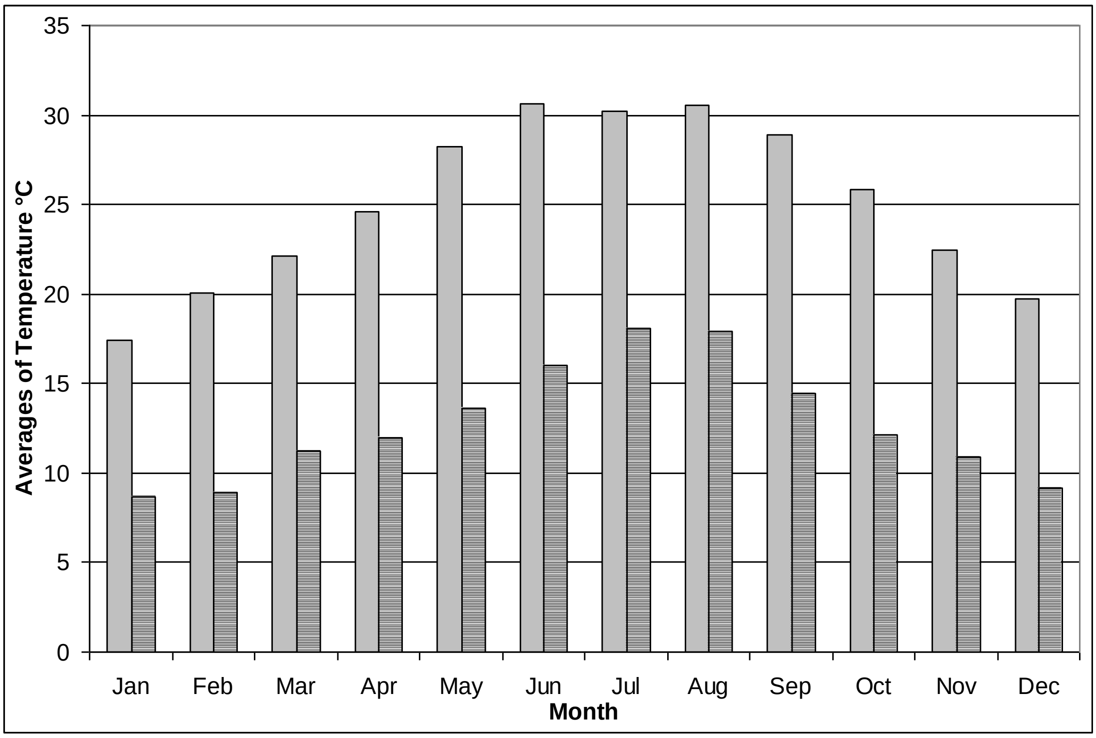


Figure 5.18: *Maximum and minimum temperature in Sabt-Alalaya (1998 -2009)*

5.12.6 Rainfall Data Description

Khamise rainfall will be assumed to be representative of all Asir and the highlands group. The monthly average rainfall in this city during the study period was presented in Section 3.11.4 for a slightly different yearly range. Rejal-Alma is assumed to be representative of rainfall of the lowlands group, and similar data for this weather station was presented also in Section 3.11.4.

The monthly average rainfall in Sabt-Alalaya sector over the study period in Figure 5.19 shows a slight seasonality with a peak incidence between November and January and also between March and May. The highest averages were in April (49.1mm) followed by May (37.3 mm). However the average rainfall between June and October also in February are lower. The lowest average occurs in July (2.4mm), with a slight peak in August (12.2mm). The standard deviation bars on the graph indicate that there is an extreme variability from year to year.

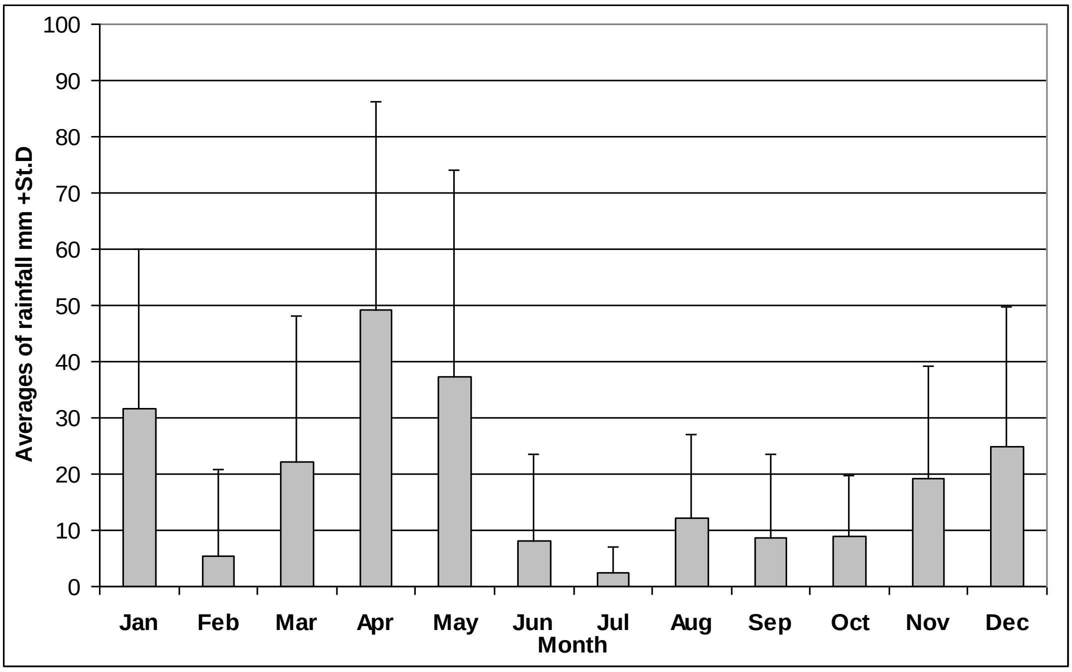


Figure 5.19: *Monthly averages rainfall in Sabt-Alalaya sector (1998 -2009)*

5.12.7 Relative Humidity Data Description

The relative humidity in Khamise will be assumed to be representative of all Asir and the highlands group, and these data were presented previously in section 3.115.

5.12.8 Statistical Analysis Data Preparation

The analysis to examine the relationship between monthly cases of schistosomiasis and the selected weather data proceeded in a number of stages. Identical stages were used for analysis of the snail data.

A histogram of the number of schistosomiasis cases each month in the whole of Asir Region was produced. There are few months with more than 40 cases. The skewed nature of the distribution may cause problems when performing regression analysis and so the natural logarithm of schistosomiasis cases (adding 1 to zero values) was performed. This produced Figure 5.20, and descriptive statistics of this distribution are presented in Table 5.2 and demonstrate that taking the natural logarithm of schistosomiasis produces a variable that is nearly normally distributed.

The same action has been carried out for the highlands group, the lowlands group, Sabt-Alalaya cases and snail numbers in all Asir. Figure 5.21 shows histograms of the highlands after transformation. Table 5.3 presents the descriptive statistic of this distribution. Figure 5.22 shows histograms of the lowlands after transformation. Table 5.4 presents the descriptive statistic of this distribution. Figure 5.23 shows histograms of the Sabt-Alalaya sector after transformation. Table 5.5 presents the descriptive statistic of this distribution. Figure 5.24 shows histograms of the snail numbers of all Asir after transformation. Table 5.6 presents the descriptive statistic of this distribution. In terms of the independent variables, rainfall for each group, also demonstrated a skewed distribution. Therefore, we took the natural logarithm of rainfall (adding 1 to zero values) to get (Ln rainfall) for each one.

The schistosomiasis data were then adjusted for any effects that could bias the results. Over time the number of schistosomiasis cases in Asir has declined and this long term trend is shown in Figure 5.25. Since the middle of 2001 the number of cases has declined from the peak number of cases in June. The long term trend in schistosomiasis in the highlands, lowlands and Sabt-Alalaya are shown in Figures 5.26, 5.27.and 5.28 respectively. The long term trend in snail numbers in the whole of Asir Region is shown in Figure 5.29. Over time the number of snails in Asir is almost constant with only a small decline over time.

In order to control for this effect, for the whole of Asir, highlands, lowlands and Sabt-Alalaya, the natural logarithm of schistosomiasis cases were put into a regression against time (each month numbered from 1 to 144). The unstandardised residual from this model represent the natural logarithm of schistosomiasis cases with the long term trend in incidence removed. The same procedure was applied to the snail data to produce the natural logarithm of snail counts with the long term trend in incidence removed.

The final stage in the analysis was to examine whether the monthly numbers of snails were related to monthly cases of schistosomiasis and this was carried out using regression analysis.

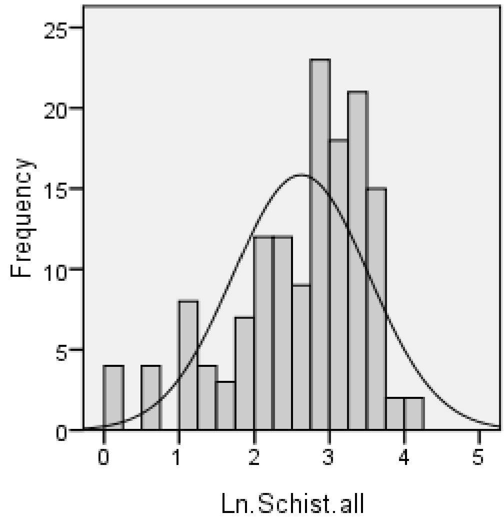


Figure 5.20: *Frequency of natural logarithm of schist (Ln. Schist) in Asir Region (1998 – 2009)*

Table 5.2: *Descriptive statistics for Ln. schist cases in Asir Region*

Ln. Schist.	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Skewness**	
						Statistic	**Std. Error**
	144	0.0	4.25	2.62	0.906	- 1.011	0.202

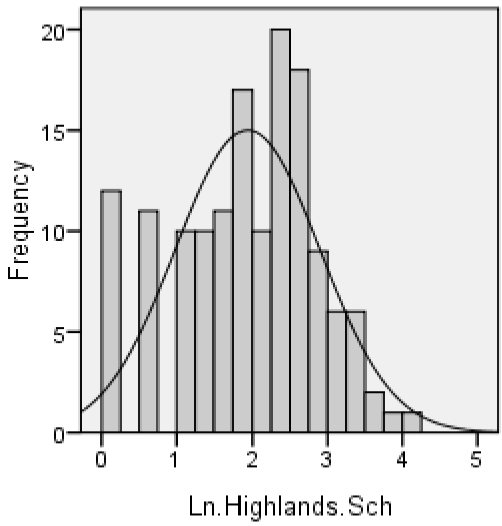


Figure 5.21: *Frequency of Natural Logarithm of Schist (Ln. Schist) in Highlands (1998 – 2009)*

Table 5.3: *Descriptive Statistics for Ln. Schist Cases in Highlands*

Ln. Highlands Schist	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Skewness**	
						Statistic	**Std. Error**
	144	0.0	4.04	1.94	0.957	-.371	.202

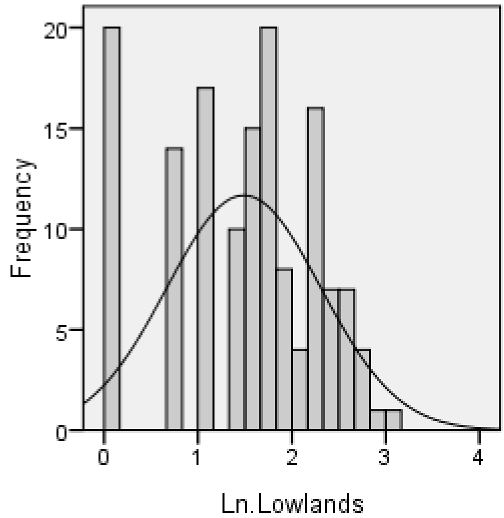


Figure 5.22: *Frequency of Natural Logarithm of Schist (Ln. Schist) in Lowlands (1998 – 2009)*

Table 5.4: *Descriptive Statistics for Ln. Schist Cases in Lowlands*

Ln. Lowlands Schist	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	0.0	3.04	1.488	0.820	-.434	.202

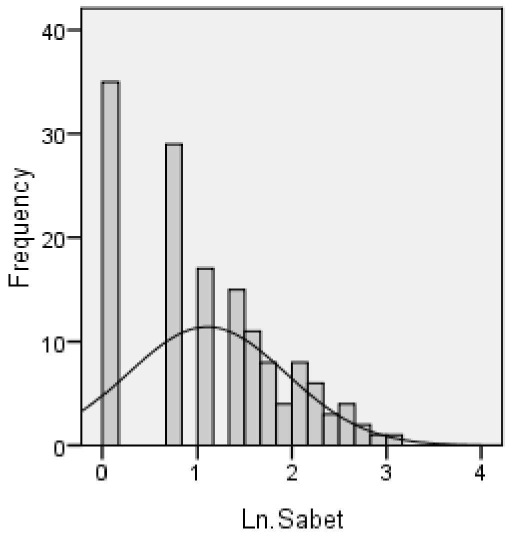


Figure 5.23: *Frequency of Natural Logarithm of Schist (Ln. Schist) in Sabt-Alalaya (1998 – 2009)*

Table 5.5: *Descriptive Statistics for Ln. Schist Cases in Sabt-Alalaya*

Ln. Highlands Schist	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	Std. Error
	144	0.0	3.04	1.102	0.838	.209	.202

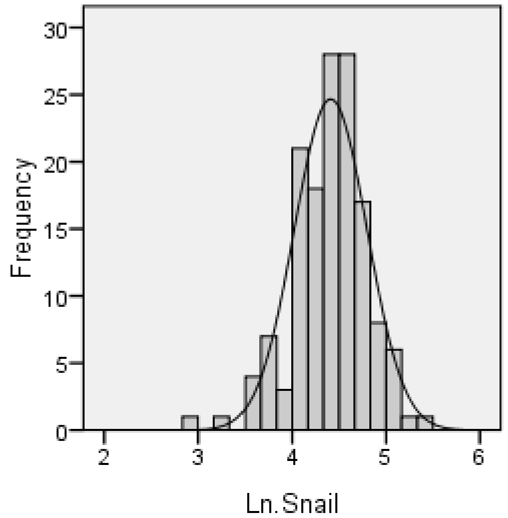


Figure 5.24: *Frequency of natural logarithm of snail (Ln. Snail) in Asir (1998 – 2009)*

Table 5.6: *Descriptive statistics for Ln. snail in Asir*

Ln.Snail All Asir	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
						Statistic	**Std. Error**
	144	2.94	5.37	4.40	.394	-.548	.202

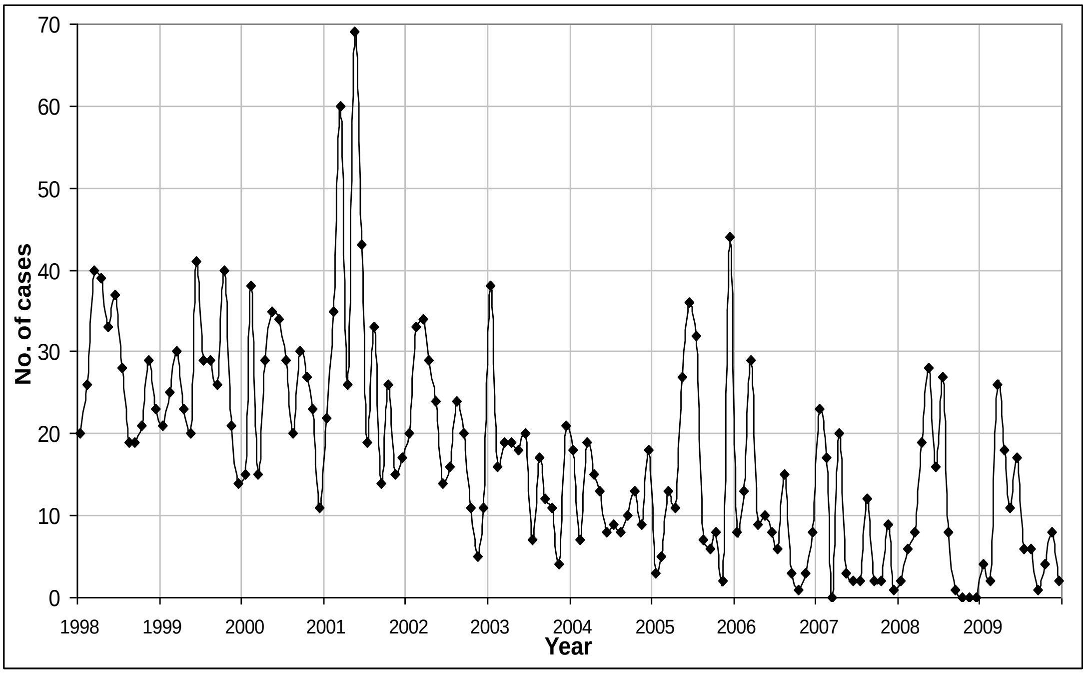


Figure 5.25: *Monthly schistosomiasis cases in all Asir Region (1998 – 2009)*

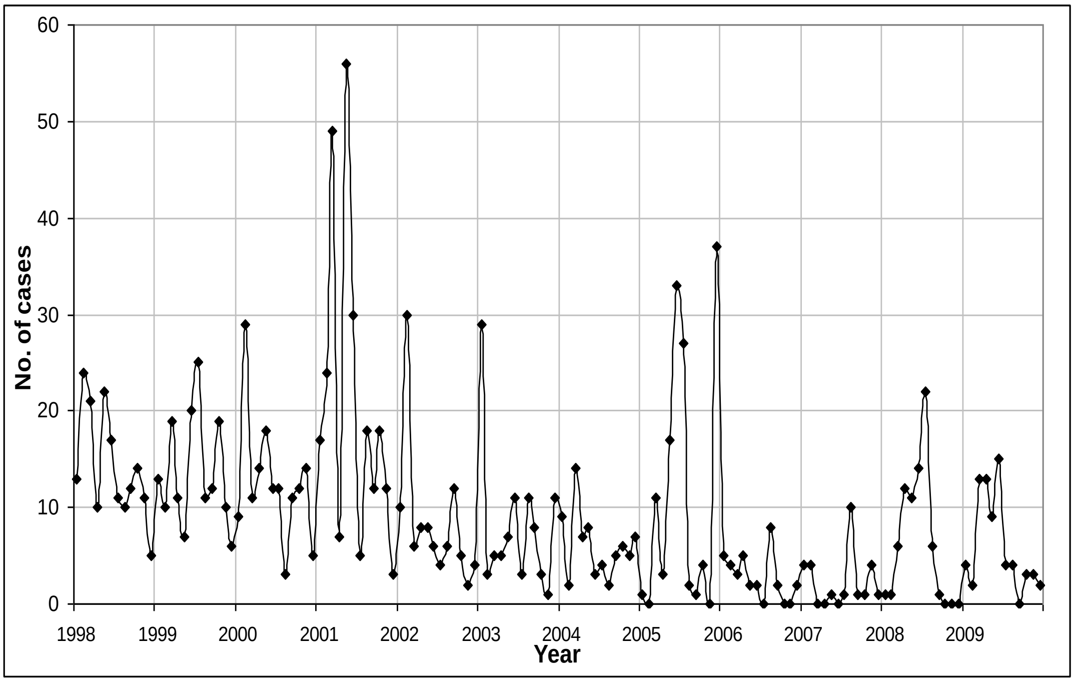


Figure 5.26: *Monthly schistosomiasis cases in the highlands group (1998 – 2009)*

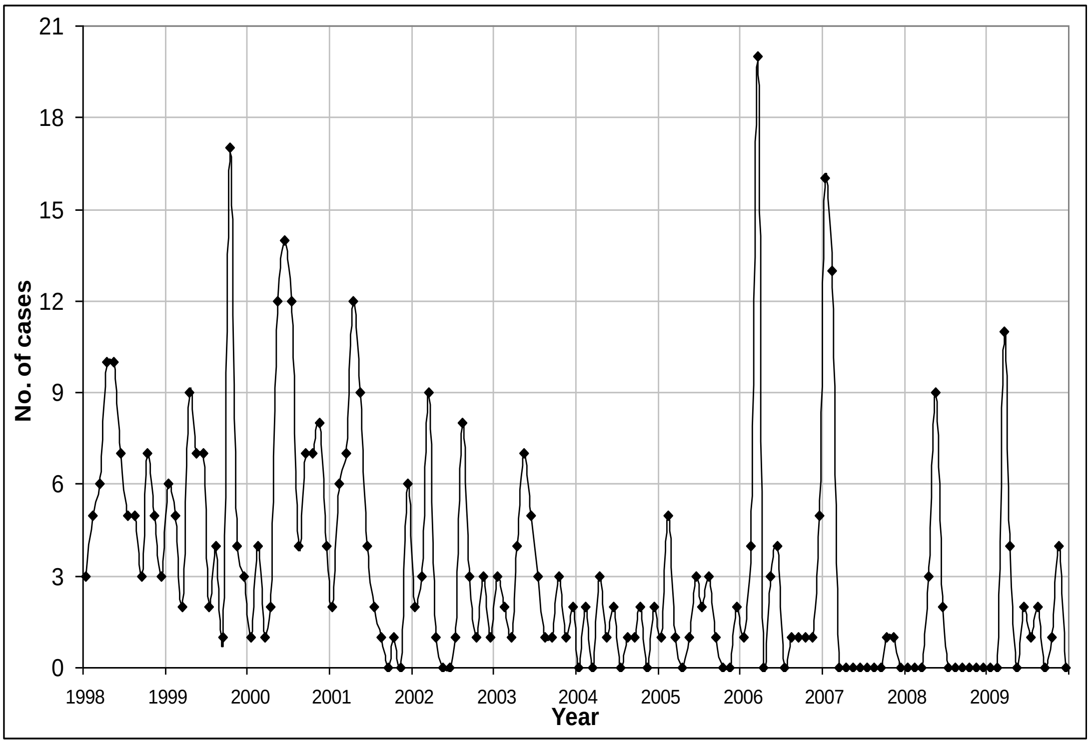


Figure 5.27: *Monthly schistosomiasis cases in the lowlands group (1998 – 2009)*

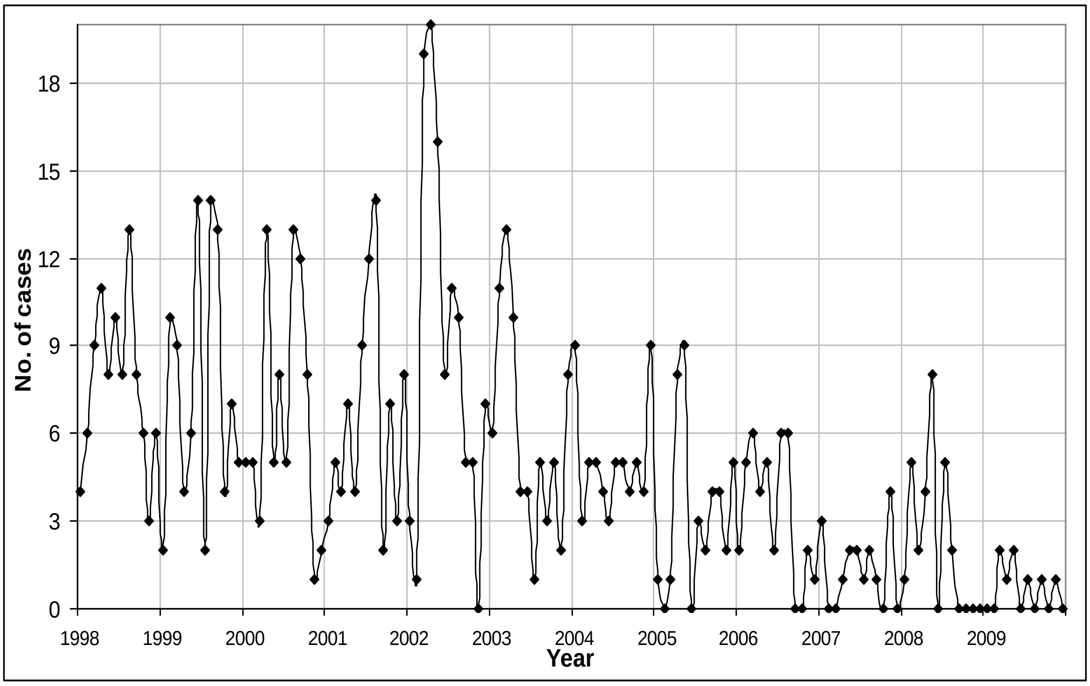


Figure 5.28: *Monthly schistosomiasis cases in Sabt-Alalaya sector (1998 – 2009)*

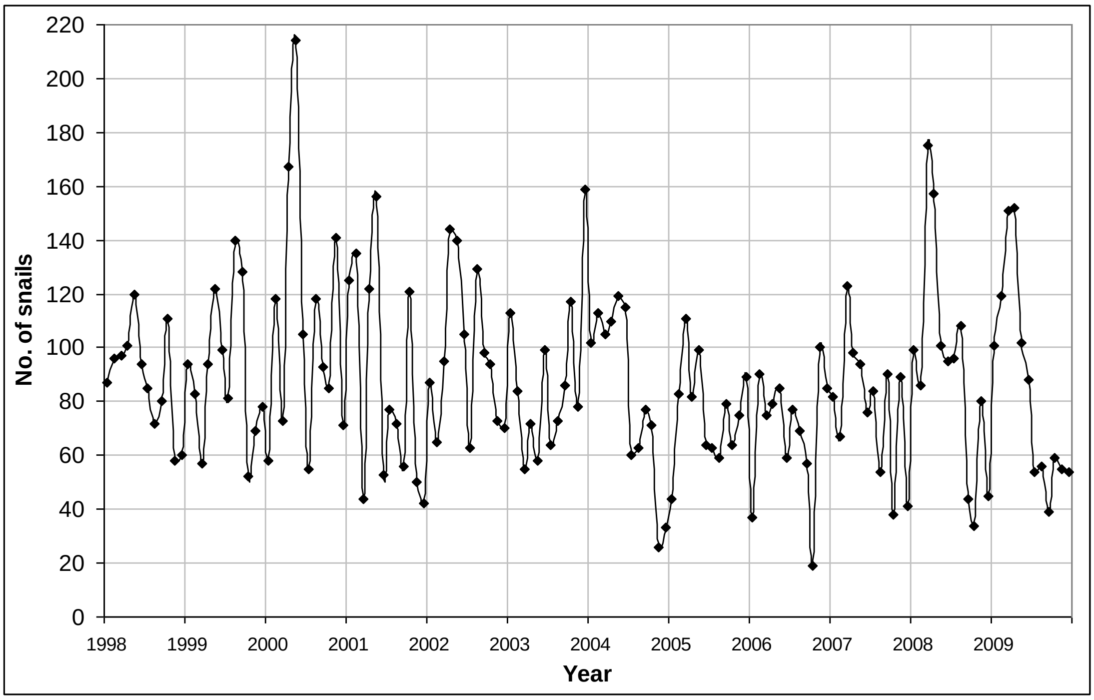


Figure 5.29: *Monthly snail numbers in the whole of Asir Region (1998 – 2009)*

5.12.9 Statistical Analysis

According to the literature review the relationship between schistosomiasis and weather may vary depending on the time of the year. The same may be true for the snail data. Therefore, the analysis proceeded in a number of stages:

Depending on the trend of schistosomiasis cases in Asir region and the other groups we separated the year into different time periods. In the Asir region the schistosomiasis was separated into three time periods: Feb to May, June to September and October to January (See Figure 5.13). The highlands group was separated into two time periods November to April and May to October (See Figure 5.14). The lowlands group was separated into two time periods; June to November and December to May (See Figure 5.15). Sabt-Alalaya sector was separated into two time periods May to October and November to April (See Figure 5.16). The snail numbers during the study period also was separated into two times, May to November and December to April (See Figure 5.17).

For each of time periods linear regressions of DT Ln schistosomiasis or DT Ln snails against each of the lagged weather variables were created (lagged up to 12 months). Longer time lags than used in the malaria and leishmaniasis chapter were produced as the incubation period for schistosomiasis and its lifecycle is more uncertain and may be longer. We then examined these relationships and combined the weather from the two or three months with the strongest association. In most cases the strongest relationships varied depending on the weather variables examined and the sector the model was produced for. Because these models contained data from multiple months it became important to control for seasonality. Therefore, all models were analyzed, incorporating dummy variables for each of the individual months. Finally in these analyses it was not possible to assume that the schistosomiasis rate in one month is unrelated to the schistosomiasis rate in the next month, and this is known as autocorrelation. Therefore the schistosomiasis in the previous month was added into these models as an independent variable. An identical procedure was used for the analysis of DT Ln snails.

Due to the low numbers of schistosomiasis cases and snails in some months and the problems that this might cause in a linear regression, an ordinal logistic regression of Ln schistosomiasis cases and Ln snails was additionally applied. This was achieved by recoding Ln schistosomiasis and Ln snails into four categories of increasing schistosomiasis incidence or snail numbers. These were then used in an ordinal logistic regression to produce an analysis that is more robust to the distribution of the data.

Multiple regression analysis was examined in the final stage of the statistical analysis. This method describes the effect of the two or three weather variables together against DT Ln of schistosomiasis cases or DT Ln snail numbers. The purpose of this test is to identify which weather variable has more influence upon schistosomiasis cases and snail numbers than others.

All of the data were analyzed using SPSS v.16 / v.18 for Windows and Microsoft Excel 2003 / 2007.

5.13 Results

The analysis is presented by first looking at relationships between schistosomiasis and temperature (maximum, mean and minimum) followed by rainfall and relative humidity. This is performed for whole Asir, highlands, lowlands and Sabt-Alalaya sector separately, but only where meteorological data is present. An identical sequence of models is then produced for the snail data against weather predictors. Finally schistosomiasis incidence is compared to snail numbers using regression analysis.

The models which do not have any significant relationship are not presented in this chapter but appear in Appendix C.1. The results for the combined lags are presented on the final line of each table.

5.13.1 Schistosomiasis with Temperature Data

This section presents the significant results for the relationships between schistosomiasis cases and temperature in all Asir, highlands group, lowlands group and Sabt-Alalaya sector. Linear regressions and ordinal logistic of detrended logarithm schistosomiasis cases against temperature data will be illustrated. Maximum temperature is considered first, followed by mean and minimum temperature.

Maximum temperature for overall Asir model between June and September is presented in Table 5.7

Table 5.7: *DT Ln schist and maximum temperature in all Asir (June to Sep)*

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.41	.818	-.52	.797	-.89	.641	.13	.721	.12	.818	.06	.910
1 P	.81	.311	-1.2	.57	-.61	.714	.08	.615	.02	.954	-.02	.955
2 P	1.5	.048	1.6	.284	1.3	.353	1.1	.013	.96	.012	.96	.013
3 P	1.4	.063	1.7	.136	1.3	.129	.83	.041	.57	.072	.38	.063
4 P	2.8	.011	2.6	.034	2.4	.030	1.2	.011	.72	.017	.686	.023
5 P	.63	.414	.45	.715	-1.5	.895	.33	.413	.23	.359	.17	.654
6 P	-.71	.663	-.65	.568	-.27	.793	.13	.971	.02	.936	.02	.944
7 P	.41	.654	-.37	.766	.21	.855	.28	.533	.14	.626	.19	.506
8 P	.65	.791	.46	.743	.84	.517	.09	.777	.05	.855	.12	.709
9 P	.2	.818	-.12	.939	.13	.930	-.03	.875	-.08	.801	-.01	.977
10 P	2.9	.081	3.1	.244	3.3	.718	.83	.117	.72	.206	1.1	.071
11 P	3.3	.036	4.1	.061	2.8	.190	1.3	.008	.96	.042	.77	.110
12 P	.21	.294	.16	.940	-.73	.713	.81	.376	.44	.351	.20	.685
3-4 P	3.6	.001	4.0	.021	3.5	.029	1.0	.008	1.2	.006	1.0	.008
2-4 P	4.0	.031	4.67	.021	4.0	.032	1.2	.010	1.9	.001	1.6	.004

0: current month. P: Previous month. Cof: Coefficient

The results indicated that in Asir over June to September schistosomiasis cases appear to be positively associated with maximum temperature in the 3 - 4 previous months in all variants of the model for both linear and ordinal logistic regression. A positive association is also observed for the 2 - 4 previous months.

The results for maximum temperature against schistosomiasis cases in the highlands, the lowlands and Sabt-Alalaya sector did not show any consistency in their significant associations. The results for mean temperature in the all Asir model between June and September are presented in Table 5.8.

Table 5.8: *DT Ln schist and mean temperature in all Asir (June to Sep)*

Model	Linear Regression						Ordinal Logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	1.5	.555	1.3	.652	1.95	.456	1.0	.545	.08	.899	.03	.598
1 P	-2.7	.265	-2.5	.281	-2.5	.243	-.07	.225	-.06	.910	-.03	.953
2 P	.90	.624	1.1	.584	.78	.683	.90	.614	.81	.098	.88	.070
3 P	1.4	.038	1.9	.102	1.5	.094	.34	.068	.52	.036	.28	.064
4 P	2.3	.079	2.2	.027	2.3	.047	.23	.048	.74	.041	.75	.070
5 P	-2.5	.160	-2.7	.134	-2.4	.145	-.55	.268	-.37	.342	-.53	.193
6 P	-2.1	.448	-2.1	.269	-.52	.773	-2.1	.444	-.38	.333	-.50	.903
7 P	3.9	.018	4.4	.026	3.5	.069	1.9	.019	1.05	.029	.90	.060
8 P	-1.7	.632	-1.5	.510	.79	.725	-.41	.662	-.496	.324	.24	.696
9 P	-3.3	.204	-4.2	.119	-2.7	.303	-1.3	.224	-1.2	.061	-.85	.189
10 P	2.7	.447	2.4	.441	2.2	.440	.17	.437	.06	.928	.66	.351
11 P	2.1	.506	2.9	.438	1.1	.715	.21	.516	.38	.579	.231	.737
12 P	-4.4	.098	-4.9	.111	-4.8	.084	-.44	.088	-.66	.324	-.63	.346
3-4 P	1.8	.047	2.2	.049	1.9	.086	2.9	.053	.65	.038	.70	.061

The results indicated that in all Asir between June and September schistosomiasis cases appear to be positively associated with mean temperature in the 3 - 4 previous months in some, but not all variants of the model.

The results for mean temperature against schistosomiasis cases in the highlands, the lowlands and Sabt-Alalaya sector do not show any consistency in their significant associations.

Minimum temperature for the all Asir model between June and September is presented in Table 5.9.

Table 5.9: *DT Ln schist and minimum temperature in all Asir (June to Sep)*

Model	Linear Regression						Ordinal Logistic					
	Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality		Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	1.2	.432	-.42	.736	-.63	.802	2.1	.532	-.14	.829	-.22	.720
1 P	-1.5	.325	-2.3	.371	-1.2	.632	-2.1	.336	-.39	.473	-.18	.749
2 P	2.2	.496	1.6	.528	1.0	.658	1.9	.396	.48	.423	.61	.314
3 P	1.3	.015	3.8	.040	3.0	.057	1.6	.043	.67	.061	.58	.087
4 P	2.0	.037	.17	.044	.21	.063	2.6	.047	.01	.078	.09	.086
5 P	-2.2	.163	-3.1	.029	-2.2	.105	-2.3	.132	.69	.046	.69	.050
6 P	-2.5	.288	-1.4	.282	-.65	.600	-1.5	.278	-.44	.111	-.25	.396
7 P	4.8	.034	2.7	.039	2.6	.028	2.6	.040	.92	.004	.91	.004
8 P	-.89	.427	-.67	.656	.57	.691	-.64	.400	-.22	.484	.229	.445
9 P	-1.9	.122	-1.2	.522	-.86	.613	-2.0	.214	-.33	.370	-.20	.600
10 P	2.4	.466	1.5	.553	1.3	.566	2.6	.445	.08	.870	.25	.634
11 P	2.5	.449	.82	.782	.06	.983	2.0	.389	.05	.938	-.24	.700
12 P	-4.2	.164	-5.6	.045	-4.7	.070	-3.4	.204	-.91	.156	-.82	.194
3-4 P	5.9	.030	5.2	.043	2.3	.062	2.1	.047	1.1	.062	.50	.087

The results indicated that in all Asir between June and September schistosomiasis cases appear to be positively associated with minimum temperature in the 3 - 4 previous months in some, but not all variants of the model.

The results for minimum temperature against schistosomiasis cases in the highlands, the lowlands and Sabt-Alalaya sector do not show any consistency in their significant associations.

5.13.2 Schistosomiasis with rainfall Data

The all Asir model with rainfall between Feb and May is presented in Table 5.10.

Table 5.10: *DT Ln schist and Ln rainfall in all Asir (Feb to May)*

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	3.2	.047	1.6	.294	1.6	.297	.31	.395	.25	.288	.24	.301
1 P	1.3	.230	3.3	.033	3.5	.025	.47	.034	.58	.028	.62	.022
2 P	.24	.861	-.26	.861	-.01	.996	-.11	.627	-.07	.777	-.06	.820
3 P	-1.4	.327	-.99	.523	-.95	.541	-.45	.324	-.30	.217	-.31	.205
4 P	.670	.623	.432	.757	.48	.735	.12	.749	.05	.837	.05	.835
5 P	2.8	.040	2.8	.043	2.8	.049	.56	.024	.45	.046	.47	.044
6 P	.46	.695	1.9	.192	1.8	.220	.25	.268	.19	.393	.195	.397
7 P	.23	.846	.83	.610	.86	.600	.44	.214	.41	.117	.41	.114
8 P	1.8	.133	2.3	.180	3.2	.187	.67	.147	.56	.038	.56	.039
9 P	-1.3	.340	-1.4	.421	-1.1	.549	-.08	.745	-.07	.878	-.03	.904
10 P	-.86	.510	-1.5	.392	-1.5	.401	-.21	.507	-.14	.601	-.15	.596
11 P	.64	.591	1.0	.517	1.02	.523	.42	.124	.33	.213	.33	.215
12 P	-.57	.611	-3.0	.089	-3.2	.075	.74	.084	.56	.050	.57	.046
5-6 P	2.4	.139	3.7	.037	3.7	.048	3.6	.081	4.6	.025	4.5	.039

The results indicated that in all Asir between Feb and May schistosomiasis cases appear to be positively associated with rainfall in the 5 - 6 previous months for all variants of the model except the rainfall only variants.

The all Asir model for rainfall between June and September is presented in Table 5.11

***Table 5.11:** DT Ln schist and Ln rainfall in all Asir (June to Sep)*

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.83	.344	-1.7	.123	-1.2	.235	-.741	.290	-.31	.193	-.27	.236
1 P	-.38	.685	-.26	.803	.22	.819	-.315	.554	-.22	.341	-.08	.737
2 P	-.19	.836	-1.4	.199	-1.1	.252	.798	.026	.55	.025	.60	.021
3 P	-.43	.609	-.93	.350	-.76	.400	-.353	.214	-.30	.175	-.19	.404
4 P	-2.4	.001	-2.3	.031	-1.9	.056	.515	.016	-.76	.105	-.64	.116
5 P	1.1	.184	.02	.090	1.4	.074	.147	.621	.10	.112	.15	.104
6 P	.83	.430	1.5	.070	.77	.059	.318	.200	.27	.044	.29	.131
7 P	3.3	.002	2.8	.009	1.8	.046	.789	.008	.63	.015	.51	.022
8 P	-.27	.798	.61	.540	.35	.717	.212	.348	.32	.144	.13	.592
9 P	.55	.604	.67	.504	.43	.641	.354	.451	.22	.307	.14	.520
10 P	.75	.393	-.42	.689	-3.8	.694	-.117	.524	-.10	.648	-.22	.347
11 P	.17	.843	-1.5	.183	-1.1	.306	-.218	.589	-.16	.491	-.14	.552
12 P	.94	.290	1.5	.194	2.1	.950	.373	.099	.29	.255	.44	.105
5-7 P	1.8	.042	3.5	.038	2.8	.034	.754	.049	.62	.037	.67	.030

The results indicated that in Asir between June and September schistosomiasis cases appear to be positively associated with rainfall in the 5- 7 previous months and in all variants of the model.

The highland group model for rainfall between Feb and July is presented in Table 5.12.

Table 5.12: *DT Ln schist and Ln rainfall in the highlands (Feb to July)*

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.07	.266	-.15	.104	-.09	.273	-.07	.196	-.22	.164	-.082	.184
1 P	-.07	.284	-.21	.020	-.153	.063	-.061	.191	-.28	.067	-.131	.050
2 P	-.06	.350	-.194	.040	-.070	.439	-.051	.265	-.214	.081	-.094	.477
3 P	-.115	.103	.128	.176	-.050	.560	-.124	.129	.166	.122	-.088	.480
4 P	-.011	.931	.011	.960	.055	.488	-.012	.861	.014	.860	.076	.421
5 P	.102	.249	.086	.365	.061	.467	.147	.278	.099	.311	.089	.397
6 P	.119	.019	.249	.006	.200	.014	.249	.029	.527	.010	.559	.007
7 P	.150	.041	.274	.004	.187	.034	.321	.031	.590	.006	.530	.016
8 P	-.038	.603	-.05	.634	-.124	.145	-.062	.524	-.015	.584	-.214	.095
9 P	.024	.746	.093	.360	.172	.055	.034	.702	.083	.311	.222	.085
10 P	-.018	.815	-.091	.409	-.092	.340	-.054	.765	-.077	.329	-.082	.301
11 P	-.033	.689	-.053	.620	.032	.733	-.067	.612	-.036	.602	.044	.513
12 P	-.011	.881	-.06	.605	-.03	.794	-.009	.791	-.051	.545	-.023	.684
5-7 P	.212	.023	.428	.001	.342	.007	.467	.020	1.02	.001	1.05	.001
6-7 P	.290	.015	.454	.001	.327	.003	.583	.026	.943	.006	.995	.006

The results indicated that in the highlands group between February and July schistosomiasis cases appear to be positively associated with rainfall in the 5 - 7 previous months, and in the 6 - 7 previous months in all variants of the model.

The results for rainfall data against schistosomiasis cases in the lowlands and Sabt-Alalaya did not show any consistency in their significant associations.

5.13.3 Schistosomiasis with relative humidity Data

The results for relative humidity data against schistosomiasis cases in all Asir, the highlands, the lowlands and Sabt-Alalaya did not show any consistency in their significant associations.

5.13.4 Snail numbers with Weather Data

The next analysis examined the relationships between snail number and weather data. This is performed for the whole Asir Region as the snail data is only available for whole the region.

Linear regressions and ordinal logistic regressions of DT snail numbers against weather data in all Asir will be illustrated. Maximum temperature over December to April and May to November periods are presented in Tables 5.13 and 5.14 respectively.

Table 5.13: *DT Ln snails and maximum temperature in all Asir Region (Dec to April)*

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	6.5	.001	8.01	.047	8.2	.042	.271	.008	.382	.041	.341	.045
1 P	1.18	.516	3.4	.446	2.3	.607	2.34	.487	4.5	.322	2.8	.536
2 P	-.121	.178	-.106	.398	.001	.994	-.344	.115	-.350	.244	-.127	.735
3 P	-.093	.120	-.151	.342	-.143	.255	-.172	.175	-.445	.209	-.433	.377
4 P	-.192	.098	-.128	.554	.029	.870	-.103	.379	-.233	.605	.304	.621
5 P	-.141	.058	-.347	.186	-.193	.357	-.139	.389	-.965	.096	-.940	.289
6 P	-.255	.169	-.172	.526	.102	.637	-.217	.575	-.565	.316	.164	.848
7 P	-.137	.002	.117	.264	.063	.402	.091	.224	-.112	.611	.209	.732
8 P	.167	.001	.053	.611	-.033	.656	-.109	.088	-.057	.789	.351	.550
9 P	-.171	.001	-.015	.899	-.069	.414	-.129	.034	-.105	.658	-.418	.577
10 P	.177	.001	.058	.642	.003	.976	.105	.108	-.041	.868	.048	.930
11 P	-.244	.001	-.011	.928	-.016	.863	-.139	.133	-.235	.383	-.351	.632
12 P	-.072	.405	.070	.556	.070	.408	-.133	.349	-.160	.520	-.092	.885

The results indicated that in all of Asir between December and April, the number of snail number appear to be positively associated with the maximum temperature in the current month only in all variants of the model.

Table 5.14: *DT Ln snails and maximum temperature in all Asir Region (May to Nov)*

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	1.6	.112	-.164	.696	-2.79	.588	.218	.186	-.83	.393	-1.02	.342
1 P	-1.93	.358	.183	.311	.071	.076	-.240	.264	2.01	.093	1.40	.091
2 P	-4.79	.940	-.024	.918	-.14	.452	-.561	.046	-1.18	.033	-.644	.424
3 P	2.8	.004	5.48	.123	5.4	.131	1.9	.007	6.01	.254	4.1	.098
4 P	2.31	.004	7.11	.032	6.75	.048	2.91	.011	6.66	.025	7.21	.041
5 P	1.9	.027	2.9	.358	2.2	.496	2.08	.030	3.4	.265	2.91	.254
6 P	3.25	.264	1.48	.113	1.23	.381	2.75	.126	1.38	.047	1.59	.667
7 P	2.50	.635	-.157	.215	-1.33	.759	2.81	.718	.124	.650	-.299	.488
8 P	-2.30	.337	-2.9	.494	-2.27	.814	1.71	.699	-.911	.670	-.248	.567
9 P	2.59	.649	2.52	.697	2.80	.464	.939	.885	.920	.941	-.928	.641
10 P	1.83	.549	1.73	.603	1.38	.736	.430	.181	.408	.219	.572	.204
11 P	-2.21	.937	-1.57	.689	-2.25	.830	-.041	.843	.236	.456	.464	.352
12 P	-1.06	.277	-1.07	.965	-1.77	.524	-.152	.450	-.085	.780	-.345	391
3-4 P	2.6	.003	10.7	.015	10.2	.022	3.2	.001	8.75	.011	9.24	.034
2-4 P	3.3	.001	10.0	.047	10.92	.044	3.1	.007	9.23	.033	9.47	.039

The results indicated that in all Asir between May and November, the number of snails appear to be positively associated with maximum temperature in the 3 - 4 previous months and in 2 - 4 previous months in all variants of the models.

The result of rainfall for all Asir model between December and April period is presented in Table 5.15

Table 5.15: *DT Ln snails and Ln rainfall in all Asir Region (Dec to April)*

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.72	.815	-7.8	.048	-8.2	.036	.67	.511	-3.46	.033	-2.49	.028
1 P	-3.2	.392	-4.3	.252	-3.5	.350	-1.18	.219	-3.11	.112	-3.7	.169
2P	1.1	.781	3.4	.379	3.7	.321	.954	.621	2.0	.412	1.91	.249
3 P	.120	.658	.041	.731	-.058	.533	.119	.119	-.151	.585	.177	.697
4 P	-.122	.758	-.116	.697	-.066	.790	-.16	.668	-1.06	.099	-.519	.662
5 P	-.615	.869	-.356	.462	-.375	.348	-.819	.913	-1.02	.298	-.469	.267
6 P	.662	.085	-.234	.364	.123	.600	.718	.795	-1.27	.424	-.705	.251
7 P	.556	.226	-.264	.305	-.37	.874	-.616	.857	-1.80	.305	-1.28	.261
8 P	-.238	.626	-.186	.404	.156	.445	-.152	.335	-1.01	.047	-.562	.304
9 P	-.198	.008	-.247	.219	-.086	.625	-.212	.179	-1.11	.018	-.915	.072
10 P	.348	.011	.200	.721	.390	.311	.227	.946	-1.47	.210	-.782	.229
11 P	-.012	.047	.94	.245	.324	.311	-.037	.054	.842	.362	.254	.318
12 P	2.0	.540	-6.0	.161	-5.3	.207	1.3	.454	-4.12	.174	-4.84	.222

The results indicated that in all Asir over December to April, the number of snails appears to be negatively associated with rainfall in the current month only in most variants of the model.

5.13.5 Schistosomiasis Cases with Snail Numbers

The final stage of the analysis investigated whether there were associations between schistosomiasis cases and snail numbers. Linear regressions and ordinal logistic regressions of DT Ln schistosomiasis cases against DT Ln the number of snails in all Asir are presented in Table 5.16.

Table 5.16: *DT Ln schist and DT Ln snails in all Asir Region*

Model	Linear Regression						Ordinal Logistic					
	Snails only		Snails with seasonality		Snails with auto correlation and seasonality		Snails only		Snails with seasonality		Snails with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0P	.082	.001	.048	.031	.06	.036	.017	.001	.012	.026	.014	.011
1 P	.101	.001	.066	.016	.06	.031	.020	.001	.016	.003	.015	.007
2 P	.047	.070	.017	.541	.010	.817	.037	.084	.042	.431	.012	.757
3 P	.028	.286	.027	.336	.024	.384	.029	.271	.034	.387	.024	.244
4 P	.021	.422	.042	.132	.038	.173	.031	.472	.032	.149	.079	.142
5 P	-.019	.475	.022	.448	.015	.603	-.029	.485	.041	.499	.027	.543
6 P	-.06	.026	-.018	.518	-.02	.434	-.05	.036	-.033	.555	-.10	.384
7 P	.073	.006	-.04	.140	-.040	.167	.078	.004	-.014	.187	-.042	.097
8 P	-.05	.064	-.023	.431	-.02	.580	-.04	.055	-.033	.466	-.026	.521
9 P	.038	.155	.057	.047	.06	.032	.033	.167	.086	.067	.046	.089
10 P	.036	.192	.026	.375	.02	.561	.031	.184	.019	.178	.022	.561
11 P	.032	.248	.010	.936	-.01	.948	.039	.227	.011	.857	-.012	.838
12 P	.110	.001	.082	.005	.08	.005	.017	.001	.013	.019	.014	.015
0-1 P	.140	.001	.094	.007	.094	.007	.029	.001	.024	.001	.023	.001

The results over the whole year indicated that in all Asir schistosomiasis cases appear to be positively associated with the number of snails collected, in average of the current month and one previous month and in all variants of the models.

5.13.6 Multiple Regressions

In this section we will present the results from the normal and multiple regressions of DT Ln schistosomiasis cases against the weather variables. For temperature, we will present maximum temperature only in the multiple regressions as it has a similar seasonality to minimum and mean temperature and appeared to have the strongest associations with schistosomiasis. No multiple regressions were produced for the snail data as in no period was more than one set of weather variables significant.

A. Multiple Regressions of Schistosomiasis Cases in All Asir

The normal regressions for schistosomiasis in all Asir against maximum temperature and rainfall, in the averages of 3 and 4 previous months, during June to September are illustrated in Tables 5.17. Table 5.18 presents the multiple regressions for these variables.

Table 5.17: *Regressions of the coefficient of DT Ln schistosomiasis cases of whole Asir for averages of 3 and 4 previous months of maximum temperature and rainfall during June to September*

Normal Regression	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	3.62	.001	.085	4.0	.021	.216	3.51	.029	.337	1.0	.008	-75.0	1.23	.006	-69.2	1.04	.008	-69.0
Rainfall Only	-2.62	.012	.109	-2.72	.045	.193	-2.24	.074	.312	-.44	.043	-75.0	-.481	.116	-71.6	-.480	.114	-71.5

Table 5.18: *Regressions of the coefficient of DT Ln schistosomiasis cases of whole Asir with multiple weather averages of 3 and 4 previous months of maximum temperature and rainfall during June to September*

Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Multiple Max.Tem	.808	.039	.155	2.95	.047	.213	2.75	.043	.329	.049	.019	-72.83	1.06	.036	-69.12	1.10	.033	-69.01
Multiple Rainfall	-2.2	.033		-1.41	.377		-1.03	.485		-.470	.038		-.09	.811		-.0.82	.817	

The results of multiple regressions for schistosomiasis in all Asir during June to September demonstrate that in no models were the two weather variables significant. We conclude therefore that the best model for this period is that of DT Ln schistosomiasis against maximum temperature. Maximum temperature was positively significant in all variants of the normal and multiple regressions.

B. Multiple Regressions of Schistosomiasis Cases in the Highlands

The normal regressions for schistosomiasis cases in the highlands against maximum temperature and rainfall, in the averages of 6 and 7 previous months, during February to July are illustrated in Tables 5.19. Table 5.20 presents the multiple regressions for these variables.

Table 5.19: *Regressions of the coefficient of DT Ln schistosomiasis cases of highlands group for averages of 6 and 7 previous months of maximum temperature and rainfall during February to July*

Normal Regression	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Max.Tem. Only	-.025	.406	.01	-.34	.087	.001	-.179	.323	.202	.010	.993	-102.8	-.580	.185	-100.2	-.231	.593	-96.0
Rainfall Only	.290	.015	.064	.454	.001	.165	.327	.003	.307	.583	.026	-99.9	.943	.006	-94.3	.995	.006	-89.7

Table 5.20: *Regressions of the coefficient of DT Ln schistosomiasis cases of the highlands group with multiple weather averages of 6 and 7 previous months of maximum temperature and rainfall during February to July*

Variables In Multiple Method	Linear regression									Ordinal logistic								
	Variables only			with seasonality			With auto correlation & Seasonality			Variables only			With Seasonality			With auto correlation & Seasonality		
	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Adj. R^2	Cof.	P	Log Likl.	Cof.	P	Log Likl.	Cof.	P	Log Likl.
Multiple Max.Tem	-.060	.053	.104	-.084	.668	.153	.003	.987	.295	.070	.293	-99.40	.024	.959	-94.30	.472	.327	-89.24
Multiple Rainfall	.287	.004		.408	.001		.327	.005		.559	.011		1.03	.002		1.18	.001	

The results of multiple regressions for schistosomiasis in the highlands during February to July demonstrate that in no models were the two weather variables significant. We conclude therefore that the best model for this period is that of DT Ln schistosomiasis against rainfall. Rainfall was positively significant in all variants of the normal and multiple regressions.

5.14 Discussion and Conclusion

Several studies of schistosomiasis disease in Saudi Arabia have been carried out, but most of them have not examined the importance of climate and weather upon the existence of the disease. This is an important research gap as schistosomiasis used to be one of the most serious public health problems in this country, especially in the southern regions (Statistical year book MOH, 2002). The highest rate of this disease in Saudi Arabia during 2005 was in Asir Region (16.3 cases/100,000) followed by Albahah and Jazan Regions, (13.0, 11.5 cases/100,000) respectively. This justifies the importance of examining schistosomiasis within the Asir region. Both intestinal and urinary schistosomiasis have been reported in Asir (Statistical year book MOH, 2006).

During this study some difficulties were encountered. The main one was the limited weather data for some selected endemic areas in Asir, and also information missing from within this data. This meant that it was not possible to produce models for each schistosomiasis endemic area in Asir. For example, we have combined several sectors for endemic schistosomiasis data in the highlands including Abha, Khamise Sarat-Abidah Ahad-Rifadah, Tathlith, Almadha, Dhahran-Aljanoub and Tanoma, into one group, and a similar combination of sectors has been carried out for the lowlands. Although all these areas are in the highlands and have the same seasonality of schistosomiasis, it would have been better to examine each separately but the weather data was not available for each sector. It was therefore necessary to group sectors together. However, there were even greater limitations with the snail data which were only available for the whole of Asir. Obtaining these data for sectors within Asir would be helpful in understanding variations in snail numbers throughout the region. Also these data appeared to correlate well with schistosomiasis cases in the same month. This indicates that they do not give an accurate picture of variations in snail numbers in the region. In the future, it would be helpful to examine whether more useful information on snail numbers in the region could be extracted.

The average number of schistosomiasis cases in the whole of Asir in the last year (2009) of the study is less than one third of the average of cases in the first year (1998), This is a lower reduction in reported cases than for leishmaniasis and malaria and indicates that there has been less progress with this illness than with malaria and leishmaniasis.

In the results presented in this chapter, temperature was associated with schistosomiasis incidence in Asir, and there is a positive association between the maximum temperature and the number of cases for the whole of Asir during June to September. The lag for this relationship is from 3 to 4 months which fits with lags reported in the literature. Mean and minimum temperature showed similar trends. This relationship did not appear in the rest of year. However, a link with temperature was not apparent in any of the groups making up Asir, specifically the highlands sector, the lowlands or in Sabt-Alalaya sector. If such a relationship exists, it is difficult to understand why it would not be apparent in any of the 3 sectors making up Asir. However, further support for this relationship comes from the number of snails collected between May and November which also appear to be associated with maximum temperature averages of the previous 3 and 4 months. In the literature there is support for an association with temperature. Pimentel-Souza., et al (1988) state that in Brazil, an increase in temperature during winter and autumn leads to more mating activity amongst snails which may lead to more schistosomiasis. Michelson, 1960 mentioned that temperature may influence the ability of miracidia to infect snails and also the development of the schistosoma larvae within snails. In Biomphalaria glabrata Coelho et al., (2006) showed that lower temperatures led to the lowest infection level. These could all be explanations for the possible positive associations between temperature and schistosomiasis and snails observed in Asir. It is important to note that positive associations are not observed in all locations. In Senegal, Sturrock et al., (2001) noted that snail numbers drop sharply in the heat of the summer. It is likely that temperatures in that country rise to a level where snail survival is affected. In Asir, temperatures in the highlands (where most cases occur) are low enough that elevated temperatures are unlikely to have a negative effect upon snail numbers.

The strongest relationship emerging from this chapter is that rainfall appears to be positively associated with schistosomiasis cases for the highlands only. Elevated rainfall 6 and 7 months previously led to elevated schistosomiasis cases between February and July. In the literature rainfall / water is constantly cited as being important for schistosomiasis. The impact of rainfall upon schistosomiasis in this study was only in the highlands. This is unsurprising as most cases (more than 80%) are reported from the highlands. The positive association between rainfall and schistosomiasis occurs between February and July. It refers to rainfall 6 and 7 months previously which is the time of year when rainfall at its lowest in the highlands (e.g. September – December). During these dry periods elevated rainfall may provide opportunities for snails to breed. This then leads to schistosomiasis cases 6-7 months later.

There is widespread support for an association between schistosomiasis and rainfall. In Saudi Arabia Al-Madani (1991) mentioned that rainfall and streams are the major sources of water in Asir region and that vector snail habitats are found in streams in the highlands and associated with precipitation. Kloos et al., (2004) state that larger snail numbers were found in standing waters from October to March during the rainy and hot season in a rural area in Brazil. Agi (1995) in the Jos metropolis area of Nigeria noted that the rainy season in this part of the country occurs during summer when more snails were found. A lack of rainfall in the Ouarzazate part of Morocco, led to the drying out of the breeding sites of Bulinus truncatus, hence stopping of transmission cycle of the schistosomiasis (Laamrani et al., 2000).

One novel feature of this chapter was the snail data which might help to explain the relationships between schistosomiasis and weather. However, as already discussed, these data had several limitations as they were available only for the whole of Asir and not for each endemic area. The results for snails against weather data indicated that in the whole of the region over winter and spring seasons, the number of snails appeared to be negatively associated with rainfall in the current month only. This is different to the schistosomiasis data which indicated a positive association with rainfall 6-7 months earlier. One hypothesis for this relationship could be that rainfall washes snails from the bodies of water being investigated leading to lower numbers being collected. An alternative explanation could be that rainfall has a negative effect on the ability of collection teams to search for snails.

The third relationship examined was between schistosomiasis cases and the number of snails. The results over the whole year indicated that in the whole of this region schistosomiasis cases appear to be associated with the average number of snails, in average of the current month and one previous month. The reason for this is not clear as the literature review has indicated that the development of the parasite of schistosoma in the snails and the incubation of the disease take more than two months. Instead the relationship may indicate that the people who are responsible for the collection of snails may try to collect more snails from the environmental sources when they realise that there is increase of the schistosomiasis cases.

In summary, this study showed that weather variation factors play a role in affecting schistosomiasis cases. The results indicated that temperature may be an important factor associated with schistosomiasis in the whole of Asir during the summer and beginning of autumn but it was unclear why this impact was not seen in any of the sectors making up Asir. The results showed that if the maximum temperature in the previous 3 to 4 months was elevated, there were more cases of schistosomiasis. There was stronger support for the role of rainfall, and transmission in the highlands was elevated if rainfall was elevated in the previous 6 to 7 months. This occurred during the spring and summer seasons only. The results also indicated that weather was not an important factor associated with snails in Asir. This may be partly due to limitations of the snail data especially the close association with the number of reported cases. Although this study shows a decrease of schistosomiasis cases during the study period, it is important to recognize that this disease is a still a significant health problem particularly in some endemic sectors in this Region.

Chapter 6

Conclusion

6.1 Introduction

Habib, (2011) states that in the Arab countries, malaria, and leishmaniasis are the major vector-borne diseases of concern. The prevalence of these diseases has been linked to climate-related environmental changes. Increased temperatures, variable humidity and rainfall trends may affect the vector population density, the patterns of transmission, and infection rates (WHO et al., 2003; Habib, 2011). The consequences of these changes may cause vector-borne illnesses to emerge in some non endemic areas or to intensify in endemic areas particularly in Arab countries (Habib, 2011).Costello et al., (2009) state that no effective vaccines exist for many climate-sensitive infectious diseases such as malaria, dengue fever, schistosomiasis, and leishmaniasis. Reliance upon finding a vaccine solution is not appropriate

The three illnesses, malaria, leishmaniasis and schistosomiasis, in this study have been chosen for some reasons. These illnesses still represent major public health problems in Saudi Arabia, and particularly in Asir region. Costello et al., (2009) state that these three diseases are sensitive to climate (climate-sensitive infectious diseases), so it was useful to study these diseases in Asir.

6.2 Development of the Study

As we have discussed, the methodology of this study was developed predominantly in the first main chapter, malaria. The other two chapters, CL and schistosomiasis, built upon the methods created in this chapter meaning that difficulties or obstacles encountered in the Malaria chapter did not need to be repeated. A good example of this was with the first stage of the malaria study in which much time was spent investigating how to account for the fact that the relationships with weather may vary over the year. Initially we produced scatter plots of malaria against the independent variables for every month. The purpose of this analysis was to determine which months should be grouped together (i.e. group consecutive months with positive or negative relationships with weather together). Unfortunately, this method proved difficult to implement because it was often unclear which months should be grouped. The situation was complicated further by the fact that some of the relationships between weather and malaria may be lagged. Therefore a new method was developed and grouped months together based upon those with similar trends in the malaria time series over the year (e.g. months of high incidence during the winter). This method was taken forward to the CL and schistosomiasis chapter and scatter plots were not used again. In the malaria chapter much effort also went into deciding that most appropriate statistical model to use. In this chapter we decided upon conducting both a multiple regression and an ordinal logistic regression. These developments were taken forward to the CL and schistosomiasis chapter.

In the first two data chapters weather was compared to disease incidence. A major development of this idea occurred in the schistosomiasis chapter where we were able to obtain data on the abundance of the environmental host of this disease (snails). It was hoped that this development might explain the relationships between schistosomiasis and weather observed. Although an exciting addition to the study it was concluded that these data had major limitations as they seemed to be a poor indicator of the numbers of snails in the environment and were more affected by sampling effort. In addition, this data was only available for Asir a whole and not for each endemic area which limited its use.

6.3 Summaries and discussions

The results of this study were divided into three main data in addition to two secondary chapters (Introduction and Study area). A brief summary of each will now be given.

6.3.1 Infectious Diseases (Chapter 1)

The study has presented an overview of infectious diseases and highlighted their global importance to health. We also demonstrated why many of these are sensitive to climate variability. One important reason to examine climate variability is because of the likely impact of climate change upon incidence. An overview of global climate change and its adverse impact upon health were presented in this chapter. The chapter ended by justifying the three illnesses (malaria, CL and schistosomiasis) which are the infectious diseases to be studied in this thesis.

6.3.2 Study Area (Chapter 2)

The next chapter presented Saudi Arabia and the Asir Region. The choice of this region was justified through its location in the Afro-tropical Zone which extends from tropical countries in Africa to the Arab Peninsula (Khalifa 2009). It was shown how this region had a number of infectious diseases and how its varied topography and weather made it an ideal study choice. Based on the literature review of the three illnesses, and all the above information, it was shown clearly that there was an urgent need to study and research the influence of climate variability upon the presence of these illnesses in Asir Region.

6.3.3 Malaria (Chapter 3)

The first main data chapter considered malaria, as this illness is the most important vector-borne disease globally (WHO/SDE/PHE, 1999) and in the study area (Asir Region) (Dr A. Abdoon 2007 pers. Comm.). Malaria is endemic in lowlands of Asir Region (Haddad, 1990). The study showed that weather variations play an important role in affecting the number of malaria cases in Asir Region. The results indicated that rainfall was the most important factor associated with malaria during the summer months in Tehama of Asir (TA) and Tehama of Qahtan (TQ) (which include valleys and foothills). Greater rainfall in the current and previous month led to more malaria cases. Although rainfall was also significant over the whole year, because rainfall was not significant in models for other times of the year we concluded that the whole year result was driven by the summer result. Because summer is the driest period any rainfall during this period may provide opportunities for mosquito breeding. At other times of the year there may always be enough breeding sites for mosquitoes and so additional rainfall is unimportant.

6.3.4 CL Leishmaniasis (Chapter 4)

The second climate-sensitive infectious disease examined in this study was Leishmaniasis. As there were only limited cases of visceral leishmaniasis in Asir over the study period this study focused upon cutaneous leishmaniasis (CL). Leishmaniasis is considered to be the vector-borne disease with the second highest number of affected people in the world after malaria (Chaves et al., 2006). This study showed that weather factors play an important role in affecting the incidence of CL cases. Temperature was the most important factor associated with CL in all Asir and in the highlands area. Between summer and the beginning of autumn if the maximum temperature in the previous 2 to 4 months was elevated there were more cases of leishmaniasis. The highlands in Asir might provide the optimum temperature for the vector during summer, and elevated temperatures may increase sandfly activity. However, there was no evidence for a relationship between temperature and CL cases in the lowlands areas. Because these areas are much hotter, a negative association with maximum temperature in the summer was anticipated. The lack of a result suggests that sandflies find mechanisms to avoid these high temperatures. Although temperature does not appear to be important rainfall plays an important role in CL transmission in the lowlands. A greater number of cases occurs if rainfall is elevated in the previous 1 to 3 months. This occurs in all months except during the winter season. Rainfall may provide more suitable conditions for sandflies.

6.3.5 Schistosomiasis (Chapter 5)

The influence of climate variability upon this disease is a significant research gap as schistosomiasis used to be one of the most important public health problems in Saudi Arabia, particularly in the southern regions (Statistical year book MOH, 2002). This study showed that weather variations play a role in affecting schistosomiasis cases. The results indicated that temperature may be an important factor associated (positive association) with schistosomiasis in all Asir during the summer and beginning of autumn. It was unclear why this impact was not seen in any of the individual sectors within Asir. The results showed that if the maximum temperature in the previous 3 to 4 months was elevated there were more recorded cases of schistosomiasis. The strongest relationship emerging from this study is that rainfall appears to be positively associated with schistosomiasis cases in the previous 6 to 7 months for the highlands only. This occurred during the spring and summer seasons. Rainfall may provide suitable breeding sites for snails. One novel feature of this study was the data on snail abundance which it was hoped might help to explain the relationships between schistosomiasis and weather. However, the associations between these data and the schistosomiasis incidence data suggest that the snail counts were not a true reflection of snail abundance within Asir. Instead they suggest that sampling effort is increased when schistosomiasis cases are more abundant.

6.4 Conclusion of the results of the three illnesses

This study shows associations between weather and malaria, schistosomiasis and leishmaniasis in Asir. Overall the total numbers of yearly cases for all three diseases have declined sharply since the 1990’s. The Vector Control Administration, Health Affairs Directorate in Asir Region has made important progress regarding the control of the vector-borne diseases in Asir, in addition to the general strategy adopted by the Ministry of Health. This progress provides an explanation for the reduction in the number of cases in Asir. This is as a result of the improved facilities and an increased number of professionals, technicians and workers concerned with the problem. Different methods for the control of malaria and control of leishmaniasis have been introduced by the Vector Control Administration and some Primary Health Care centres. Two methods both involved spraying pesticides to combat malaria: (Seasonal spraying) in the houses which has a residual effect and space spraying (Fogging) which can make a significant impact upon the vector of leishmaniasis (sandfly) as well as the mosquito vectors. The greatest effort has been concentrated on the control of malaria as this has been the most prevalent disease. However, there was a massive spray against rift valley fever disease for more than six months which started in Asir and Jazan in 2000. This action had an important impact upon the vectors of malaria and leishmaniasis.

However, it is important to recognize that these diseases still represent significant health problems in Asir, especially schistosomiasis and Leishmaniasis with a concern of malaria incidence in some endemic areas if there is any control shortage in these areas (Dr A. Abdoon 2007 pers. Comm.).

To summarize, Table 6.1 shows the most important results for the relationships of between malaria, CL and schistosomiasis with the climate variables (Temperature, rainfall and relative humidity) in Asir Region during the study period.

Table 6.1*: Summary of the significant relationships between the climate variables and selected infectious diseases in Asir (Malaria, CL and Schistosomiasis)*

		Temperature		Rainfall		Humidity	
Disease	Lag	Location	Time	Location	time	Location	time
Malaria	0-1 P	-	-	TA&TQ	Summer	All Asir	Whole year
CL	2-4 P	All Asir	Summer + beginning of Autumn	-	-	-	-
	2-4 P	Highland		-	-	-	-
	1-3 P	-	-	Lowland	Spring + Summer + Autumn	-	-
Schistosomiasis	3-4 P	All Asir	Summer + beginning of Autumn	-	-	-	-
	6-7 P	-	-	Highland	Spring + Summer	-	-

P: Previous month. TA: Tehama of Asir. TQ: Tehama of Qahtan

The previous table illustrates the following points:

1. Weather variations play an important role upon the three illnesses. However, the influence varies by region and different weather variable have different lags. The shortest lag times were found for malaria cases. The longest lag times were for schistosomiasis. These are biologically plausible.
2. Rainfall is positively associated with all three illnesses indicating the importance of rainfall on disease transmission in Asir. In general rainfall during drier periods appears to be important.
3. Temperature has an influence upon only CL and Schistosomiasis. Summer and beginning of autumn temperatures appear to be important for both these diseases.
4. Humidity does not seem to be an important factor for many illnesses. Although it is significant for malaria in all Asir, it is not significant in any of the sectors. In this study the ability to detect a humidity effect was limited by the lack of humidity data in many parts of Asir.

5. Most associations between weather and disease appear for illnesses reported in the summer season.

6.5 The importance of climate change in this Study

The key measures of climate change in any particular region may depend on changes in temperature and rainfall (Islam, 2009). Cross and Hyams, 1996 carried out the influences on human health. This study was not designed to examine how the distribution of diseases in Saudi Arabia and Asir might change. Instead it provides evidence on how disease rates may change in areas where they are already present.

During a presentation in Amman, Jordan 2006 “Regional Workshop on Adaptation Strategies to Protect Health under Climate Change Variability and Change in Water Stressed Countries in EMR” it was mentioned that the annual temperature change in the Middle East between 1955 and 1994 was a 0.5°C increase. It is forecast that the increase by 2030 and 2050 will be 1 - 2°C respectively (MOH, workshop, 2006). Almazroui, 2011 states that forecasting the future climate of Saudi Arabia, projections using previously calibrated data reveals that rainfall will have a tendency to increase by 1.04% per decade. The tendency of maximum temperature will be to increase 0.66°C - 0.64°C per decade, compared to the base period. The projected rainfall will tend to increase particularly over the coastal areas along the central parts of the Red Sea as well as over the south-south-western areas of Saudi Arabia (Almazroui, 2011) i.e. Asir.

In this study there was a positive association between temperature 2-4 months previously and CL in summer and beginning of autumn. Should climate change lead to higher temperatures as is indicated this might increase the incidence of CL in highland areas in summer and the beginning of autumn. Rainfall 0-1 month previously was associated with elevated cases of malaria in TA and TQ. Again should climate change increase rainfall as indicated then malaria cases could increase in TA and TQ. Temperature 3-4 months previously was associated with increased cases of schistosomiasis. Should climate change lead to increased temperatures this might increase the incidence of this disease also in summer and beginning of autumn. Again with an increase in rainfall due to climate change, as rainfall 6-7 month previously was associated with the increased cases of schistosomiasis in the highlands of Asir Region.

In addition to these changes in incidence is also possible that areas which do not currently have malaria, schistosomiasis and CL could become endemic or that transmission could be extended throughout most or all months of year.

6.6 Study limitations and future work

During this study several difficulties were encountered. The main one was the limited weather data for some selected areas in Asir, and missing information from within this data. This meant that it was not possible to produce models for each endemic area in Asir. The situation in some endemic areas was even more difficult as no weather stations were available within some of these areas. Instead we had to use the weather data from nearby stations which were sometimes outside the sector boundaries. Although these stations were chosen because of their close similarity to the weather in the endemic areas, this can cause problems in the analysis if the variations in temperature, rainfall and humidity in those areas are different to that in the chosen weather stations. The problem was greatest with humidity where data was only available for one weather station. This meant that in all three data chapters the influence of humidity in many sectors could not be assessed. This highlights the importance of weather data collected to epidemiological studies. Should improved weather data exist then it would be possible to explore the relationships in this study further.

There were also limitations with the health data as only monthly reports were available. For diseases such as malaria where time lags between weather and illness are short, an analysis of weekly malaria cases would be preferable and would be an important addition to this study. Also the degree of under-reporting in these data is unknown.

Although this study was based in Asir the study could easily be extended to other areas where malaria, CL or schistosomiasis are endemic. In Saudi Arabia such regions as Jizan or Albahah would be ideal. It might also be possible to combine health data (e.g. Asir (Tehama) with some areas in Jizan) as these regions are similar topographically and environmentally. This might help overcome problems of low numbers.

It is also possible that similar methods could be used to investigate the influence of the climate variables upon other diseases such as food-borne diseases or air-borne diseases. Chapter 1 indicated that amoebic dysentery and brucellosis have a relatively high incidence in Asir so could be investigated in future research.

Understanding how weather affects vector populations is important to understanding weather health relationships. In this study the relationship between schistosomiasis cases and the number of snails was examined as this data might explain the relationships between schistosomiasis and weather. However, as already discussed this data had several limitations as it was available only for Asir as a whole and not for each endemic area.

Although our study may have some limitations, we strongly believe that our findings are relevant from a public health perspective to better understand the epidemiology of these illnesses. This study adds to the growing evidence linking the three diseases to climate variability. It suggests that variations in the incidence of these diseases in Asir are associated to changes in weather conditions. Although during the study period there were activities to control these diseases in this region, the number of cases for each disease correlated statistically, with climate variables. The result of this study could contribute to an increased awareness of these diseases and help to diagnosis the problem for the decision-makers in related health agencies in this region particularly and in Saudi Arabia generally.

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Appendix

Appendix A

Malaria
Appendix A.1

Table 1. Correlation of DT Ln malaria in all Asir against maximum temperature in Khamise

Month	Unstandardized Coefficients	Significance
Jan	-0.10	0.70
Feb	-0.06	0.86
Mar	0.03	0.90
Apr	-0.20	0.31
May	-0.16	0.49
Jun	-0.43	0.09
Jul	-0.10	0.62
Aug	-0.36	0.48
Sep	0.02	0.99
Oct	0.37	0.44
Nov	0.04	0.88
Dec	-0.20	0.40

Figure 1. DT Ln malaria in Asir with maximum temperature in Khamise for each month

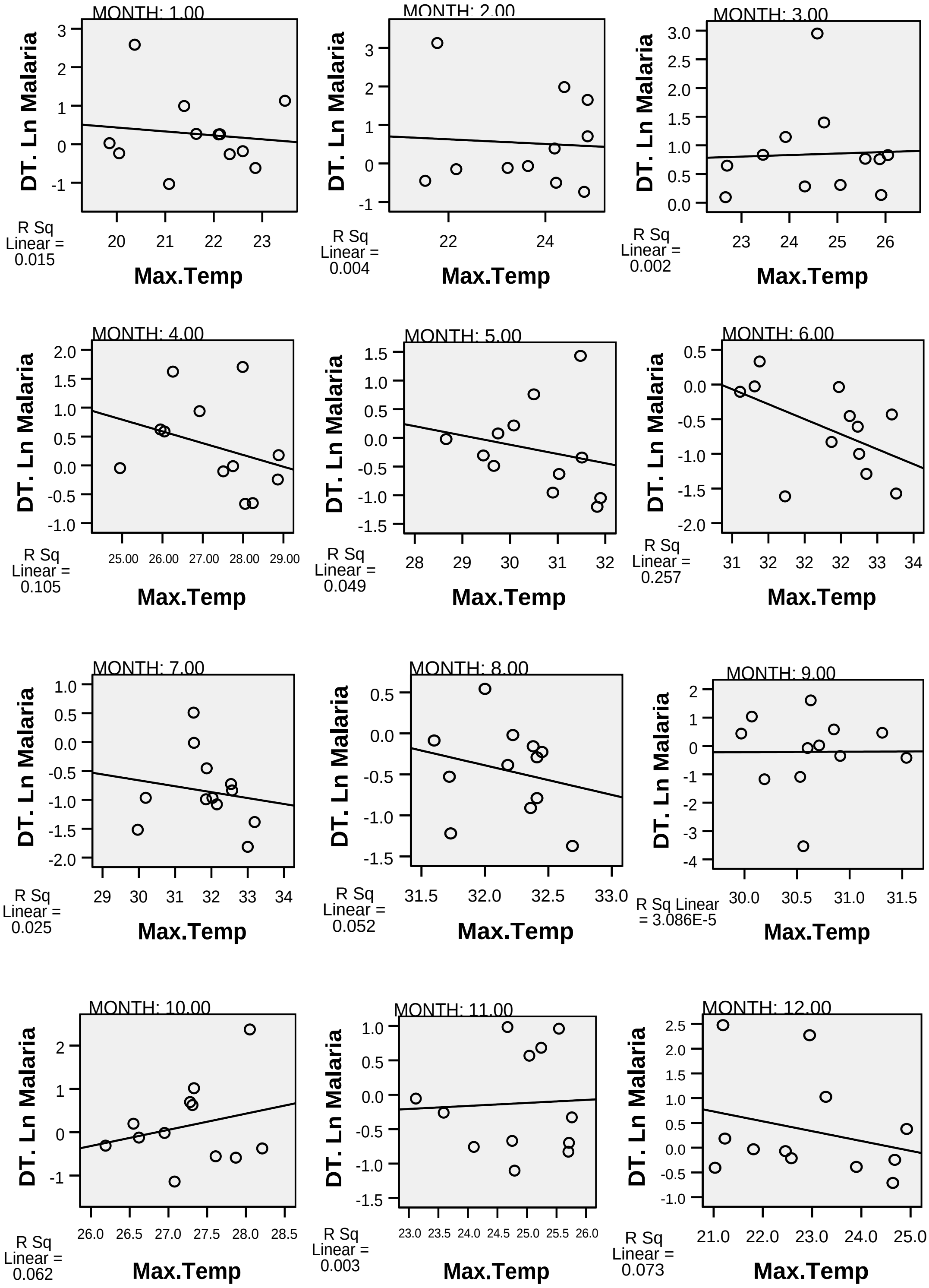


Table 2. Correlation of DT Ln malaria in TA against maximum temperature in Majaredah

Month	Unstandardized Coefficients	Significance
Jan	-0.151	0.677
Feb	0.168	0.532
Mar	0.187	0.599
Apr	-0.29	0.920
May	0.302	0.292
Jun	0.493	0.262
Jul	-0.29	0.931
Aug	0.137	0.360
Sep	-0.052	0.722
Oct	0.260	0.443
Nov	-0.362	0.515
Dec	0.680	0.044

Figure 2: DT Ln malaria in TA with maximum temperature in Majaredah for each month

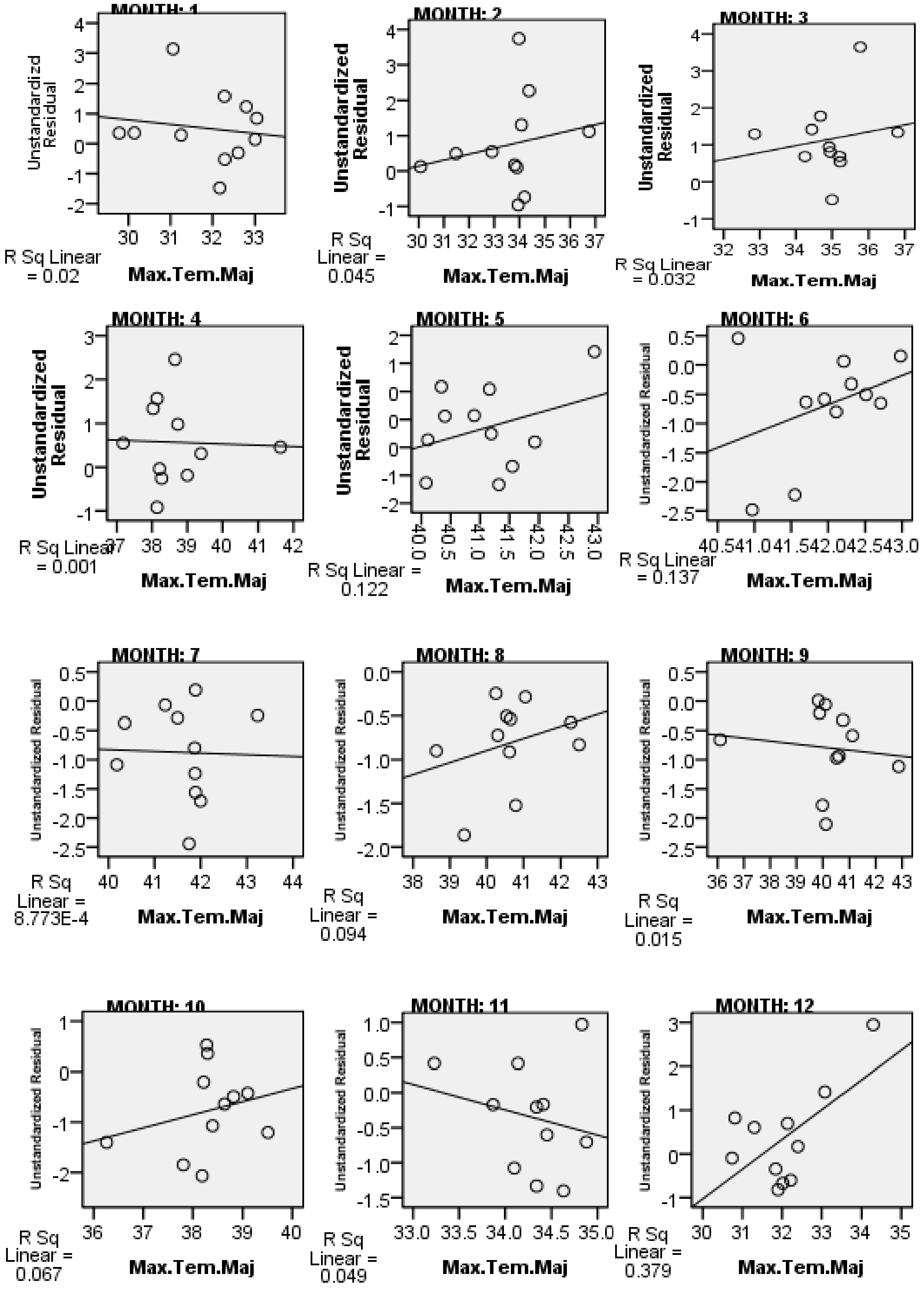


Table 3. Correlation of DT Ln malaria in TQ against maximum temperature in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	-0.248	0.272
Feb	0.252	0.427
Mar	0.705	0.026
Apr	-0.082	0.838
May	-0.350	0.316
Jun	-0.886	0.034
Jul	-0.471	0.047
Aug	-1.406	0.161
Sep	-0.383	0.683
Oct	-0.448	0.470
Nov	-0.029	0.947
Dec	-0.255	0.188

Figure 3. DT Ln malaria in TQ with maximum temperature of Khamise for each month

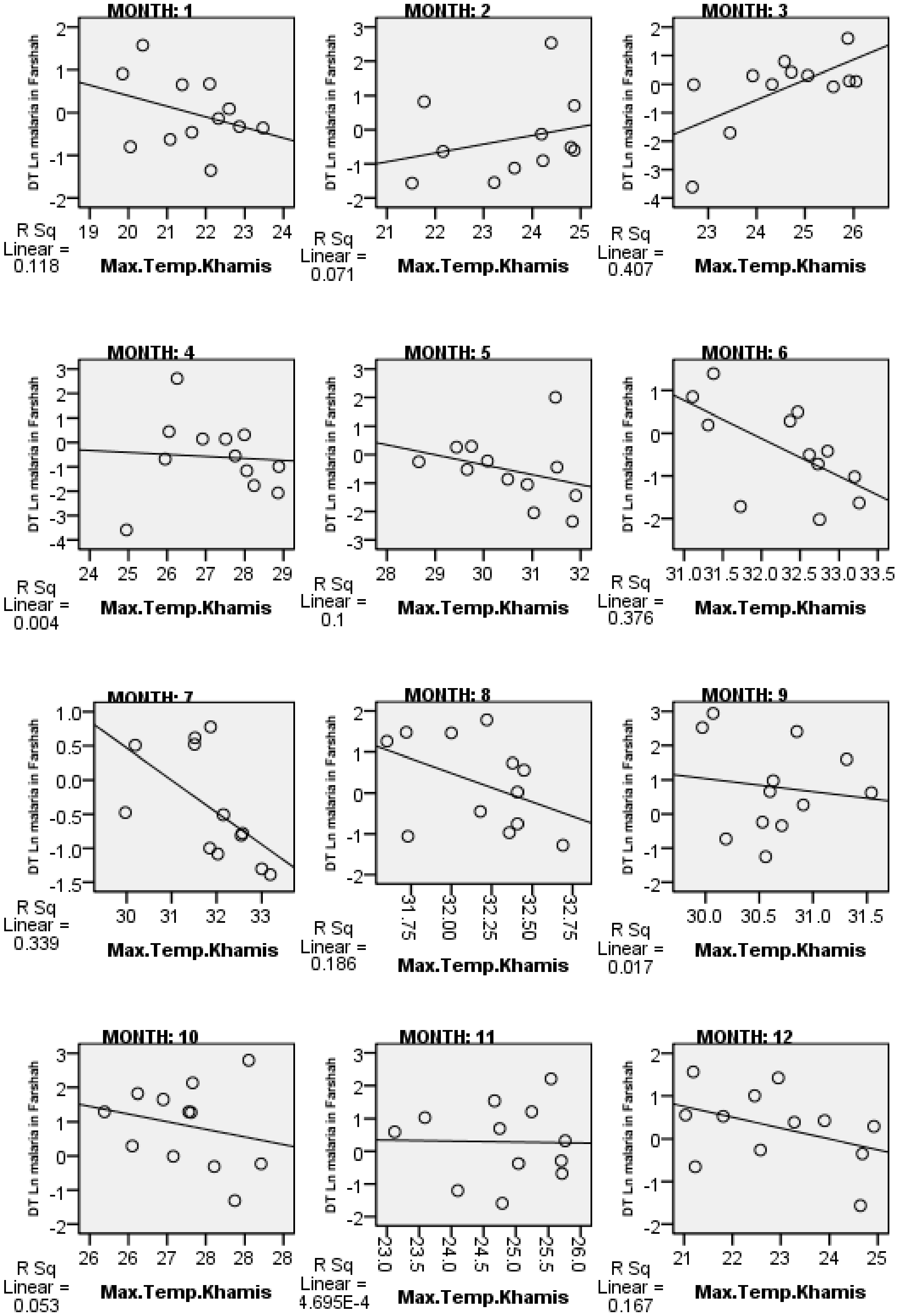


Table 4. Correlation of DT Ln malaria in Asir against mean temperature in Khamise

Month	Unstandardized Coefficients	Significance
Jan	-0.05	0.92
Feb	-0.46	0.37
Mar	0.03	0.92
Apr	-0.52	0.10
May	-0.13	0.62
Jun	-0.32	0.35
Jul	-0.40	0.29
Aug	-0.58	0.14
Sep	0.25	0.82
Oct	0.96	0.18
Nov	-0.12	0.74
Dec	-0.43	0.46

Figure 4: DT Ln malaria in Asir with mean temperature in Khamise for each month

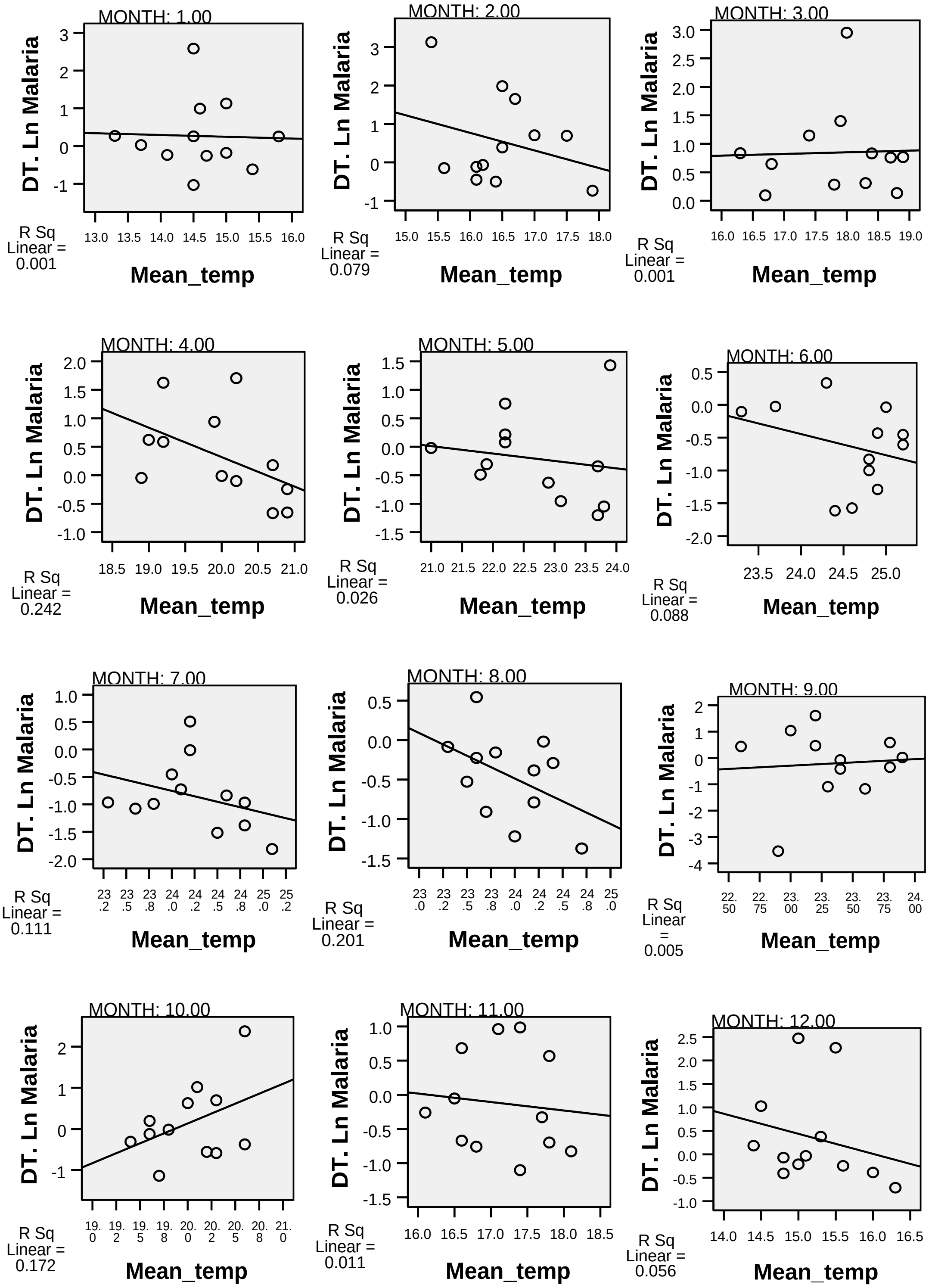


Table 5 Correlation of DT Ln malaria in TQ against mean temperature in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.125	0746
Feb	-0.160	0.767
Mar	1.01	0.019
Apr	-0.455	0.491
May	-0.172	0.661
Jun	-0.719	0.210
Jul	-0.860	0.051
Aug	-1.457	0.063
Sep	-1.027	0.344
Oct	-0252	0.795
Nov	-0.684	0.223
Dec	-0473	0.330

Figure 5: DT Ln malaria in TQ with mean temperature in Khamise for each month

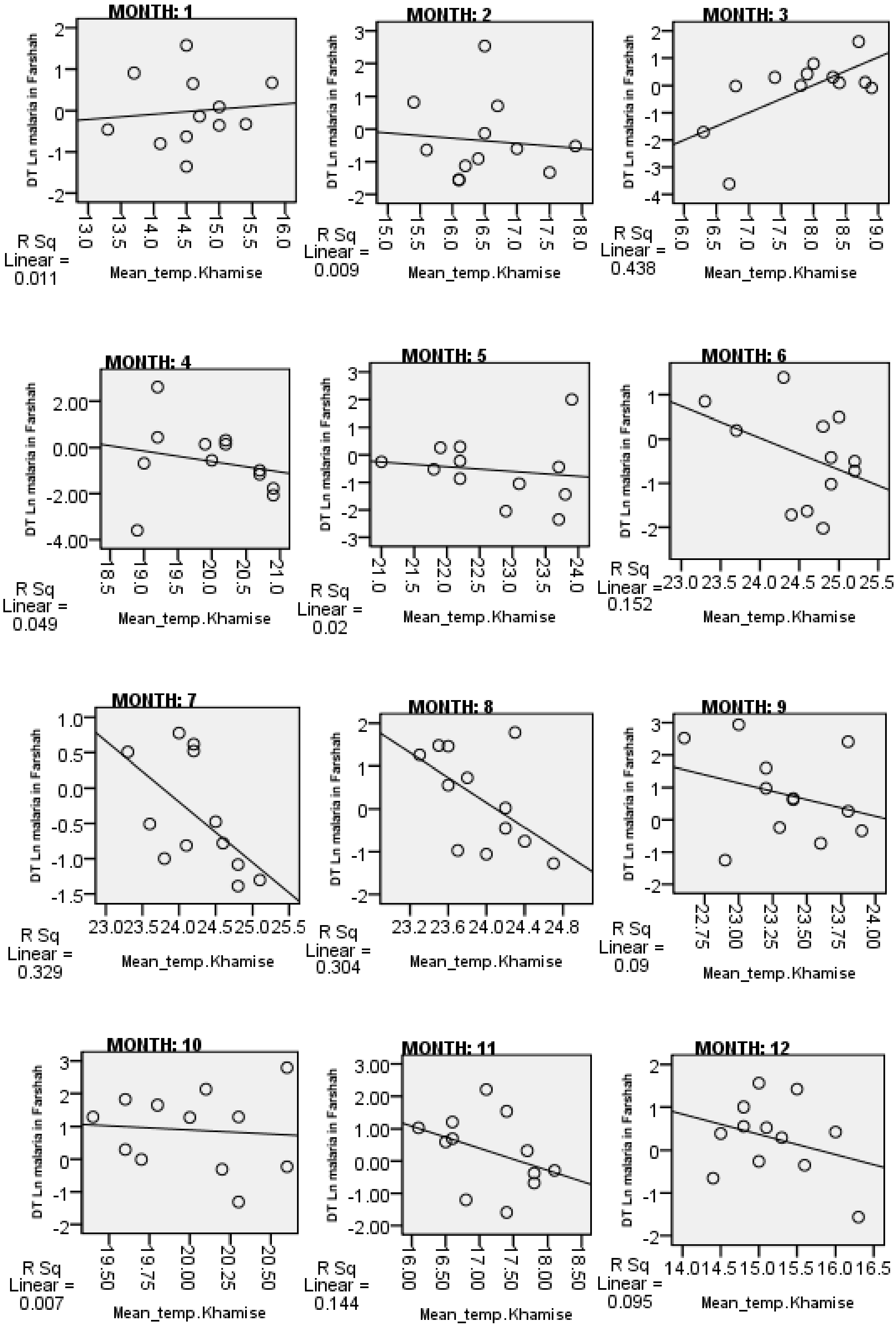


Table 6 :Correlation of DT Ln malaria in all Asir against minimum temperature in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.33	0.27
Feb	-0.18	0.70
Mar	0.22	0.49
Apr	-0.63	0.27
May	-0.37	0.42
Jun	0.01	0.97
Jul	-0.44	0.30
Aug	-0.01	0.98
Sep	-1.24	0.38
Oct	0.63	0.34
Nov	-0.17	0.51
Dec	0.25	0.46

Figure 6 : DT Ln malaria in all Asir with minimum temperature for each month

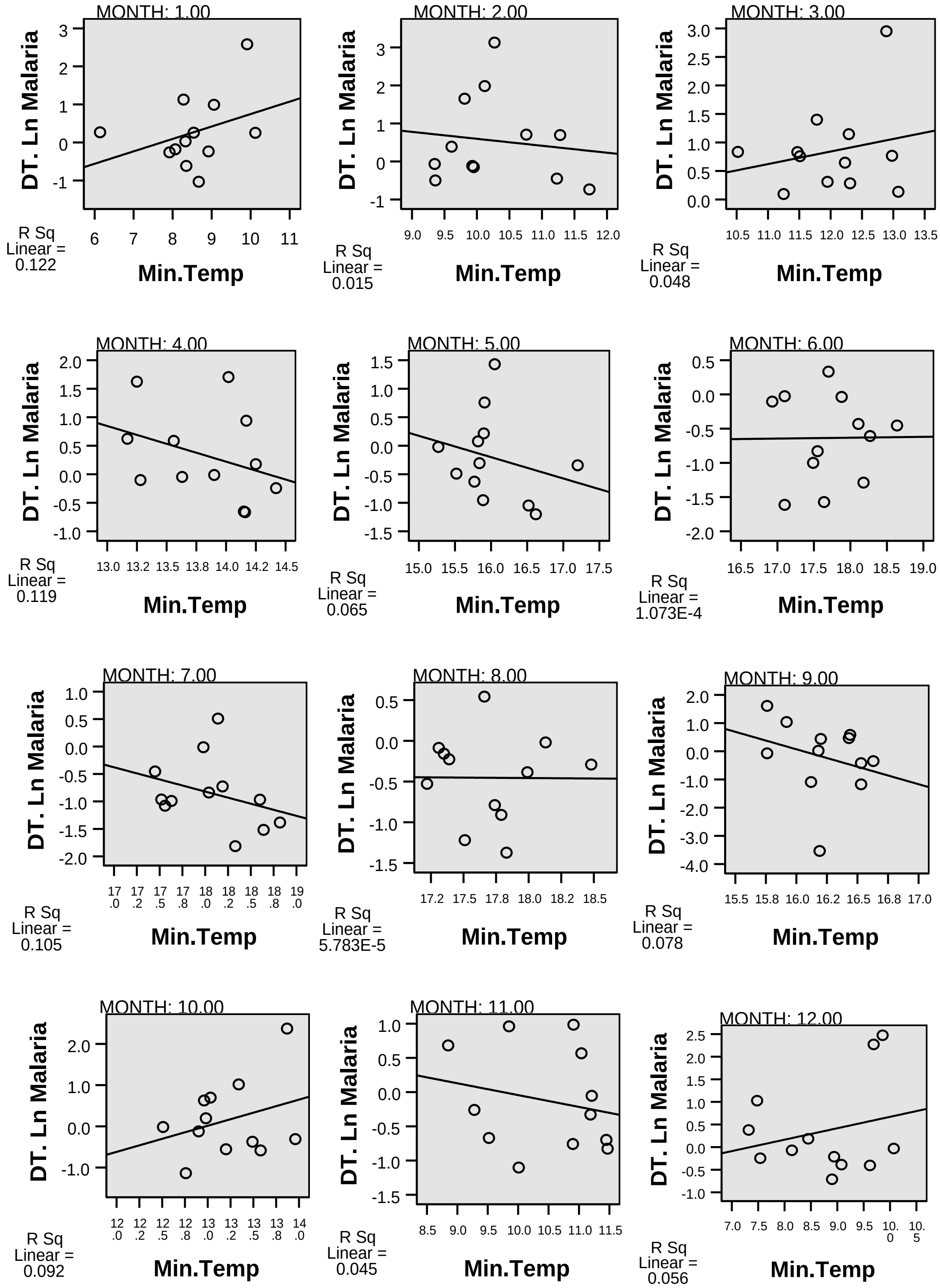


Table 7: Correlation of DT Ln malaria in TA against mean temperature in Majaredah

MONTH	Unstandardized Coefficients	Significance
Jan	1.560	0.09
Feb	0.118	0.832
Mar	0.124	0.673
Apr	-0.109	0.839
May	-0.170	0.643
Jun	0.216	0.550
Jul	0.343	0.073
Aug	-0.013	0.912
Sep	-0.073	0.469
Oct	-0.673	0.283
Nov	-0.940	0.137
Dec	1.211	0.035

Figure 7: DT Ln malaria in TA with minimum temperature in Majaredah for each month

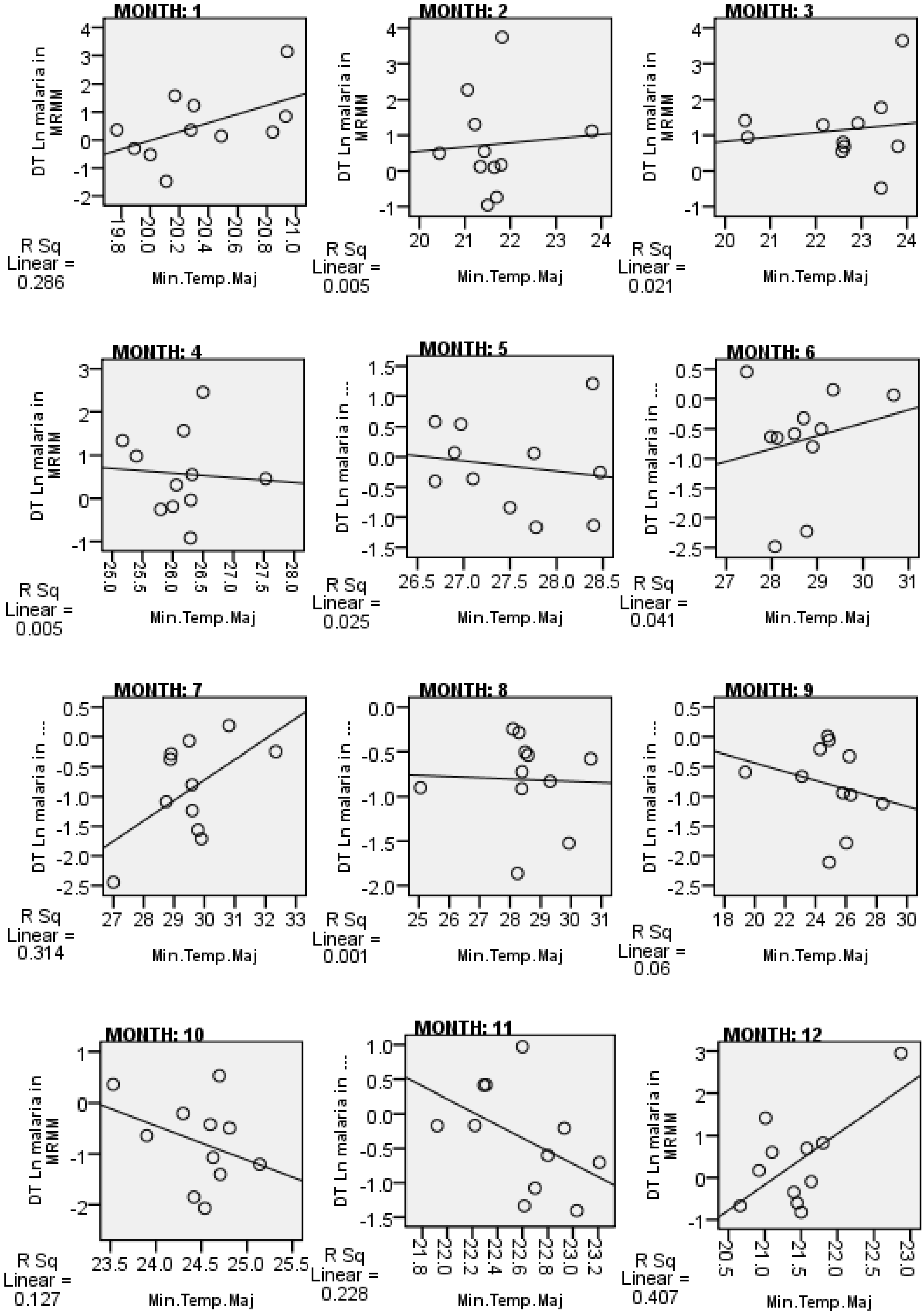


Table 8: Correlation of DT Ln malaria in TQ against minimum temperature in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.379	0.128
Feb	-0.272	0.578
Mar	0.798	0.131
Apr	-1.472	0.181
May	-0.480	0.499
Jun	-0.198	0.767
Jul	-0.980	0.052
Aug	-1.097	0.240
Sep	-0723	0.621
Oct	0.072	0.934
Nov	-0.522	0.175
Dec	0.307	0.285

Figure 8: DT Ln malaria in TQ with minimum temperature in Khamise for each month

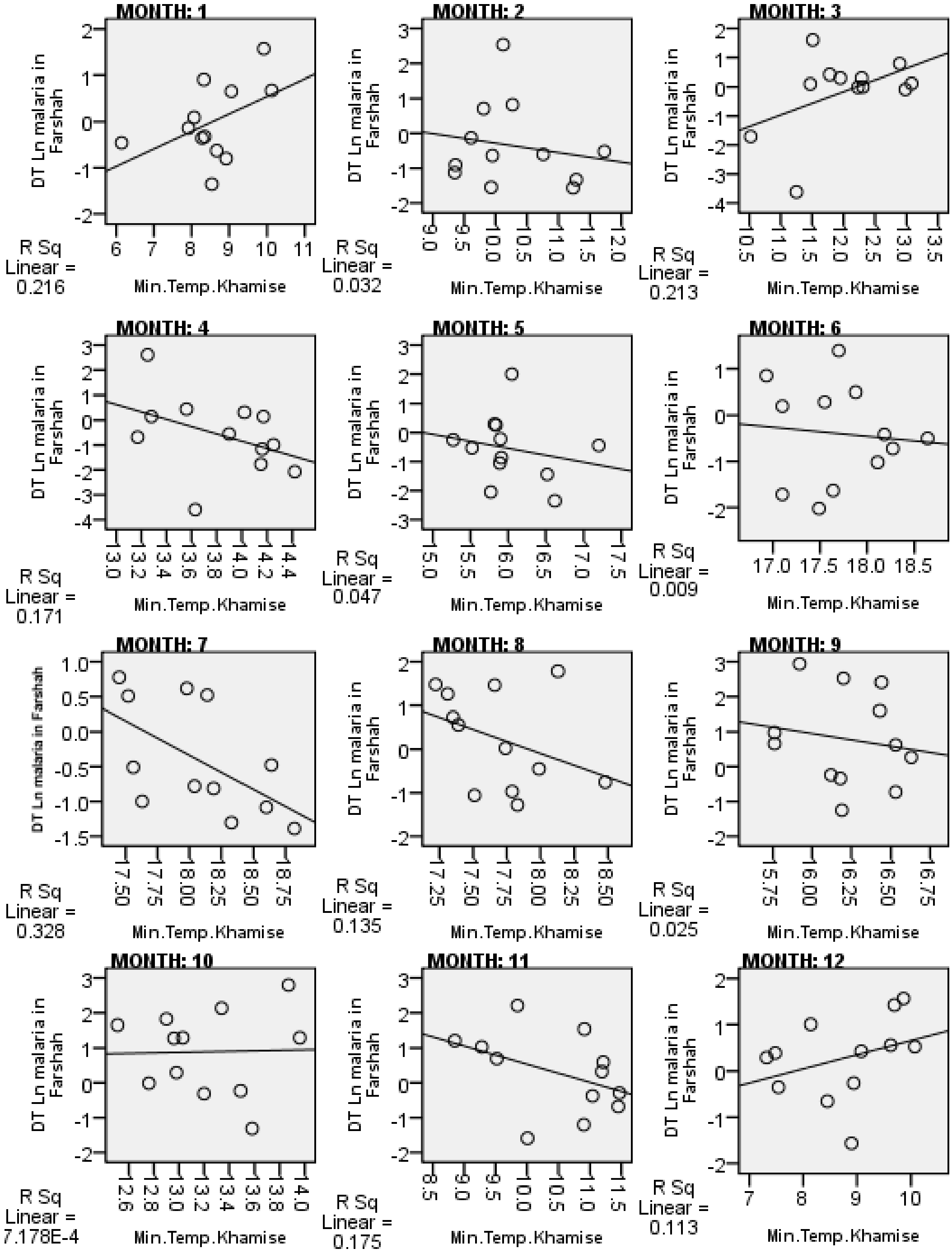


Table 9: Correlation of DT Ln malaria in Asir against Ln. rainfall in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.06	0.81
Feb	-0.38	0.38
Mar	-0.23	0.10
Apr	0.19	0.36
May	0.33	0.20
Jun	0.26	0.03
Jul	0.32	0.11
Aug	-0.16	0.44
Sep	0.17	0.73
Oct	-0.13	0.57
Nov	-0.15	0.42
Dec	-0.07	0. 85

Figure 9: DT Ln malaria with Ln. rainfall for each month

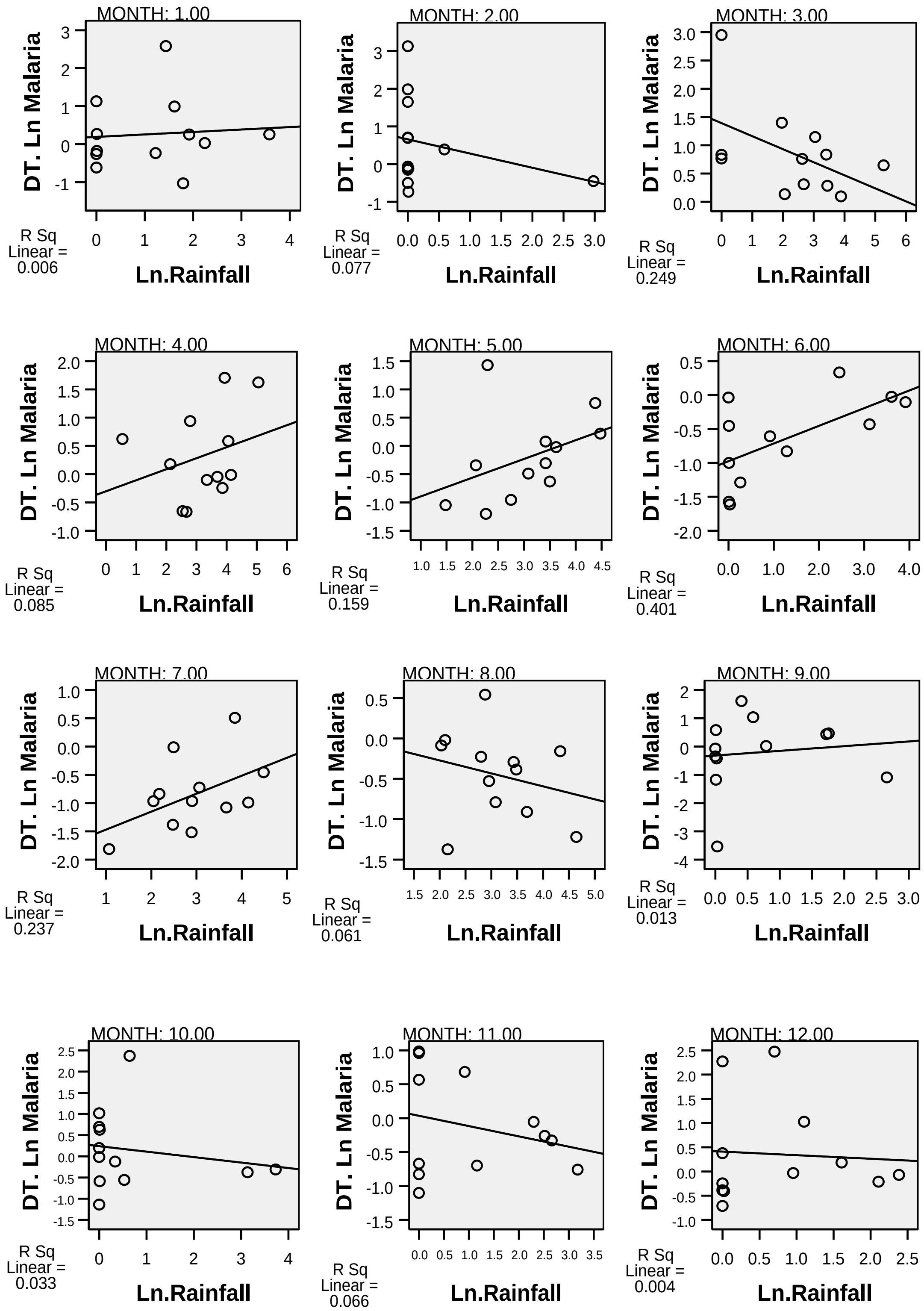


Table 10: Correlation of DT Ln malaria in TA against rainfall in Rejal

MONTH	Unstandardized Coefficients	Significance
Jan	0216	0.205
Feb	0.299	0.097
Mar	0.205	0.257
Apr	0.430	0.009
May	0.343	0.014
Jun	0.413	0.033
Jul	-0.026	0.874
Aug	0.204	0.010
Sep	0.106	0.453
Oct	-0.188	0.441
Nov	0.139	0.466
Dec	0.312	0.244

Figure 10: DT Ln malaria in TA with rainfall in Rejal for each month

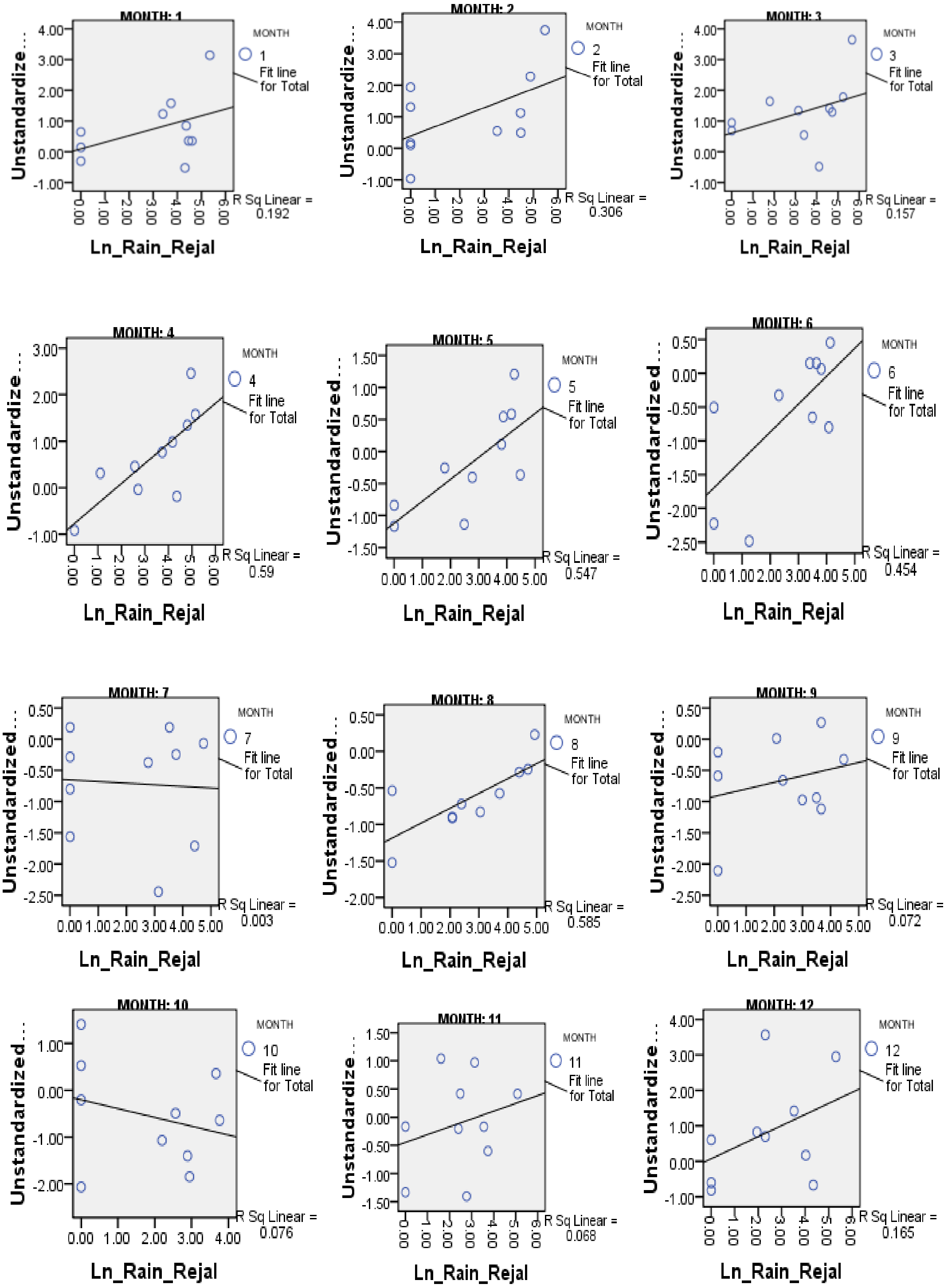


Table 11: Correlation of DT Ln malaria in

TQ against rainfall in Sarat

MONTH	Unstandardized Coefficients	Significance
Jan	0.325	0.069
Feb	0.204	0.435
Mar	0.082	0.794
Apr	0.631	0.039
May	0.400	0.145
Jun	0.461	0.148
Jul	0.307	0.112
Aug	0.404	0.078
Sep	0.564	0.007
Oct	0.373	0.016
Nov	0.464	0.133
Dec	0.404	0.022

Figure 11: DT Ln malaria in TQ with rainfall in Sarat for each month

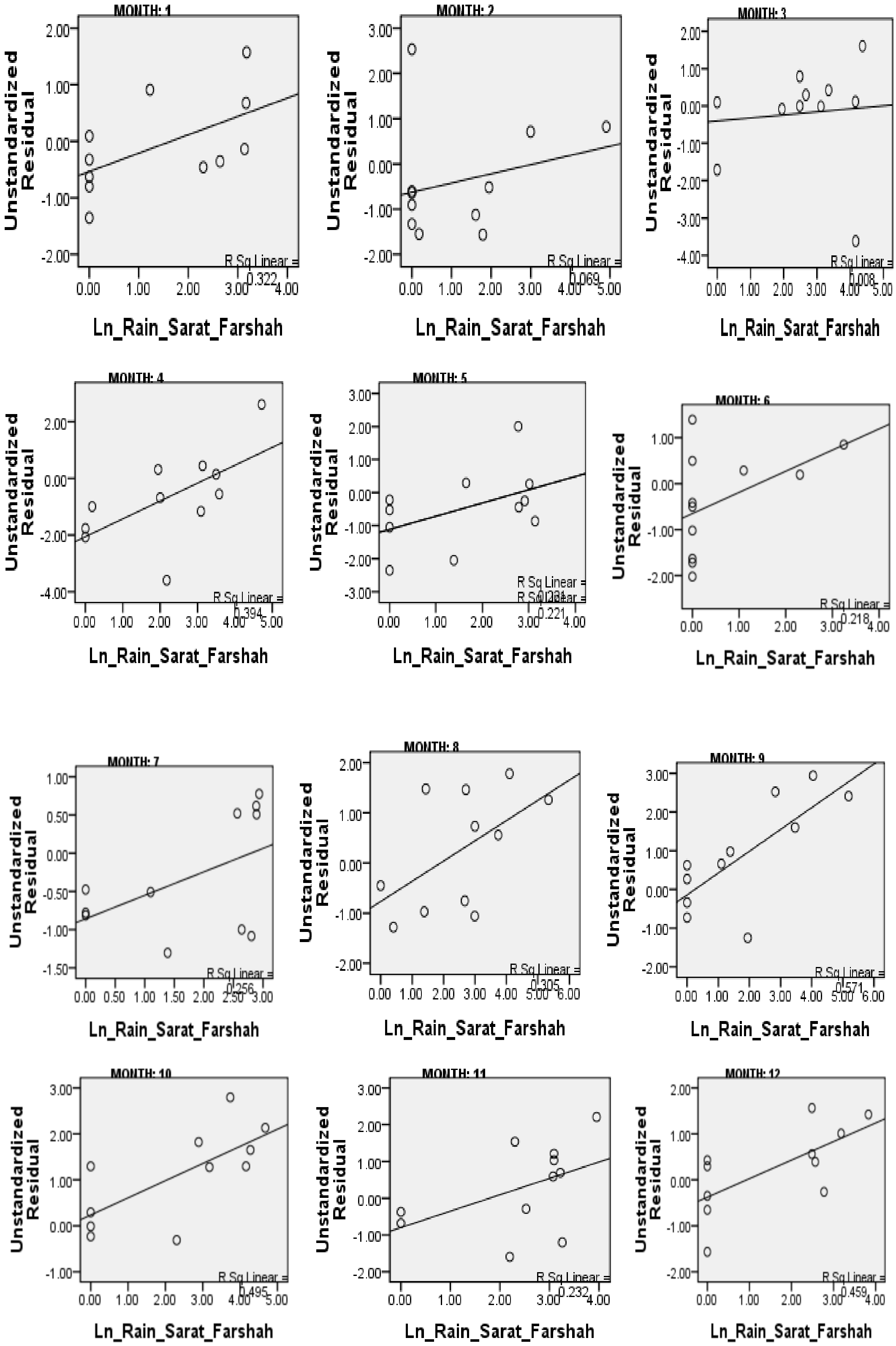


Table 12: Correlation of DT Ln malaria in Asir against humidity in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.03	0.51
Feb	0.11	0.29
Mar	0.01	0.85
Apr	0.07	0.09
May	0.02	0.55
Jun	-0.01	0.78
Jul	-0.02	0.71
Aug	0.01	0.73
Sep	0.08	0.45
Oct	0.03	0.57
Nov	0.00	0.88
Dec	0.06	0.20

Figure 12: DT Ln malaria in all Asir with humidity in Khamise for each month

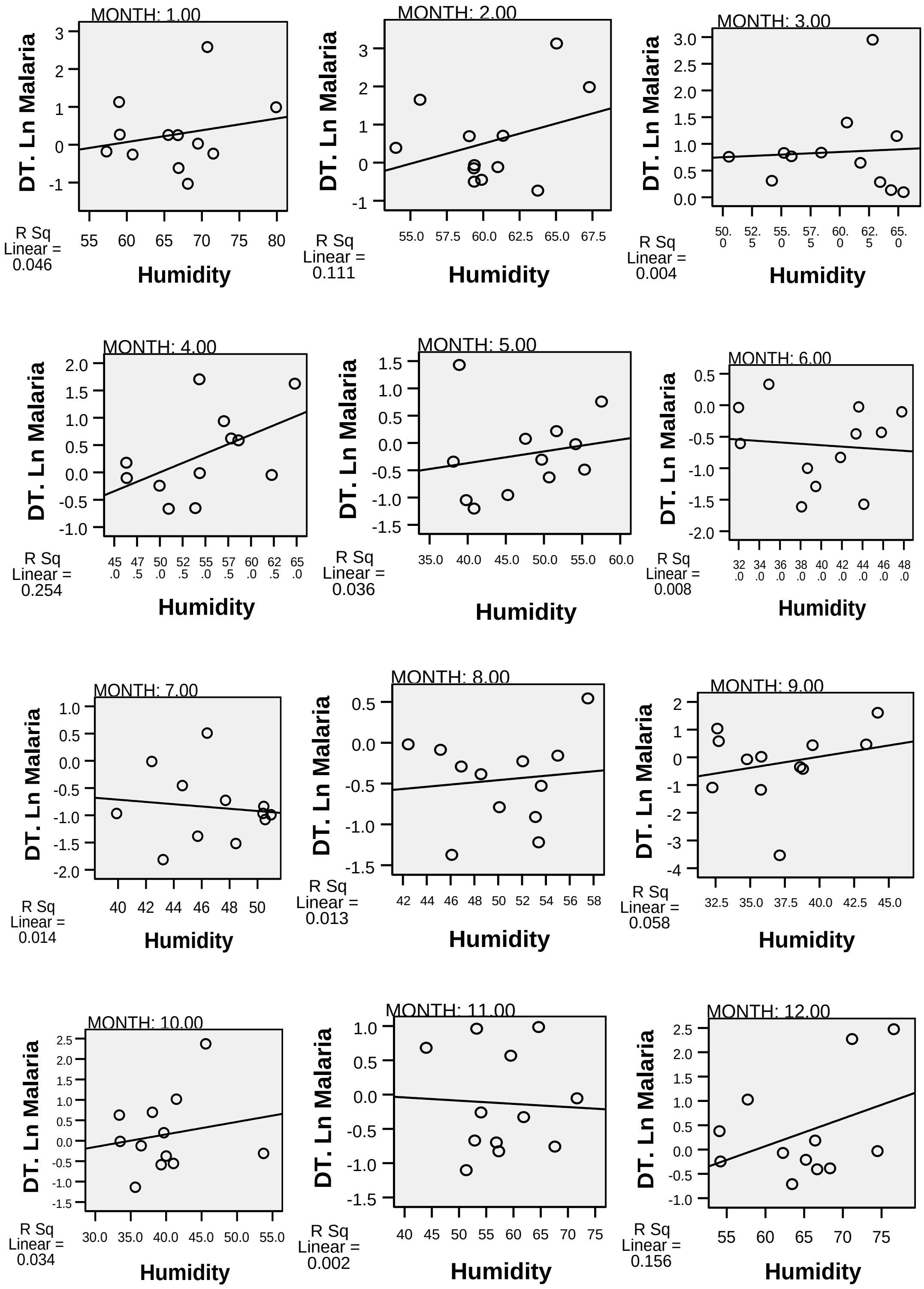
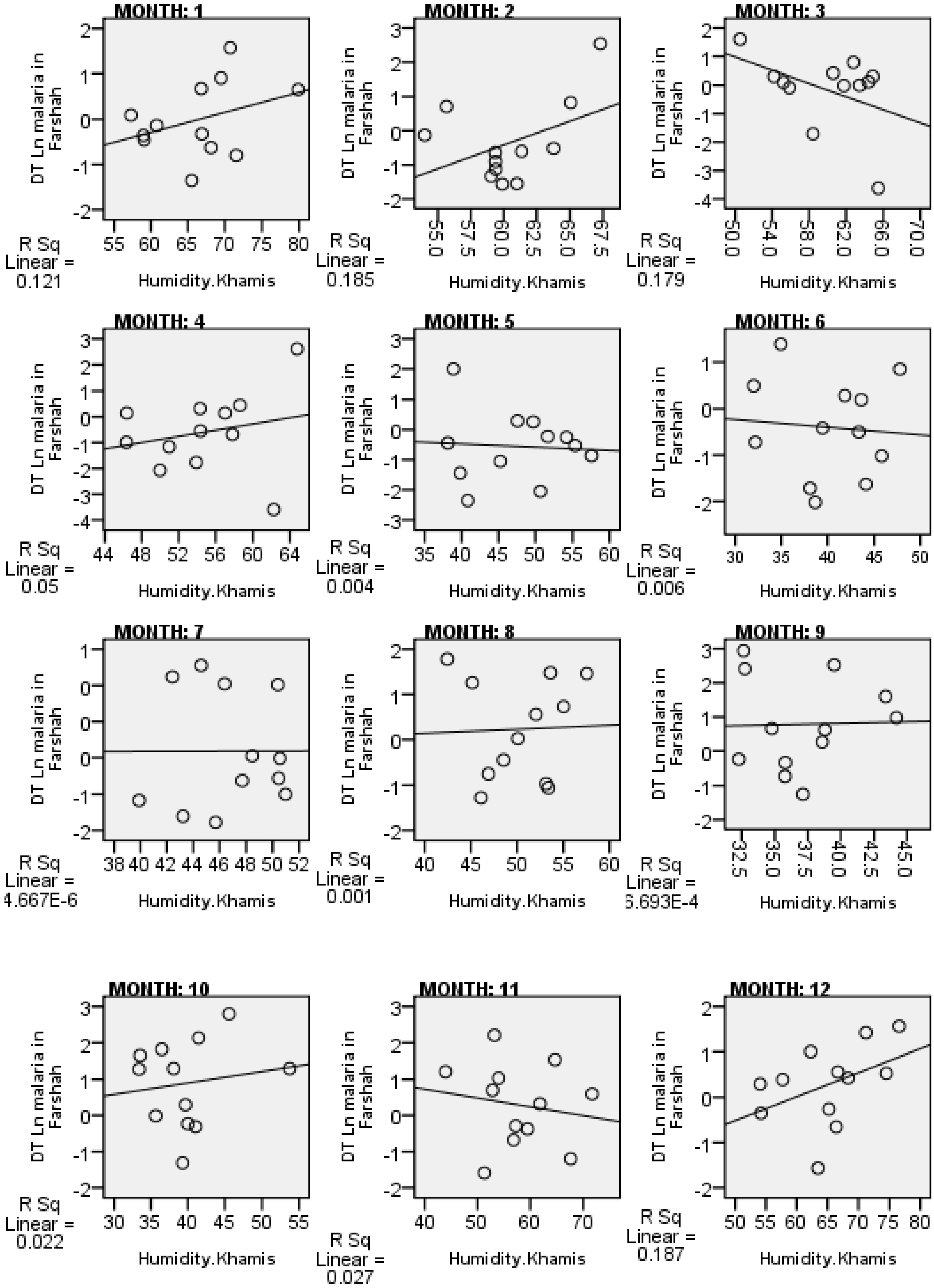


Table 13: Correlation of DT Ln malaria in TQ against humidity in Khamise

MONTH	Unstandardized Coefficients	Significance
Jan	0.044	0.268
Feb	0.140	0.163
Mar	-0.115	0.171
Apr	0.060	0.483
May	-0.011	0.843
Jun	-0.017	0.805
Jul	0.00	0.995
Aug	0.009	0.911
Sep	0.009	0.936
Oct	0.032	0.648
Nov	-0.024	0.611
Dec	0.053	0.160

Figure 13: DT Ln malaria in TQ with humidity in Khamise for each month



Appendix A.2

1. Maximum Temperature with Malaria in the whole of Asir

Table 14: DT Ln malaria and maximum temperature (Sept to Nov)

Model	LR						OL					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-0.10	.888	.134	.625	.183	.417	-.053	.697	-.729	.192	.391	.715
1 P	.010	.906	-.192	.612	-.279	.366	.034	.830	-1.08	.165	-.435	.159
2 P	-.134	.477	-.397	.145	-.262	.253	-.096	.794	-.380	.485	-.499	.791
3 P	-.288	.213	-.215	.305	.113	.617	-.546	.259	-.527	.290	-.432	.652
4 P	-021	.889	-.135	.430	.003	.984	-.262	.373	-.563	.157	.324	.755
5 P	-.013	.861	-.195	.256	.085	.566	-.099	.501	-.627	.090	-1.08	.341
6 P	-.036	.571	-.259	.091	-.103	.451	-.182	.167	-1.28	.003	-.963	.261
0-1 P	-.053	.751	-.165	.751	.695	.302	.038	.801	-.925	.170	-235	.611

Table 15: December to March

Model	LR						OL					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.035	.700	-.094	.447	-.086	.380	-.327	.107	-.724	.021	-.013	.976
1 P	-.033	.724	-.037	.785	-.007	.945	-.394	.064	-.442	.144	.035	.894
2 P	-.087	.164	-.070	.640	-.084	.476	-.165	.219	-.259	.429	.035	.939
3 P	-.071	.153	-.064	.718	.060	.671	-.138	.191	-.674	.110	1.24	.058
4 P	-.096	.058	-.469	.067	-.349	.090	-.113	.295	-.963	.124	-.629	.498
5 P	-.119	.100	-.112	.642	.059	.764	-.074	.627	.287	.560	.143	.841
6 P	-.168	.295	-.050	.827	-.207	.254	-.058	.860	-.016	.971	.177	.777
0-1 P	.038	.129	.058	.611	-.054	.702	.350	.085	.538	.101	.032	.911

2. Maximum Temperature with Malaria in Tehama of Asir

Table 16: September to March

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.226	.002	.049	.651	.049	.521	-.137	.279	.042	.855	-.133	.847
1 P	-.217	.000	-.071	.503	-.071	.344	-.134	.114	-.044	.839	-.301	.687
2 P	-.195	.000	-.01	.961	.036	.615	-.126	.071	-.056	.786	-.081	.885
3 P	-.206	.000	.041	.662	.045	.493	-.117	.113	-.066	.738	.068	.879
4 P	-.204	.000	.01	.931	-.013	.855	-.132	.136	.004	.984	.245	.648
5 P	-.105	.108	-.027	.725	-.022	.696	-.081	.448	.077	.704	.136	.820
6 P	.115	.033	.022	.808	.023	.726	.072	.416	.099	.604	.198	.564
0-1 P	.275	.000	-.025	.869	-.024	.826	-.174	.121	-.025	.935	-.471	.654

3. Maximum Temperature with Malaria in Tehama of Qahtan

Table 17: October to March

Model	LR						OL					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.122	.064	.049	.698	.131	.233	-.107	.371	-.541	.031	-.371	.177
1 P	.127	.003	.148	.290	.196	.104	.028	.718	-.258	.327	-.020	.947
2 P	.082	.117	-.093	.561	-.087	.526	.024	.695	-.489	.114	-.495	.159
3 P	.054	.129	-.212	.170	-.122	.363	.021	.758	-.351	.275	-.205	.548
4 P	.055	.215	-.191	.296	-.011	.947	.007	.938	-.615	.124	-.486	.260
5 P	-.21	.745	-.124	.474	.093	.551	-.059	.655	-.214	.546	-.019	.961
6 P	-.181	.005	-.199	.175	-.084	.514	-.157	.245	-.439	.162	-.446	.204
0-1 P	.145	.008	.116	.459	.213	.119	-.023	.816	-.639	.044	-.355	.310

4. Mean Temperature with Malaria in the whole of Asir

Table 18: Whole Year

Model	LR						OL					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.110	.000	-.192	.106	-.108	.249	-.156	.001	-1.89	.000	-1.81	.002
1 P	-.118	.000	-.268	.024	-.152	.105	-.173	.001	-2.00	.000	-1.17	.022
2 P	-.101	.000	-.332	.005	-.159	.093	-.149	.002	-1.92	.000	-1.01	.056
3 P	-.046	.048	-.170	.155	.065	.503	-.093	.050	-1.78	.000	-.799	.126
4 P	.014	.552	-.227	.059	-.123	.195	-.022	.637	-1.68	.000	-.879	.104
5 P	.072	.002	-.179	.138	-.043	.654	.036	.447	-1.82	.000	-1.22	.017
6 P	.110	.000	-.252	.037	-.140	.142	.074	.123	-1.76	.000	-1.22	.017

Table 19: September to November

Model	LR						OL					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.01	.896	.198	.596	.199	.520	-.075	.571	-2.71	.007	-.995	.606
1 P	-.027	.781	-.837	.050	-.952	.007	-.087	.645	-3.06	.008	-2.08	.112
2 P	-.582	.045	-1.01	.008	-.564	.116	-1.75	.021	-3.63	.004	-2.91	.279
3 P	-.466	.120	-.588	.106	.020	.953	-2.18	.006	-3.36	.004	-1.19	.560
4 P	-.013	.935	-.245	.335	-.049	.822	-.519	.126	-1.80	.012	-.694	.769
5 P	-.014	.866	-.273	.241	-.110	.580	-.154	.359	-1.38	.014	-2.92	.246
6 P	-.040	.612	-.364	.096	-.149	.418	-.218	.186	-1.83	.003	-1.02	.342

Table 20: December to March

Model	LR						OL					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.093	.358	-.183	-.396	-.071	.677	.240	.264	-2.01	.003	-1.40	.091
1 P	.009	.940	-.024	.918	.140	.452	-.561	.046	-1.18	.033	.644	.424
2 P	-.087	.192	-.127	.631	-.177	.393	-.248	.082	-1.88	.008	-1.18	.192
3 P	-.066	.167	.027	.931	.253	.306	-.131	.191	-2.21	.008	-1.74	.102
4 P	-.102	.050	-.634	.050	-.530	.041	-1.47	.808	-3.99	.001	-4.07	.014
5 P	-.146	.085	-.372	.300	.011	.970	-.189	.314	-2.70	.006	-.981	.445
6 P	-.484	.030	-.471	.133	-.462	.061	-1.44	.011	-2.73	.006	-1.79	.167

5. Mean Temperature with Malaria in TQ

Table 21: Whole Year

Model	LR						OL					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.019	.492	-.209	.178	-.089	.467	-.094	.048	-1.28	.000	-.797	.030
1 P	.038	.176	-.275	.077	-.148	.228	-.048	.309	-1.33	.000	-.921	.014
2 P	.071	.012	-.475	.002	-.304	.012	-.08	.858	-1.6	.000	-1.19	.014
3 P	.096	.000	-.317	.035	-.016	.896	.026	.573	-1.25	.000	-.554	.139
4 P	.088	.001	-.291	.047	-.109	.363	.039	.406	-1.21	.000	-.731	.048
5 P	.065	.015	-.202	.171	-.019	.869	.051	.281	-.921	.003	-.378	.313
6 P	.025	.365	-.284	.053	-.157	.169	.036	.449	-1.25	.000	-1.09	.007

Table 22: October to March

Model	LINEAR REGRESSION						ORDINAL LOGISTIC					
	Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality		Mean. temperature only		Mean. temperature with seasonality		Mean. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.124	.081	.100	.630	.288	.115	-.054	.670	-.788	.055	-.230	.620
1 P	.121	.006	.018	.940	.187	.366	.024	.760	-1.05	.029	-.690	178
2 P	.087	.016	-.194	.459	-.123	.584	.030	.640	-1.17	.027	-.896	.102
3 P	.062	.085	-.234	.364	.123	.600	.018	.795	-1.27	.024	-.705	.251
4 P	.056	.226	-.264	.305	-.37	.874	-.016	.857	-1.80	.005	-1.28	.061
5 P	-.038	.626	-.186	.404	.156	.445	-.152	.335	-1.01	.047	-.562	.304
6 P	-.198	.008	-.247	.219	-.086	.625	-.212	.179	-1.11	.018	-.915	.072
0+1 P	.148	.011	.100	.721	.390	.111	.007	.946	-1.47	.010	-.782	.229

6. Minimum Temperature with Malaria in the whole of Asir

Table 23: The whole of year

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.104	.000	.027	.817	.068	.448	-.133	.008	-.762	.010	-.535	.219
1 P	-.113	.000	-.06	.956	.004	.962	-.155	.002	-.985	.002	-.882	.097
2 P	-.099	.000	-.075	.522	-.060	.513	-.138	.006	-1.0	.002	-.641	.190
3 P	-.045	.059	.149	.206	.215	.180	-.070	.152	-.313	.266	1.33	.073
4 P	.016	.516	.126	.286	.018	.844	.000	.990	-.272	.324	-.047	.919
5 P	.079	.001	.156	.189	.074	.428	.066	.179	-.316	.253	-.272	.532
6 P	.120	.000	.041	.731	-.058	.533	.119	.019	-.151	.585	.177	.697

Table 24: September to November

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.022	.758	-.116	.697	-.066	.790	-.06	.668	-1.06	.099	-.519	.662
1 P	-.015	.869	-.356	.462	-.375	.348	-.019	.913	-1.02	.298	-7.69	.267
2 P	-.105	.590	-.692	.137	-.236	.576	-.234	.541	-1.76	.083	1.78	.450
3 P	-.040	.913	-.178	.655	.300	.389	-.190	.030	-2.48	.014	-1.18	.587
4 P	.112	.506	.175	.629	.358	.232	-.329	.329	-1.98	.027	-1.31	.518
5 P	.039	.707	.160	.465	.132	.666	-.073	.719	-1.03	.176	-2.21	.386
6 P	.025	.791	.110	.723	.165	.518	-.072	.712	-.651	.298	-.928	.625

Table 25: December to March

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.165	.056	.185	.275	.225	.092	-.001	.994	-.344	.352	-.069	.883
1 P	.137	.250	.194	.274	.177	.177	-.384	.142	-.462	.213	.407	.500
2 P	-.056	.431	.120	.506	-.034	.814	-.310	.048	-1.27	.016	-1.51	.067
3 P	-.055	.286	.288	.195	.328	.060	-1.11	.291	-.448	.366	.754	.338
4 P	-.074	.154	.159	.575	-.121	.602	-.116	.297	-1.26	.078	-.733	.444
5 P	-.114	.135	.104	.797	-.027	.934	-.129	.429	-1.53	.084	-.499	.678
6 P	-.320	.086	-.317	.388	-.344	.237	-.586	.159	-2.27	.013	-1.33	.266

7. Minimum Temperature with Malaria in TA

Table 26: Whole of Year

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.103	.000	.074	.347	-.011	.845	-.074	.180	.200	.286	-.274	.473
1 P	-.189	.000	-.041	.608	-.081	.149	-.100	.070	.042	.809	-.691	.139
2 P	-.149	.000	-.018	.816	.010	.870	-.115	.040	-.055	.754	-.618	.216
3 P	-.142	.000	.018	.814	.027	.618	-.064	.242	.054	.757	.570	.151
4 P	-.051	.105	-.015	.854	-.017	.773	-.015	.778	.080	.648	.185	.681
5 P	.045	.149	-.049	.455	-.048	.311	.032	.561	.027	.882	-.451	.362
6 P	.134	.000	.027	.738	.046	.419	.098	.076	.149	.407	.436	.198
0+1 P	-.181	.000	.028	.783	.078	.291	-.100	.091	.176	.434	-.624	.195

Table 27: September to March

Model	LR						OL					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.226	.002	.049	.651	.049	.521	-.137	.279	.042	.855	-.133	.847
1 P	-.217	.000	-.071	.503	-.071	.344	-.134	.114	-.044	.839	-.301	.687
2 P	-.195	.000	-.01	.961	.036	.615	-.126	.071	-.056	.786	-.081	.885
3 P	-.206	.000	.041	.662	.045	.493	-.117	.113	-.066	.738	.068	.879
4 P	-.204	.000	.01	.931	-.013	.855	-.132	.136	.004	.984	.245	.648
5 P	-.105	.108	-.027	.725	-.022	.696	-.081	.448	.077	.704	.136	.820
6 P	.115	.033	.022	.808	.023	.726	.072	.416	.099	.604	.198	.564
0+1 P	.275	.000	-.025	.869	-.024	.826	-.174	.121	-.025	.935	-.471	.654

8. Minimum Temperature with Malaria in TQ

Table 28: Whole Year

Model	LINEAR REGRESSION						ORDINAL LOGISTIC					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.023	.421	-.063	.674	.035	.768	-.075	.125	-.314	.211	.141	.677
1 P	.036	.220	-.210	.169	-.153	.200	-.040	.406	-.709	.015	-.715	.035
2 P	.079	.006	-.253	.097	-.114	.341	.008	.876	-.675	.020	-.402	.236
3 P	.110	.000	.130	.382	-.303	.008	.055	.259	-.074	.783	.525	.140
4 P	.100	.000	.068	.640	-.016	.888	.069	.158	-.087	.747	-.107	.751
5 P	.085	.002	.228	.114	.184	.096	.089	.074	.221	.417	.488	.200
6 P	.044	.120	.099	.447	-.049	.662	.070	.159	-.059	.827	-.304	.368
0+1 P	.007	.822	-.227	.247	-.098	.526	-.060	.240	-.876	.020	-.527	.246

Table 29: October to March (TQ)

Model	LINEAR REGRESSION						ORDINAL LOGISTIC					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.110	.132	.131	.426	.192	.176	.048	.710	.156	.605	.478	.176
1 P	.123	.010	-.043	.812	-.025	.871	.032	.709	-.392	.245	-.517	.158
2 P	.100	.007	.134	.489	.093	.572	.049	.470	-.161	.645	-.126	.738
3 P	.072	.038	.171	.412	.313	.082	.032	.635	-.241	.561	.119	.804
4 P	.064	.148	.093	.702	.159	.443	.004	.962	-.953	.076	-.610	.278
5 P	-.002	.180	.104	.725	.336	.190	-.057	.695	-.587	.321	-.046	.945
6 P	-.192	.019	.018	.952	.021	.932	-.191	.252	-1.11	.070	-1.02	.123
0+1 P	.153	.017	.089	.694	.159	.415	.054	.638	-.144	.726	.001	.998

9. Rainfall with Malaria in the Whole of Asir

Table 30: Whole Year

Model	LR						OL					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.057	.280	-.009	.890	.027	.609	.060	.575	.259	.106	.200	.466
1 P	-.096	.069	.050	.455	.044	.401	.018	.866	.295	.068	.193	.429
2 P	-.085	.110	.107	.109	.066	.206	-.016	.855	.263	.104	.024	.921
3 P	-.093	.084	.088	.193	.018	.730	.080	.463	.448	.010	.564	.041
4 P	-.059	.274	.041	.831	-.045	.398	.055	.612	.304	.065	-.085	.753
5 P	.021	.697	.000	.998	-.012	.826	.123	.262	.214	.177	-.089	.721
6 P	.102	.061	.091	.181	.099	.061	.229	.042	.287	.076	.381	.196
0+1 P	.133	.056	.057	.553	.071	.338	.076	.590	.576	.014	.401	.286

Table 31: September to November

Model	LR						OL					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.082	.588	.079	.612	-.021	.872	.140	.636	.155	.608	.471	.492
1 P	-.075	.504	-.054	.760	-.017	.907	-.089	.687	-.117	.736	.003	.997
2 P	.196	.099	.440	.023	.338	.039	.069	.771	.052	.894	-.210	.836
3 P	.145	.240	.163	.299	-.017	.400	.423	.118	.599	.073	1.08	.348
4 P	-.047	.704	.024	.877	-.122	.356	.420	.116	.791	.031	-1.07	.354
5 P	-.014	.907	-.042	.777	-.010	.935	.332	0.174	.471	.125	.001	.890
6 P	.264	.041	.258	.061	.212	.064	.257	.346	.253	.370	.510	.631

Table 32: December to March

Model	LR						OL					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.050	.635	-.157	.215	-.033	.759	.081	.718	.124	.650	-.299	.488
1 P	-.130	.337	-.049	.494	-.027	.814	.000	.999	.011	.970	-.248	.567
2 P	.059	.649	.052	.697	.080	.444	.039	.885	.020	.941	-.028	.641
3 P	.083	.549	.073	.603	.038	.736	.430	.181	.408	.219	.572	.204
4 P	-.008	.937	.057	.689	-.025	.830	-.041	.843	.236	.456	.464	.352
5 P	-.106	.277	.007	.965	-.077	.524	-.152	.450	-.085	.780	-.345	.391
6 P	-.027	.792	.041	.770	.139	.219	.378	.085	.548	.088	.689	.177

10. Malaria with rainfall in TA

Table 33: September to March

Model	LR						OL					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.239	.003	.188	.008	.085	.109	.612	.000	.784	.000	.396	.025
1 P	.236	.005	.226	.002	.083	.148	.486	.001	.524	.002	.378	.060
2 P	.220	.012	.217	.005	.081	.163	.316	.027	.346	.025	.020	.946
3 P	.252	.007	.271	.001	.090	.159	.380	.015	.448	.009	-.475	.117
4 P	.196	.042	.233	.006	.064	.317	.277	.070	.361	.032	.101	.707
5 P	.038	.693	.149	.082	.036	.564	.122	.402	.220	.173	.333	.252
6 P	.053	.572	.155	.061	.048	.425	.323	.031	.480	.007	.380	.165
0+1 P	.314	.001	.259	.002	.109	.097	.793	.000	.897	.000	.315	.041

11. Malaria with rainfall in TQ

Table 34: October to March

Model	LINEAR REGRESSION						ORDINAL LOGISTIC					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.311	.000	.529	.030	.173	.021	.581	.001	.710	.001	.620	.011
1 P	.263	.003	.244	.006	.050	.149	.648	.001	.733	.001	.518	.031
2 P	.286	.001	.253	.004	.100	.251	.969	.000	1.02	.000	.900	.001
3 P	.077	.370	.110	.193	.011	.844	.567	.003	.725	.001	.533	.034
4 P	.010	.948	.101	.250	.040	.956	.539	.004	.729	.001	.593	.016
5 P	.062	.467	.102	.242	.046	.545	.705	.001	.809	.001	.740	.005
6 P	.125	.151	.140	.120	.074	.351	.429	.021	.553	.010	.426	.073
0+1 P	.413	.000	.382	.000	.176	.045	1.03	.000	1.22	.000	1.02	.003

12. Malaria with Relative Humidity in Asir

Table 35: September to November

Model	LR						OL					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.003	.856	.018	.549	.011	.669	-.012	.704	-.025	.673	.029	.798
1 P	.018	.463	.081	.029	.061	.050	.006	.904	.015	.843	.047	.749
2 P	.043	.082	.101	.019	.044	.282	.027	.590	.040	.645	.025	.889
3 P	.021	.455	.028	.484	.000	.990	.064	.277	.122	.150	-.256	.276
4 P	-.005	.862	.012	.726	.001	.966	.077	.193	.134	.070	-.257	.359
5 P	.017	.410	.042	.167	.031	.221	.077	.089	.173	.018	.424	.115
6 P	.025	.264	.048	.113	.023	.381	.075	.126	.138	.047	.059	.667

Table 36: December to March

Model	LR						OL					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.021	.371	.045	.038	.057	.006	.000	.996	.021	.707	.122	.152
1 P	.039	.067	.051	.035	.038	.045	.000	.993	.031	.551	.030	.717
2 P	.020	.090	.034	.152	.012	.541	.002	.935	.090	.096	.146	.080
3 P	.029	.011	.062	.014	.040	.057	.024	.340	.038	.499	.415	.017
4 P	.029	.051	.059	.036	.021	.395	.001	.982	.054	.393	.166	.172
5 P	.007	.744	.044	.238	.015	.633	.003	.939	.067	.410	.060	.615
6 P	-.024	.301	-.031	.410	-.041	.173	.063	.197	.100	.212	-.077	.526

13. Malaria with Relative Humidity in TQ

Table 37: October to March

Model	LINEAR REGRESSION						ORDINAL LOGISTIC					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.019	.139	.015	.504	.022	.261	.003	.383	.036	.402	.059	.239
1 P	-.015	.161	.050	.036	.038	.067	-.006	.745	.023	.595	.008	.867
2 P	-.005	.624	.051	.030	.031	.127	-.008	.678	.022	.617	.010	.840
3 P	.005	.650	.050	.033	.034	.102	.001	.950	.035	.459	.042	.444
4 P	.015	.308	.039	.115	.011	.621	.037	.211	.066	.208	.049	.404
5 P	.028	.136	.022	.401	.005	.828	.059	.120	.091	.107	.075	.228
6 P	.015	.372	.005	.838	-.007	.765	-.003	.934	-.15	.775	-.017	.767
0+1 P	-.020	.116	.048	.094	.043	.075	.003	.906	.051	.344	.050	.405

Multiple regressions

Table 38: Multiple regressions of Malaria in All Asir
Maximum Temperature with rainfall

Whole year --------- Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.090	.003	-.042	.631	-.014	.836	-.154	.026	-.798	.001	-.480	.217
Rainfall	.006	.538	.025	.100	.026	.035	.015	.819	.030	.028	.094	.042
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.064	.031	-.006	.941	.010	.876	.131	.058	-.775	.001	-.330	.341
Rainfall	.021	.040	.050	.001	.037	.002	.011	.647	.083	.039	.073	.034
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.070	.044	-.024	.813	.004	.962	-.145	.074	-1.17	.000	-.621	.184
Rainfall	.023	.045	.057	.003	.048	.001	.006	.842	.016	.036	.133	.037

Table 39: Multiple regressions of Malaria in All Asir
Maximum Temperature with rainfall

April To Aug. Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & Seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.171	.000	-.131	.185	-.121	.098	-.220	.119	-.588	.087	-.875	.113
Rainfall	.129	.065	.182	.029	.082	.184	.302	.210	.314	.255	.614	.241
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.126	.000	-.148	.113	-.081	.238	-.170	.076	-.890	.012	-.774	.097
Rainfall	.101	.096	.114	.135	.078	.164	.435	.049	.396	.148	.448	.272
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.140	.000	-.152	.152	-.117	.140	-.177	.140	-1.13	.018	-1.45	.052
Rainfall	.321	.000	.336	.002	.197	.019	.997	.008	1.01	.026	1.59	.050

Table 40: Multiple regressions of Malaria in all Asir
Maximum temperature with humidity

Whole year --------- Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & Seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.090	.003	-.042	.631	-.014	.836	-.154	.026	-.789	.001	-.480	.217
R.Hum.	.006	.538	.025	.100	.026	.035	.015	.819	.030	.028	.094	.042
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.064	.031	.006	.941	.010	.876	-.131	.058	-.775	.001	-.330	.341
R.Hum.	.021	.040	.050	.001	.037	.002	.011	.647	.083	.039	.073	.064
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.070	.044	-.024	.813	.004	.962	-.145	.074	-1.17	.000	-.621	.184
R.Hum.	.023	.085	.057	.003	.048	.001	.006	.842	.016	.036	.133	.037

Table 41: Multiple regressions of Malaria in all Asir
Maximum temperature with humidity

April To Aug. Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.188	.001	-.192	.094	-.155	.060	-.181	.280	-.578	.120	-.583	.358
R.Hum.	.01	.717	.004	.842	.001	.932	.048	.349	.040	.538	.181	.117
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.081	.098	-.160	.111	-.084	.25	-.076	.644	-.762	.041	-.510	.354
R.Hum.	.025	.169	-.018	.350	.014	.332	.126	.059	.131	.082	.142	.250
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.108	.050	-.338	.063	-.160	.086	-.046	.801	-1.04	.038	-.999	.233
R.Hum.	.033	.122	.019	.457	.011	.552	.150	.050	.148	.114	.307	.076

Table 42: Multiple regressions of Malaria in All Asir
Maximum Temperature with rainfall and relative humidity

Whole Year ------- Curr. Mon.	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.090	.010	-.064	.480	-.025	.726	-.240	.005	-.770	.002	-.550	.179
Rainfall	-.001	.985	-.069	.358	-.033	.570	.259	.059	.103	.584	-.207	.570
R.Hum.	.007	.581	.029	.068	.027	.030	-.031	.266	-.036	.360	.104	.118
1 Prev. Mon.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.034	.318	-.027	.757	.000	.998	-.180	.029	-.752	.002	-.350	.330
Rainfall	-.096	.086	-.064	.384	.032	.580	.152	.261	.071	.706	-.063	.833
R.Hum.	.031	.009	.054	.001	.039	.002	.004	.889	.001	.980	.077	.256
Aver. Cur. & 1 prev	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.50	.232	-.059	.582	-.011	.893	.282	.008	-1.11	.000	-.673	.186
Rainfall	-.061	.426	-.111	.297	.047	.571	.407	.031	.215	.445	-.179	.707
R.Hum.	-.028	.059	.063	.002	.050	.001	.031	.374	-.026	.597	.140	.080

Table 43: Multiple regressions of Malaria in All Asir
Maximum Temperature with rainfall and relative humidity

April To Aug.	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & Seasonality	
Curr. Mon.	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.195	.000	-.168	.127	-.145	.074	-.195	.248	-.564	.135	-.560	.378
Rainfall	.170	.047	.211	.022	.102	.137	.259	.368	.295	.330	.270	.665
R.Hum.	.016	.396	.017	.431	.011	.481	.017	.785	.011	.878	.157	.221
1 Prev. Mon.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.93	.063	-.121	.244	.059	.436	.022	.900	-.677	.076	.489	.389
Rainfall	.080	.221	.102	.196	.069	.237	.328	.159	.296	.294	.320	.461
R.Hum.	.015	.422	.012	.557	.010	.514	.092	.196	.113	.146	.113	.388
Aver. Cur. & 1 prev	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.115	.044	-.184	.124	-.135	.132	-.082	.676	-.999	.049	-1.06	.216
Rainfall	.342	.002	.366	.003	.214	.023	.865	.044	.865	.075	1.12	.223
R.Hum.	.01	.713	.016	.544	.010	.659	.054	.546	.075	.465	.206	.291

Multiple for TA

Table 44: Multiple regressions of Malaria in TA
Maximum temperature with rainfall

Whole Year -------- Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.014	.867	-.053	.427	.031	.625	-.074	.193	.086	.695	.212	.686
Rainfall	.257	.000	.101	.021	.128	.002	.518	.000	.553	.000	.497	.097
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.168	.000	.014	.867	-.053	.422	-.104	.081	.114	.606	1.07	.197
Rainfall	.255	.000	.257	.000	.101	.021	.595	.000	.645	.000	1.22	.033
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.163	.000	.112	.262	-.001	.987	-.112	.095	.222	.468	.797	.303
Rainfall	.365	.000	.341	.000	.168	.001	.827	.000	.875	.000	1.05	.031

Table 45: Multiple regressions of Malaria in TA
Maximum temperature with rainfall

April To Aug. Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.183	.037	-.096	.430	-.018	.855	.064	.769	.327	.361	-.045	.947
Rainfall	.297	.000	.266	.000	.134	.026	.365	.050	.356	.032	.787	.033
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.158	.000	.010	.972	-.103	.323	.028	.826	.428	.266	.699	.389
Rainfall	.229	.001	.233	.001	.068	.270	.708	.004	.733	.004	1.27	.083
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.199	.001	-.078	.610	-.089	.502	-.029	.870	-.543	.230	.443	.600
Rainfall	.351	.000	.342	.000	.156	.038	.759	.005	.781	.006	1.11	.046

Multiple of TQ

Table 46: Multiple regressions of Malaria in TQ
Maximum Temperature with rainfall

Whole Year -------- Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.005	.828	.068	.478	.077	.325	-.047	.357	-.411	.067	-.321	.247
Rainfall	.375	.000	.397	.000	.251	.000	.636	.000	.759	.000	.735	.001
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.063	.015	.050	.618	.002	.979	-.006	.910	-.341	.123	-.170	.518
Rainfall	.337	.000	.349	.000	.126	.050	.595	.000	.757	.000	.533	.008
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.040	.128	.095	.397	.055	.576	-.023	.688	-.569	.048	-.304	.370
Rainfall	.497	.000	.507	.000	.278	.000	.986	.000	1.22	.000	1.04	.000

Table 47: Multiple regressions of Malaria in TQ
Maximum Temperature with rainfall

April To Aug. Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & Seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.118	.113	-.096	.549	-.120	.288	.170	.268	-.366	.337	-.652	.390
Rainfall	.477	.000	.462	.000	.295	.000	.806	.000	.885	.001	1.16	.038
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.166	.000	-.125	.380	-.187	.082	.156	.119	-.444	.168	-.387	.421
Rainfall	.519	.000	.452	.000	.200	.018	.742	.001	.848	.001	.834	.048
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.193	.001	-.108	.524	-.191	.133	.363	.043	-.196	.627	-.506	.462
Rainfall	.682	.000	.601	.000	.342	.000	1.34	.000	1.37	.000	1.41	.035

Table 48: Multiple regressions of Malaria in TQ
Maximum temperature with humidity

Whole Year -------- Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & Seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.81	.042	-.105	.361	.035	.702	-.086	.198	-.570	.009	-.338	.193
R.Hum.	-.028	.048	.004	.857	.025	.118	.002	.916	.016	.667	.065	.172
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.053	.187	.014	.899	.074	.401	-.029	.659	-.371	.081	-.072	.785
R.Hum.	.007	.615	.039	.050	.038	.016	.006	.803	.045	.234	.052	.263
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.030	.526	-.069	.610	.076	.476	-.061	.440	-.698	.009	-.320	.317
R.Hum.	-.017	.354	.031	.210	.047	.016	.008	.785	.051	.283	.086	.138

Table 49: Multiple regressions of Malaria in TQ
Maximum temperature with humidity

April To Aug. Cur. Month	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.073	.417	-.445	.019	-.310	.019	-.020	.891	-.83	.093	-1.33	.038
R.Hum.	-.033	.139	-.025	.423	.002	.941	.034	.046	.055	.341	.069	.457
1 prev. Month	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.157	.035	-.339	.054	-.211	.087	.161	.192	-.466	.150	-.210	.657
R.Hum.	.045	.114	-.008	.802	.011	.636	.094	.057	.098	.108	.146	.119
Aver. Curr. & 1prev.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.044	.677	-.556	.010	-.361	.017	.220	.194	-.756	.075	-.982	.131
Rainfall	.005	.886	-.027	.502	.007	.803	.126	.048	.128	.098	.176	.130

Table 50: Multiple regressions of Malaria in TQ
Maximum Temperature with rainfall and relative humidity

Whole Year ------- Curr. Mon.	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.076	.040	.073	.498	.114	.192	-.088	.256	-.400	.106	-.261	.394
Rainfall	.378	.000	.398	.000	.250	.000	.644	.000	.759	.000	.737	.001
R.Hum.	-.039	.004	.002	.918	.015	.339	-.021	.479	.005	.917	.026	.648
1 Prev. Mon.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.064	.101	.139	.210	.093	.319	.022	.776	-.164	.502	.090	.759
Rainfall	.337	.000	.350	.000	.126	.049	.593	.000	.794	.000	.575	.007
R.Hum.	.000	.982	.038	.064	.039	.024	.014	.630	.088	.073	.118	.044
Aver. Cur. & 1 prev	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	-.17	.692	.148	.240	.132	.214	-.029	.759	-.441	.160	-.124	.738
Rainfall	.496	.000	.505	.000	.271	.000	.987	.000	1.23	.000	1.04	.000
R.Hum.	-.028	.098	.022	.345	.033	.098	-.003	.932	.065	.312	.086	.247

Table 51: Multiple regressions of Malaria in TQ
Maximum Temperature with rainfall and relative humidity

April To Aug.	LR						OL					
	Variables only		with seasonality		With auto correlation & Seasonality		Variables only		with seasonality		With auto correlation & seasonality	
Curr. Mon.	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.012	.881	-.149	.405	-.121	.337	.193	.272	-.148	.728	-.346	.677
Rainfall	.506	.000	.458	.000	.295	.000	.796	.000	.921	.001	1.25	.040
R.Hum.	-.055	.008	-.020	.497	.000	.978	.012	.789	.095	.197	.114	.412
1 Prev. Mon.	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.167	.015	-.175	.285	-.193	.119	.277	.073	-.152	.685	.174	.758
Rainfall	.518	.000	.453	.000	.200	.019	.703	.002	.937	.001	1.29	.044
R.Hum.	.001	.972	-.019	.526	.002	.927	.064	.288	.133	.077	.266	.077
Aver. Cur. & 1 prev	LR						OL					
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Max.T	.123	.138	-.159	.407	-.185	.198	.629	.014	.024	.964	-.364	.676
Rainfall	.686	.000	.597	.000	.342	.000	1.29	.000	1.47	.000	1.91	.026
R.Hum.	.033	.302	.021	.561	.003	.916	.160	.075	.260	.025	.390	.093

Appendix A.3

Malaria Data with The Hottest Temperature days in the Whole of Asir

All Asir

Table52: Whole Year

Model	LR						OL					
	Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality		Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.136	.000	-.161	.027	-.117	.041	-.187	.001	-.737	.001	-.381	.236
1 P	-.142	.000	-.164	.026	-.077	.187	-.207	.001	-.787	.000	-.547	.092
2 P	-.124	.000	-.165	.026	-.053	.368	-.192	.001	-.831	.000	-.417	.154
3 P	-.075	.006	-.109	.007	-.092	.122	-.147	.011	-.907	.000	-.618	.055
4 P	-.007	.812	-.148	.047	-.026	.671	-.072	.202	-.791	.000	-.338	.262
5 P	.054	.052	-.180	.015	-.089	.135	-.012	.837	.999	.000	-.971	.011
6 P	.103	.000	-.167	.025	-.058	.331	.035	.533	-1.07	.000	-.765	.037
0+1P	-2.15	.000	-.190	.085	-.130	.100	-.356	020.	-1.28	.005	-.880	.158

Table 53: April to August

Model	LR						OL					
	Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality		Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.248	.000	-.156	.045	-.094	.019	-.441	.024	-.914	.019	-.447	.041
1 P	-.136	.000	-.138	.122	-.103	. 06	-.258	.028	-.908	.007	-.849	.052
2 P	-.137	.000	-.153	.061	-.054	.374	-.247	.023	-1.18	.001	-.757	.088
3 P	-.128	.001	-.216	.002	-.104	.052	-.257	.025	-1.14	.001	-.641	.128
4 P	-.149	.003	-.149	.026	-.048	.351	-.477	.007	-.997	.001	-.649	.094
5 P	-.133	.062	-.148	.037	-.038	.489	-.720	.005	-1.01	.001	-.909	.043
6 P	.117	.088	-.075	.345	.002	.969	-.381	.051	-1.22	.001	-.963	.072
0+1 P	-.15	.000	-.22	.008	-.13	.044	-.218	.000	-1.20	.000	-.69	.046

Table54: September to November

Model	LR						OL					
	Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality		Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P nt	-.046	.551	-.186	.412	-.092	.627	-.088	.561	-.723	.151	-.793	.533
1 P	-.021	.806	-.279	.369	.007	.980	-.049	.768	-.890	.162	-2.35	.341
2 P	-.206	.297	-.626	.053	-.386	.168	-.348	.380	-1.18	.101	.441	.816
3 P	-.111	.702	-.232	.464	.206	.470	-.958	.118	-1.26	.067	-2.26	.247
4 P	-.121	.570	-.167	.496	.036	.864	-.582	.188	-.739	.143	1.43	.388
5 P	-.022	.829	-.194	.217	-.092	.539	-.261	.210	-1.01	.022	-1.96	.248
6 P	-.073	.327	-.312	.030	-.161	.217	-.245	.118	-1.11	.006	-1.52	.162

Table 55: December to March

Model	LR						OL					
	Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality		Hottest temperature only		Hottest temperature with seasonality		Hottest temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P nt	-.046	.621	-.157	.148	-.133	.120	-.312	.152	-.628	.034	.322	424
1 P	-.105	.324	-.168	.151	-.068	.477	-.551	.057	-.624	.056	-.202	.627
2 P	-.121	.178	-.106	.398	.001	.994	-.344	.115	-.350	.244	-.127	.735
3 P	-.093	.120	-.151	.342	-.143	255	-.172	.175	-.445	.209	-.433	377
4 P	-.192	.098	-.128	.554	.029	.870	-.103	.379	-.233	.605	.304	.621
5 P	-.141	.058	-.347	.186	-.393	.057	-.139	.389	-.965	.096	-.940	.289
6 P	-.255	.169	-.172	.526	-.102	.637	-.217	.575	-.565	.316	.164	.848

Appendix B
CL

1. CL with Maximum Temperature in Asir

Table 1: Maximum Temperature in Asir (February to May)

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.002	-.020	.632	-.020	.624	-.190	.041	-.340	.184	-.310	.261
1 P	-.060	.004	-.030	.546	-.020	.690	-.220	.044	-.400	.118	-.200	.442
2 P	-.070	.035	-.010	.775	-.010	.828	-.330	.047	-.310	.186	-.210	.380
3 P	-.030	.405	.010	.882	.020	.626	-.080	.607	-.220	.390	.090	.724
4 P	.060	.007	.000	.875	.000	.999	.100	.378	-.280	.350	-.330	.264
5 P	.040	.015	-.040	.536	-.050	.427	.100	.266	-.210	.525	-.320	.343
6 P	.050	.007	-.030	.715	-.030	.729	.120	.227	-.610	.206	-.420	.404

Table 2: October to January

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.050	.023	-.100	.091	-.070	.220	-.140	.206	-.430	.122	-.300	.309
1 P	-.030	.141	.000	.957	.050	.500	-.050	.614	-.060	.849	.610	.081
2 P	-.040	.064	-.170	.106	-.180	.066	-.080	.394	-.920	.082	-.580	.323
3 P	-.040	.159	-.040	.718	-.100	.330	-.050	.741	.410	.347	-.680	.218
4 P	-.030	.643	.050	.617	.030	.719	.050	.863	.400	.365	-.290	.533
5 P	.050	.360	.020	.824	-.030	.672	.190	.522	.250	.520	-.040	.916
6 P	.030	.226	-.010	.892	-.020	.778	.030	.827	-.040	.897	-.660	.071

2. CL with Maximum Temperature in the highlands

Table 3: Maximum Temperature in the highlands (February to May)

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.006	-.040	.514	-.040	.518	-.190	.031	-.260	.307	-.180	.484
1 P	-.080	.003	-.060	.225	-.050	.337	-.280	.012	-.440	.080	-.340	.174
2 P	-.050	.189	.000	.978	.010	.814	-.270	.090	-.230	.329	-.140	.550
3 P	.040	.300	.000	.958	.020	.776	.010	.926	-.240	.335	.010	.962
4 P	.070	.019	.020	.744	-.040	.485	.150	.178	-.270	.350	-.410	.163
5 P	.050	.030	-.070	.368	-.070	.335	.130	.198	-.270	.393	-.400	.232
6 P	.050	.022	.030	.783	-.030	.805	.130	.171	-.770	.115	-.570	.256

Table 4: October to January

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.030	-.080	.246	-.010	.858	-.180	.109	-.440	.103	-.060	.835
1 P	-.030	.141	.050	.577	.010	.236	-.070	.473	.040	.903	.310	.124
2 P	-.040	.116	-.130	.270	-.170	.116	-.100	.308	-1.00	.047	-1.4	.024
3 P	-.030	.438	-.050	.687	-.060	.606	-.040	.769	.330	.517	-.150	.774
4 P	.010	.894	.080	.462	.080	.445	.050	.867	.410	.380	-.110	.826
5 P	.060	.184	.020	.866	-.030	.738	.270	.369	.130	.735	-.260	.500
6 P	.060	.058	.020	.816	.000	.979	.120	.377	.080	.790	-.300	.409

3. CL with Maximum Temperature in the lowlands

Table 5: December to February

Model	Linear regression						Ordinal logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.060	.319	.030	.674	.270	.174	.070	.711	-.080	.751	.090	.755
1 P	-.020	.807	.090	.423	.130	.260	-.170	.424	-.020	.958	.310	.436
2 P	-.020	.571	.040	.778	.040	.757	-.090	.422	.160	.698	.100	.814
3 P	-.040	.337	-.010	.952	.000	.988	-.140	.260	-.090	.766	.060	.849
4 P	-.070	.245	-.050	.564	-.050	.524	-.250	.277	-.140	.647	-.260	.370
5 P	-.060	.463	-.040	.622	-.030	.698	-.140	.570	-.040	.879	.020	.946
6 P	-.110	.259	-.080	.419	-.060	.601	-.450	.151	-.370	.329	-.270	.531

4. CL with Mean Temperature in Asir

Table 6: February to May

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.002	-.020	.744	-.030	.646	-.220	.034	-.680	.059	-.510	.183
1 P	-.070	.002	-.040	.544	-.030	.632	-.290	.028	-.930	.018	-.510	.223
2 P	-.080	.029	.070	.317	.080	.272	-.410	.026	-.640	.081	.000	.999
3 P	.050	.285	.090	.253	.090	.224	-.260	.228	-.910	.034	-.320	.508
4 P	.070	.003	.090	.332	.060	.534	.090	.459	-.920	.053	-.860	.090
5 P	.050	.005	.050	.642	.020	.826	.080	.334	-1.50	.011	-.850	.170
6 P	.050	.004	.060	.585	.060	.588	.110	.286	-1.70	.011	-.750	.276

Table 7: October to January

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.050	.037	-.200	.058	-.170	.082	-.170	.158	-1.80	.001	-1.20	.032
1 P	-.030	.155	.090	.457	.160	.186	-.070	.438	-1.10	.058	.460	.480
2 P	-.040	.095	-.140	.304	-.230	.079	-.100	.294	-2.10	.003	-1.70	.024
3 P	-.050	.140	-.110	.465	-.190	.184	-.160	.332	-.920	.162	-1.90	.014
4 P	-.230	.013	-.250	.057	-.260	.036	-1.30	.005	-2.30	.001	-2.50	.002
5 P	.010	.628	-.020	.822	-.040	.638	-.360	.245	-.840	.074	-.560	.269
6 P	.040	.191	-.010	.924	-.020	.861	-.050	.733	-.840	.050	-1.00	.053

5. CL with Mean Temperature in the highlands

Table 8: February to May

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.070	.004	-.060	.487	-.060	.431	-.250	.017	-.640	.078	-.350	.359
1 P	-.090	.002	-.100	.253	-.080	.344	-.330	.009	-.970	.017	-.690	.104
2 P	-.060	.149	.120	.185	.150	.091	-.350	.049	-.430	.253	.240	.579
3 P	.080	.129	.110	.259	.110	.273	-.050	.819	-.750	.088	-.180	.714
4 P	.080	.004	.090	.433	.020	.867	.180	.141	-.620	.183	-.700	.154
5 P	.050	.100	.060	.767	.040	.778	.130	.151	-1.10	.053	-.590	.321
6 P	.060	.020	.100	.502	.090	.526	.120	.217	-1.30	.042	-.520	.434

Table 9: October to January

Model	Linear regression						Ordinal logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.070	.027	-.150	.211	-.100	.379	-.220	.070	-1.80	.001	-1.30	.020
1 P	-.030	.134	.140	.329	.190	.146	-.090	.323	-.570	.172	.470	.450
2 P	-.030	.193	-.120	.434	-.250	.081	-.110	.283	-2.30	.002	-2.50	.001
3 P	-.030	.453	-.050	.752	-.110	.505	-.140	.383	-.930	.168	-1.10	.093
4 P	-.270	.014	-.330	.027	-.320	.017	-1.60	.002	-2.70	.000	-2.90	.000
5 P	.100	.178	-.010	.939	.000	.991	-1.20	.707	-.770	.112	-.400	.457
6 P	.070	.045	.050	.620	.030	.751	.040	.793	-.630	.144	-.810	.104

6. CL with Minimum Temperature in all Asir

Table 10: February to May

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.070	.001	-.090	.243	-.100	.190	-.230	.044	-.680	.096	-.610	.164
1 P	-.080	.001	-.070	.262	-.070	.294	-.210	.089	-.220	.514	.030	.944
2 P	-.060	.064	.090	.133	.010	.088	-.210	.196	.030	.934	.610	.082
3 P	.040	.346	.070	.187	.060	.276	-.160	.446	-.190	.496	-.080	.805
4 P	.070	.004	.050	.384	.030	.675	.100	.452	-.310	.334	-.350	.309
5 P	.050	.005	.040	.591	.030	.710	.080	.366	-.810	.051	-.390	.377
6 P	.050	.004	.070	.457	.080	.383	.120	.225	-.570	.252	.490	.395

Table 11: October to January

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.040	.164	.010	.844	-.020	.729	-.130	.297	-.490	.151	-.350	.330
1 P	-.030	.223	.110	.614	.110	.187	-.070	.421	-5.50	.157	-.260	.547
2 P	-.030	.154	.060	.614	-.010	.912	-.080	.393	-.950	.084	-.630	.272
3 P	-.040	.161	-.010	.955	-.070	.598	-.110	.430	-.560	.389	-1.80	.014
4 P	-.120	.108	-.160	.233	-.150	.239	-.550	.094	-1.50	.028	-1.00	.129
5 P	.070	.310	.000	.987	-.010	.978	-.240	.428	-1.10	.063	-.280	.656
6 P	.050	.160	-.020	.897	.000	.987	-.020	.871	-1.10	.045	-.850	.151

7. CL with Minimum Temperature in the highlands

Table 12: February to May

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.090	.001	-.150	.120	-.150	.120	-.280	.017	-.700	.099	-.420	.349
1 P	-.100	.001	-.130	.120	-.100	.222	-.270	.260	-.300	.392	-.170	.661
2 P	-.050	.182	.120	.118	.150	.034	-.210	.194	.100	.769	.660	.058
3 P	.080	.152	.100	.176	.080	.254	.000	.996	-.120	.686	-.030	.924
4 P	.090	.004	.060	.412	.020	.789	.190	.137	-.180	.574	-.290	.399
5 P	.060	.008	.070	.428	.060	.493	.130	.155	-.480	.221	-.030	.941
6 P	.060	.014	.800	.491	.090	.414	.140	.150	-.500	.329	.090	.394

Table13: October to January

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.091	.030	.713	-.010	.881	-.190	.165	-.460	.179	-.570	.120
1 P	-.030	.163	.090	.380	.060	.496	-.090	.345	-.320	.413	-.090	.830
2 P	-.030	.182	.010	.915	-.090	.490	-.090	.343	-.860	.112	-1.00	.079
3 P	-.040	.308	-.090	.583	-.160	.291	-.110	.468	-.630	.353	-1.20	.080
4 P	-.080	.359	-.210	.172	-.180	.231	-.500	.137	-1.60	.019	-1.40	.046
5 P	.150	.049	.070	.640	.080	.507	.020	.946	-.750	.205	-.030	.962
6 P	.700	.051	.080	.547	.040	.754	.060	.711	-.790	.145	-.830	.153

7. CL with Minimum Temperature in the lowlands

Table 14: December to February

Model	Linear regression						Ordinal logistic					
	Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality		Min. temperature only		Min. temperature with seasonality		Min. temperature with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.180	.122	.180	.265	.180	.302	.500	.227	.780	.160	1.20	.057
1 P	-.070	.461	-.020	.937	-.020	.931	-.320	.300	.340	.648	-.100	.902
2 P	-.080	.258	-.290	.176	-.290	.185	-.250	.274	-.360	.619	-.530	.483
3 P	-.130	.030	-.140	.067	-.110	.155	-.360	.102	-.360	.198	-.240	.374
4 P	-.100	.832	.010	.899	.040	.564	-.060	.681	.050	.820	.230	.363
5 P	-.080	.034	-.120	.051	-.130	.058	-.250	.680	-.310	.162	-.490	.052
6 P	-.040	.576	-.020	.854	-.010	.953	-.010	.681	-.050	.871	.080	.820

8. CL with Rainfall in all Asir

Table 15: Rainfall in Asir (February to May)

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.060	.069	.000	.978	-.010	.915	-.170	.294	-.110	.619	-.100	.696
1 P	-.070	.027	-.020	.663	-.020	.662	-.280	.093	-.210	.344	-.200	.396
2 P	-.030	.502	-.010	.915	.000	.986	-.060	.778	.030	.891	.000	.997
3 P	.000	.971	-.030	.559	-.030	.556	.160	.497	.090	.749	-.020	.931
4 P	-.070	.107	-.060	.177	-.060	.141	.090	.679	.140	.546	-.120	.610
5 P	-.030	.549	-.010	.794	.010	.838	.240	.342	.320	.221	.410	.126
6 P	.040	.279	.000	.970	.020	.703	.150	.392	.190	.445	.220	.389

Table16: October to January

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.020	.693	-.030	.582	-.040	.408	.020	.942	-.010	.951	-.140	.519
1 P	-.050	.278	-.060	.238	-.060	.223	-.130	.546	-.120	.582	-.150	.501
2 P	-.020	.652	.010	.788	.020	.621	-.040	.792	-.030	.910	.080	.748
3 P	-.060	.116	-.040	.442	-.030	.541	-.140	.414	-.210	.412	.050	.857
4 P	.000	.996	.020	.738	.060	.268	.010	.934	.130	.580	.610	.032
5 P	-.010	.846	-.030	.602	-.030	.587	.130	.508	.140	.557	.080	.740
6 P	-.040	.406	-.030	.587	-.040	.437	.030	.892	.030	.909	-.150	.530

9. CL with Rainfall in all the highlands

Table 17: Rainfall in the highlands (February to May)

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.070	.062	.010	.902	-.010	.898	-.270	.106	-.120	.624	-.110	.635
1 P	-.050	.214	.010	.848	.010	.844	-.210	.209	-.080	.719	-.050	.812
2 P	-.040	.419	-.020	.734	-.020	.696	-.090	.664	-.050	.845	-.110	.657
3 P	+.o2	.763	-.010	.846	-.010	.907	.180	.441	.060	.542	.060	.823
4 P	-.100	.072	-.040	.126	-.800	.128	-.020	.921	.030	.896	-.200	.406
5 P	-.040	.575	-.010	.846	.030	.639	.130	.611	.220	.411	.390	.160
6 P	.060	.154	.000	.948	.020	.709	.250	.158	.190	.462	.260	.315

Table 18: October to January

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.010	.894	-.020	.757	-.020	.732	.010	.977	-.040	.852	-.080	.715
1 P	-.070	.211	-.090	.117	-.080	.118	-.170	.448	-.190	.406	-.220	.327
2 P	-.060	.175	-.010	.864	.010	.830	-.090	.591	.030	.909	.260	.311
3 P	-.060	.141	-.050	.138	-.040	.476	-.110	.534	-.070	.516	-.070	.777
4 P	.050	.285	.040	.534	.070	.213	.140	.423	.260	.290	.730	.010
5 P	-.010	.901	.010	.917	.000	.939	.050	.781	.150	.537	.020	.941
6 P	-.070	.181	-.040	.469	-.060	.254	-.070	.720	-.170	.756	-.310	.218

10. CL with Rainfall in all the lowlands

Table 19: December to February

Model	Linear regression						Ordinal logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.030	.519	-.030	.614	-.030	.599	.520	.005	.520	.004	.230	.347
1 P	-.030	.656	-.040	.524	-.040	.483	.370	.052	.350	.065	-.090	.710
2 P	.020	.776	.020	.713	.010	.892	.540	.012	.570	.011	.230	.402
3 P	-.100	.112	-.180	.076	-.110	.087	.130	.538	.120	.578	-.220	.363
4 P	.060	.375	.060	.370	.080	.210	.260	.231	.310	.169	.340	.171
5 P	-.030	.629	-.020	.708	-.040	.501	.170	.409	.170	.397	-.120	.595
6 P	.060	.385	-.020	.708	.050	.483	.180	.369	.190	.354	.120	.575

11. CL with relative humidity in all Asir

Table 20: relative humidity in Asir (February to May)

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.020	.008	.010	.464	.010	.476	.030	.350	-.030	.629	.000	.963
1 P	.020	.043	.000	.875	.000	.970	.020	.565	-.030	.556	.000	.981
2 P	.020	.013	.010	.204	.010	.155	.030	.490	-.010	.890	.060	.231
3 P	.000	.690	.010	.316	.000	.598	-.020	.596	-.030	.526	-.030	.537
4 P	-.010	.071	.010	.431	.000	.699	-.030	.190	-.030	.495	-.040	.424
5 P	-.010	.052	.010	.250	.010	.385	-.020	.115	-.030	.569	-.020	.676
6 P	.000	.895	.010	.179	.010	.190	-.020	.509	.000	.960	.050	.363

Table 21: October to January

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.010	.065	.010	.340	.010	.609	.010	.760	-.020	.713	.010	.838
1 P	.010	.089	.010	.464	.010	.661	.000	.930	-.050	.242	-.060	.235
2 P	.010	.233	.020	.172	.010	.256	.000	.997	-.040	.471	.020	.727
3 P	.000	.790	.020	.069	.020	.078	-.020	.533	-.040	.508	.060	.405
4 P	.000	.603	.010	.310	.010	.232	-.010	.888	.010	.870	.090	.129
5 P	-.010	.492	-.010	.215	-.010	.292	.000	.953	-.010	.806	.010	.792
6 P	-.010	.089	-.010	.222	-.010	.294	.000	.950	.000	.983	.010	.881

12. CL with relative humidity in the highlands

Table 22: relative humidity in the highlands (February to May)

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.020	.022	.010	.561	.010	.645	.040	.241	-.020	.741	-.010	.940
1 P	.020	.036	.000	.786	.000	.817	.030	.376	-.030	.496	.000	.985
2 P	.020	.070	.010	.379	.010	.251	.030	.503	-.010	.777	.060	.244
3 P	.000	.779	.010	.265	.010	.459	-.030	.368	-.020	.654	-.020	.641
4 P	-.010	.082	.010	.307	.010	.516	-.040	.085	-.010	.807	-.010	.767
5 P	-.010	.160	.020	.143	.010	.318	-.030	.143	.000	.995	.020	.635
6 P	.000	.577	.020	.114	.010	.205	.000	.872	.020	.643	.070	.186

Table 23: October to January

Model	Linear regression						Ordinal logistic					
	Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality		Relative humidity only		Relative humidity with seasonality		Relative humidity with auto correlation& seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.010	.027	.010	.383	.010	.641	.010	.497	-.020	.649	-.020	.655
1 P	.010	.168	.000	.743	.000	.851	.000	.975	-.050	.315	-.060	.232
2 P	.000	.650	.000	.783	.000	.956	-.020	.534	-.050	.347	-.030	.576
3 P	.000	.719	.010	.458	.010	.413	-.030	.494	-.050	.331	.030	.679
4 P	.020	.073	.020	.122	.020	.103	.020	.644	.030	.563	.090	.124
5 P	-.010	.220	-.020	.205	-.020	.138	-.030	.411	-.040	.394	-.070	.197
6 P	-.020	.018	-.020	.163	-.010	.252	-.020	.620	.000	.931	.040	.517

Appendix C
Schistosomiasis

All Asir Region (Schist.)

Table 1: Maximum temperature (Feb to May)

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.23	.697	-2.5	.152	-.24	.167	-.13	.697	-.38	.171	-.37	.189
1 P	1.1	.109	1.9	.256	2.2	.207	.94	.181	.45	.119	.48	.104
2 P	-.05	.96	-.47	-.77	-.43	.788	-.15	.81	-.09	.744	-.08	.772
3 P	-.44	.68	-.45	.796	-.35	.844	-.24	.61	.03	.903	.05	.865
4 P	-.95	.196	-2.1	.291	-2.2	.274	-.84	.211	-.27	.376	-.28	.364
5 P	-.84	.147	3.4	.074	-3.8	.010	-.71	.168	.81	.050	.83	.053
6 P	-.56	.356	-2.3	.540	-1.8	.639	-.65	.401	.29	.610	.32	.583
7P	-.51	.563	1.8	.565	1.5	.624	-.49	.511	.09	.835	.09	.848
8 P	-1.2	.557	.76	.801	.57	.853	-1.0	.598	.12	.815	.11	.822
9 P	1.5	.442	-.21	.937	-.39	.887	1.1	.472	-.17	.675	-.17	.669
10 P	.86	.326	.64	.772	.83	.711	.68	.291	-.05	.876	-.05	.894
11 P	.54	.379	.24	.909	.32	.878	.48	.312	-.36	.287	-.36	.290
12 P	.97	.127	3.5	.05	3.5	.05	.90	.127	.56	.06	.04	.849
4+3 P	-.12	.318	-.17	.470	-1.7	.479	-.95	.377	-.10	.786	-.01	.788
2+3+4	-.59	.421	-1.6	.557	-1.5	.572	-.02	.465	-.01	.977	-.01	.988
2+3 4+5	-2.7	.241	-4.7	.178	-4.5	.198	-1.9	.201	-4.5	.433	-4.5	.437

Table 2: Maximum temperature (Oct to Jan)

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	1.0	.51	1.2	.42	.909	.574	-.11	.845	-.05	.864	-.20	.521
1 P	.65	.654	-.80	.631	.73	.669	-.08	.801	-.09	.805	.13	.720
2 P	-.1.1	.569	-1.2	.657	-1.1	.697	.06	.863	.04	.948	-.09	.868
3 P	2.1	.258	2.5	.275	2.5	.274	.47	.291	.49	.283	.46	.323
4 P	-.89	.787	-.42	.847	-.35	.875	-.04	.921	-.01	.980	-.05	.910
5 P	-.28	.321	-2.9	.136	-.28	.418	-.26	.458	-.20	.632	-.26	.553
6 P	1.8	.312	1.6	.296	1.6	.316	.41	.289	.41	.201	.40	.213
7P	-1.3	.200	-1.9	.199	-1.9	.216	-.06	.845	-.06	.840	-.11	.725
8 P	.52	.417	.46	.378	.40	.773	.09	.635	.12	.666	.13	.635
9 P	.23	.782	.22	.868	.27	.838	.04	.997	.06	.831	.03	.907
10P	.78	.666	.56	.647	.64	.606	.08	.827	.05	.844	.04	.844
11P	-.25	.501	-.80	.550	-.76	.575	-.14	.852	-.09	.726	-.11	.697
12P	-2.2	.054	-2.6	.089	-2.7	.083	-.25	.355	-.31	.341	-.29	.388
4+3	1.7	.542	1.8	.558	2.0	.537	1.2	.555	1.8	.557	2.0	.537
2+3+4	1.5	.636	1.2	.768	1.5	.723	.58	.511	.55	.521	.44	.623
2+3 4+5	2.0	.489	2.1	.593	1.9	.633	.29	.795	.21	.808	.06	.947

All Asir Region (Schist.)

Table 3: Mean temperature (Feb to May)

Model	Linear Regression						Ordinal Logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.95	.402	-1.5	.529	-1.7	.492	-.26	.402	-2.8	.429	-.28	.433
1 P	1.8	.551	1.6	.534	1.7	.502	.15	.524	.13	.765	.14	.735
2 P	-1.5	.524	-1.7	.510	-1.7	.530	.05	.254	.04	.933	.06	.897
3 P	-2.2	.254	-3.1	.275	-2.9	.318	-.45	.101	-.40	.350	-.39	.358
4 P	-5.5	.101	-5.3	.101	-5.3	.100	-.25	.681	-.20	.681	-.20	.670
5P	8.2	.012	8.4	.026	8.25	.032	2.2	.025	1.9	.046	1.9	.046
6 P	-2.1	.450	-3.6	.404	-3.1	.500	-.07	.885	-.03	.959	-.01	.997
7P	1.7	.745	1.6	.721	1.4	.759	-.45	.715	-.48	.487	-.51	.468
8 P	2.2	.458	2.75	.530	2.3	.611	.75	.478	.71	.291	.71	.294
9 P	1.5	.652	1.6	.653	1.2	.744	-.08	.672	-.07	.900	-.09	.873
10 P	-.33	.956	-.32	.917	-.10	.974	-.35	.478	-.37	.451	-.36	.458
11 P	-.52	.789	-.42	.883	-.34	.907	-.59	.248	-.53	.253	-.53	.255
12 P	4.5	.201	4.2	.191	4.1	.117	.20	.020	1.0	.024	1.1	.023
2+4+3 P	-1.9	.658	-.23	.675	-.28	.681	.22	.587	.23	.675	.23	.627
7+8+9	4.9	.400	5.2	.433	4.5	.526	.10	.891	.12	.909	.09	.937

All Asir Region (Schist.)

Table 4: Mean temperature (Oct to Jan)

Model	Linear Regression						Ordinal Logistic					
	Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality		Mean temperature only		Mean temperature with seasonality		Mean temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.25	.895	.23	.925	.26	.916	2.0	.435	-2.8	.566	-.37	.454
1 P	2.7	.665	3.8	.619	3.9	.171	.77	.205	.88	.123	.87	.129
2 P	.95	.624	-1.4	.650	-1.2	.703	.19	.763	.18	.769	.12	.850
3 P	3.4	.158	4.6	.141	4.5	.153	1.3	.058	1.38	.045	1.4	.045
4 P	-1.3	.579	-1.9	.536	-1.8	.568	-.23	.347	-.52	.380	-.56	.348
5 P	1.5	.560	1.4	.576	1.4	.574	.65	.296	.47	.364	.45	.376
6 P	3.1	.148	3.2	.143	3.5	.126	.871	.044	.82	.084	.81	.102
7P	3.9	.118	-2.9	.148	-2.9	.162	-.19	.719	-.13	.778	-.18	.691
8 P	-.76	.732	-.63	.740	-.87	.664	-.04	.762	-.07	.854	-.03	.930
9 P	.83	.604	.85	.659	.83	.671	.13	.628	.18	.662	.17	.680
10 P	.27	.847	.28	.891	.36	.862	-.17	.837	-.06	.889	-.06	.890
11 P	-2.1	.206	-2.5	.264	-2.5	.259	-.21	.411	-.38	.402	-.34	.460
12 P	-4.4	.298	-32	.211	-3.4	1.88	-.44	.588	-.52	.506	-.61	.259
2+4+3 P	1.0	.887	.92	.848	1.2	.809	.52	.477	.66	.497	.58	.553
7+8+9	-2.1	.457	-2.5	.463	-2.7	.443	-.03	.984	.01	.991	.01	.982

All Asir Region (Schist.)

Table 5: Minimum temperature (Feb to May)

Model	Linear Regression						Ordinal Logistic					
	Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality		Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.85	.582	-1.3	.591	-1.5	.539	-.31	.432	-.27	.454	-.28	.438
1 P	-1.7	.561	-1.1	.580	-1.0	.615	.19	.422	-.27	.427	-.26	.449
2 P	-1.7	.324	-1.6	.377	-1.6	.383	.05	.864	.01	.972	.01	.976
3 P	-2.7	.054	-3.3	.066	-3.2	.080	.65	.031	.61	.043	.62	.042
4 P	-3.5	.101	-2.5	.232	-2.4	.252	-.02	.881	-.03	.915	-.03	.920
5 P	-1.2	.512	-1.4	.582	-1.5	.383	-.42	.325	-.48	.243	-.47	.245
6 P	2.3	.480	2.5	.477	3.0	.398	.07	.725	.22	.716	.26	.674
7 P	.71	.745	-.67	.874	-1.1	.797	.35	.645	.36	.585	-.37	.573
8 P	-1.0	.858	-.09	.981	-.26	.949	.05	.868	.01	.984	.01	.987
9 P	-3.5	.462	-3.4	.364	-3.5	.365	.08	.172	.76	.185	.77	.179
10 P	-3.4	.256	-4.2	.241	-3.9	.299	.35	.168	.83	.121	.89	.114
11 P	-.52	.729	-.33	.917	-.22	.945	-.19	.801	-.12	.813	-.11	.825
12 P	.44	.781	.612	.807	.56	.826	.50	.120	.57	.163	.57	.161
2+3 P	3.8	.058	4.5	.061	5.9	.071	.52	.186	.56	.144	.57	.139
5+6	.53	.800	.04	.991	4.4	.084	.30	.491	.42	.493	.40	.510

All Asir Region (Schist.)

Table 6: Minimum temperature (Oct to Jan)

Model	Linear Regression						Ordinal Logistic					
	Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality		Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.2.0	.164	-2.2	.165	-1.9	.250	-.39	.124	-.43	.180	-.32	.322
1 P	4.8	.025	4.3	.018	4.4	.021	.81	.021	.80	.046	.87	.035
2 P	-.11	.951	-.10	.970	-.04	.999	.09	.842	.08	.878	.07	.886
3 P	3.4	.308	3.1	.307	3.0	.330	.31	.541	.32	.587	.36	.544
4 P	-4.5	.107	-4.8	.101	-4.8	.104	1.7	.034	1.2	.044	1.2	.046
5 P	.55	.854	.59	.833	.46	.872	-.06	.884	-.05	.928	-.01	.985
6 P	6.4	.028	5.9	.021	6.2	.019	.90	.051	1.1	.061	1.0	.071
7P	-3.3	.157	-3.1	.187	-3.0	.202	-.57	.277	-.54	.266	-.56	.249
8 P	-.14	.924	-.11	.951	-.27	.890	-.04	.904	-.03	.945	.01	.971
9 P	.57	.625	.66	.674	.56	.681	-.08	.754	-.07	.832	-.08	.793
10P	.08	.921	.09	.948	.12	.935	.04	.468	.01	.468	.02	.951
11P	-1.4	.249	-1.8	.204	-1.8	.196	-.36	.270	-.35	.234	-.33	.257
12P	-.49	.754	-.51	.756	-.62	.713	.37	.210	.34	.289	.30	.354
2+3 P	2.5	.514	2.3	.544	2.3	549	.39	.647	.35	.642	.37	.621
5+6	5.2	.080	6.0	.093	6.1	.097	.88	.218	.92	.222	.91	.227

All Asir Region (Schist.)

Table 7: Rainfall (Oct to Jan)

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	1.3	.611	-.54	.603	-.55	.602	.270	.288	.044	.814	.06	.772
1 P	-2.6	.351	-1.2	.238	-1.3	.235	.481	.028	-.30	.149	-.30	.160
2 P	1.2	.485	-.66	.540	-.77	.489	-.172	.777	-.17	.415	-.15	.506
3 P	1.8	.258	-1.5	.204	-1.6	.171	-.203	.217	-.42	.081	-.42	.098
4 P	2.5	.379	.33	.776	.25	.838	.115	.837	-.09	.701	-.07	.754
5 P	-2.1	.261	.29	.803	.26	.823	.548	.046	.06	.791	.09	.704
6 P	-2.7	.875	-1.1	.369	-1.1	.357	.215	.393	-.25	.320	-.26	.301
7P	4.6	.009	-.08	.941	-.14	.899	.466	.117	-.07	.721	-.04	.839
8 P	-1.0	.532	-.30	.816	-.26	.844	.537	.038	-.15	.559	-.17	.510
9 P	-4.9	.157	.71	.560	.70	.567	-.094	.878	-.04	.885	-.01	.960
10 P	2.0	.489	-.12	.922	-.08	.949	-.229	.601	-.12	.605	-.12	.600
11 P	1.2	.441	-.01	.990	-.04	.971	.242	.213	-.06	.790	-.05	.834
12 P	-1.7	.187	-.88	.410	-.88	.418	.615	.050	-.29	.166	-.30	.158
5+6+7 P	2.6	.055	-.65	.716	-.71	.691	.820	.30	-1.7	.611	-1.4	.694
6+7	4.6	.155	.95	.528	-1.0	.511	.415	.114	.24	.404	-.22	.452
6+7+8	-1.4	.694	-1.1	.541	-1.1	.540	.019	.811	.34	.343	-.32	.366

All Asir Region (Schist.)

Table 8: Relative Humidity (Feb to May)

Model	Linear Regression						Ordinal Logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Cur. Mon.	.055	.559	.18	.561	.15	.613	.021	.254	.034	.468	.03	.504
1 P	.021	.248	-.25	.434	-.25	.424	.025	.321	-.06	.308	-.06	.310
2 P	.045	.853	.09	.760	.07	.814	.365	.651	.04	.305	.04	.317
3 P	.078	.799	-.24	.387	-.26	.354	.024	.294	-.05	.237	-.06	.190
4 P	.032	.768	.03	.923	.04	.893	.254	.214	.01	.856	.01	.853
5 P	.213	.391	.23	.478	.20	.547	.014	.365	.04	.476	.03	.479
6 P	-.032	.382	.71	.066	.69	.081	.025	.065	.13	.06	.13	.06
7P	-.049	.562	-.12	.777	.12	.779	.026	.451	.05	.514	.05	.498
8 P	.211	.838	.36	.343	-.32	.425	.078	.328	-.05	.375	-.05	.379
9 P	-.064	.145	-.01	.967	.02	.958	.078	.426	.02	.639	.03	.616
10P	-.049	.566	.26	.411	-.17	.600	.065	.326	.05	.307	.05	.310
11P	-.065	.361	.15	.622	.13	.671	.062	.348	.06	.214	.06	.216
12P	.021	.780	-.17	.600	-.17	.600	.034	.512	-.05	.330	-.05	.317
4+5 P	.016	.898	.18	.622	.17	.649	.031	.254	.03	.601	.03	.601
6+7	-.071	.361	.49	.324	.46	.358	.054	.210	.14	.110	.14	.109

All Asir Region (Schist.)

Table 9: Relative Humidity (Jun to Sep)

Model	Linear Regression						Ordinal Logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	.25	.521	.13	.629	.27	.253	.03	.858	.02	.710	.07	.266
1 P	-.26	.274	.29	.188	.21	.294	.02	.476	.02	.716	-.01	.918
2 P	.15	.412	-.01	.984	-.08	.692	-.01	.254	-.04	.459	-.06	.254
3 P	.21	.652	.08	.707	.12	.520	-.02	.365	-.04	.379	-.04	.400
4 P	-.25	.357	-.25	.240	-.21	.292	-.05	.214	-.09	.063	.09	.069
5 P	.12	.164	.37	.099	.21	.331	.02	.061	-.12	.070	-.10	.060
6 P	.32	.254	-.28	.158	-.24	.196	-.15	.088	-.09	.084	-.07	.118
7P	-.62	.541	-.15	.443	-.17	.348	-.07	.074	-.08	.091	-.07	.145
8 P	.23	.325	.19	.350	-.20	.290	-.05	.365	-.04	.383	-.03	.549
9 P	-.05	.854	-.02	.921	.06	.778	-.02	.922	0.0	.969	.014	.764
10P	.28	.655	.46	.095	.39	.118	-.06	.124	-.09	.114	-.10	.092
11P	-.09	.985	-.03	.932	.04	.903	.02	.854	.01	.911	.01	.915
12P	.45	.021	.54	.041	.50	.039	.11	.054	.13	.041	.13	.043
4+5	-.38	.050	-.57	.059	-.40	.160	-.22	.094	-.19	.117	-.17	.114
6+7	-.35	.099	-.36	.167	-.33	.157	-.13	.214	-.15	.136	.13	.143

All Asir Region (Schist.)

Table 10: Relative Humidity (Oct to Jan)

Model	Linear Regression						Ordinal Logistic					
	Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality		Humidity only		Humidity with seasonality		Humidity with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.12	.239	-.21	.317	-1.9	.387	.02	.653	.03	.559	-.02	.685
1 P	.51	.813	.41	.081	.41	.091	.03	.267	.06	.248	.07	.170
2 P	.26	.627	.24	.414	.23	.420	.02	.458	.01	.835	.02	.772
3 P	.12	.456	-.13	.677	-.12	.703	.05	.654	.01	.819	.02	.741
4 P	.26	.962	.02	.947	.02	.958	.06	.865	.02	.774	.02	.757
5 P	.45	.862	.06	.803	.06	.808	.02	.564	.00	.431	.00	.954
6 P	.26	.753	-.09	.693	-.10	.674	-.01	.231	-.04	.394	-.04	.433
7P	-.01	.851	-.05	.831	-.05	.825	-.05	.482	-.05	.333	.04	.361
8 P	.02	.963	.01	.962	.01	.979	.01	.824	0.0	.948	.01	.925
9 P	-.03	.852	-.02	.928	-.02	.934	-.08	.299	-.07	.192	-.07	.203
10P	.06	.587	.18	.416	.18	.419	-.06	.745	-.03	.518	-.03	.554
11P	-.36	.395	-.22	.295	-.25	.225	-.04	.365	-.05	.241	-.05	.302
12P	.24	.478	.22	.323	.21	.345	.02	.867	.01	.800	.02	.705
4+5 P	.07	.854	.06	.842	.06	.850	.02	.862	.01	.918	.01	.893
6+7	-.24	.564	-.11	.703	-.12	.668	-.08	.452	-.07	.241	-.07	.273

Sabt-Alalaya Sector

Sabt-Alalaya Group

Table 11: Maximum temperature (Nov to April)

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Cur. Mon.	-0.10	.888	.134	.625	.183	.417	-.053	.697	-.729	.192	.391	.715
1 P	.010	.906	-.192	.612	-.279	.366	.034	.830	-1.08	.165	-.435	.159
2 P	-.134	.477	-.397	.145	-.262	.253	-.096	.794	-.380	.485	-.499	.791
3 P	-.288	.213	-.215	.305	.113	.617	-.546	.259	-.527	.290	-.432	.652
4 P	-021	.889	-.135	.430	.003	.984	-.262	.373	-.563	.157	.324	.755
5 P	-.013	.861	-.195	.256	.085	.566	-.099	.501	-.627	.090	-1.08	.341
6 P	-.036	.571	-.259	.091	-.103	.451	-.182	.167	-1.28	.003	-.963	.261
7P	.035	.700	-.094	.447	-.086	.380	-.327	.107	-.724	.021	-.013	.976
8 P	-.033	.724	-.037	.785	-.007	.945	-.394	.064	-.442	.144	.035	.894
9 P	-.087	.164	-.070	.640	-.084	.476	-.165	.219	-.259	.429	.035	.939
10P	-.071	.153	-.064	.718	.060	.671	-.138	.191	-.674	.110	1.24	.058
11 P	-.096	.058	-.469	.067	-.349	.090	-.113	.295	-.963	.124	-.629	.498
12P	-.119	.100	-.112	.642	.059	.764	-.074	.627	.287	.560	.143	.841

Sabt-Alalaya (Schist.)

Table 12: Maximum temperature (May to Oct)

Model	Linear Regression						Ordinal Logistic					
	Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality		Max. temperature only		Max. temperature with seasonality		Max. temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.01	.896	.198	.596	.199	.520	-.075	.571	-2.71	.007	-.995	.606
1 P	-.027	.781	-.837	.050	-.952	.107	-.087	.645	-3.06	.008	-2.08	.112
2 P	-.582	.045	-1.01	.008	-.564	.116	-1.75	.021	-3.63	.004	-2.91	.279
3 P	-.466	.120	-.588	.106	.020	.953	-2.18	.006	-3.36	.004	-1.19	.560
4 P	-.013	.935	-.245	.335	-.049	.822	-.519	.126	-1.80	.012	-.694	.769
5 P	-.014	.866	-.273	.241	-.110	.580	-.154	.359	-1.38	.014	-2.92	.246
6 P	-.040	.612	-.364	.096	-.149	.418	-.218	.186	-1.83	.003	-1.02	.342
7P	.093	.358	-.183	-.311	-.071	.677	.240	.264	-2.01	.003	-1.40	.091
8 P	.009	.940	-.024	.918	.140	.452	-.561	.046	-1.18	.033	.644	.424
9 P	-.087	.192	-.127	.631	-.177	.393	-.248	.082	-1.88	.008	-1.18	.192
10 P	-.066	.167	.027	.931	.253	.306	-.131	.191	-2.21	.008	-1.74	.102
11 P	-.102	.050	-.634	.050	-.530	.141	-1.47	.808	-3.99	.081	-4.07	.114
12 P	-.146	.085	-.372	.300	.011	.970	-.189	.314	-2.70	.006	-.981	.445

Minimum Temperature

Sabt-Alalaya (Schist.)

Table 13: Min temperature (Nov to April)

Model	Linear Regression						Ordinal Logistic					
	Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality		Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Cur.	.003	.856	.018	.549	.011	.669	-.012	.704	-.025	.673	.029	.798
1 P	.018	.463	.081	.029	.061	.050	.006	.904	.015	.843	.047	.749
2 P	.043	.082	.101	.019	.044	.282	.027	.590	.040	.645	.025	.889
3 P	.021	.455	.028	.484	.000	.990	.064	.277	.122	.150	-.256	.276
4 P	-.005	.862	.012	.726	.001	.966	.077	.193	.134	.070	-.257	359
5P	.017	.410	.042	.167	.031	.221	.077	.089	.173	.018	.424	.115
6 P	.025	.264	.048	.113	.023	.381	.075	.126	.138	.047	.059	.667
7P	.050	.635	-.157	.215	-.033	.759	.081	.718	.124	.650	-.299	.488
8 P	-.130	.337	-.049	.494	-.027	.814	.000	.999	.011	.970	-.248	.567
9P	.059	.649	.052	.697	.180	.464	.039	.885	.020	.941	-.028	.641
10 P	.083	.549	.073	.603	.038	.736	.430	.181	.408	.219	.572	.204
11 P	-.008	.937	.057	.689	-.025	.830	-.041	.843	.236	.456	.464	.352
12 P	-.106	.277	.007	.965	-.077	.524	-.152	.450	-.085	.780	-.345	391

Sabt-Alalaya (Schist.)

Table 14: Min temperature (May to Oct)

Model	Linear Regression						Ordinal Logistic					
	Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality		Min temperature only		Min temperature with seasonality		Min temperature with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.046	.621	-.157	.148	-.133	.120	-.312	.152	-.628	.034	.322	424
1 P	-.105	.324	-.168	.151	-.068	.477	-.551	.057	-.624	.056	-.202	.627
2 P	-.121	.178	-.106	.398	.001	.994	-.344	.115	-.350	.244	-.127	.735
3 P	-.093	.120	-.151	.342	-.143	.255	-.172	.175	-.445	.209	-.433	.377
4 P	-.192	.098	-.128	.554	.029	.870	-.103	.379	-.233	.605	.304	.621
5 P	-.141	.058	-.347	.186	-.193	.357	-.139	.389	-.965	.096	-.940	.289
6 P	-.255	.169	-.172	.526	.102	.637	-.217	.575	-.565	.316	.164	.848
7P	-.137	.002	.117	.264	.063	.402	.091	.224	-.112	.611	.209	.732
8 P	.167	.000	.053	.611	-.033	.656	-.109	.088	-.057	.789	.351	.550
9 P	-.171	.000	-.015	.899	-.069	.414	-.129	.034	-.105	.658	-.418	.577
10 P	.177	.000	.058	.642	.003	.976	.105	.108	-.041	.868	.048	.930
11 P	-.244	.000	-.011	.928	-.016	.863	-.139	.133	-.235	.383	-.351	.632
12P	-.072	.405	.070	.556	.070	.408	-.133	.349	-.160	.520	-.092	.885

Rainfall

Sabt-Alalaya (Schist.)

Table 15: Rainfall (Nov to April)

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
Cur.	.124	.081	.100	.630	.288	.195	-.054	.670	-.788	.555	-.230	.620
1P	.121	.006	.018	.940	.187	.366	.024	.760	-1.05	.229	-.690	178
2P	.087	.016	-.194	.459	-.123	.584	.030	.640	-1.17	.627	-.896	.102
3P	.062	.085	-.234	.364	.123	.600	.018	.795	-1.27	.424	-.705	.251
4P	.056	.226	-.264	.305	-.37	.874	-.016	.857	-1.80	.305	-1.28	.261
5 P	-.038	.626	-.186	.404	.156	.445	-.152	.335	-1.01	.047	-.562	.304
6 P	-.198	.008	-.247	.219	-.086	.625	-.212	.179	-1.11	.018	-.915	.072
7P	.148	.011	.100	.721	.390	.311	.007	.946	-1.47	.210	-.782	.229
8 P	.096	.844	-.317	.835	-.016	.896	.026	.573	-1.25	.214	-.554	.139
9 P	.088	.301	-.291	.047	-.109	.363	.039	.406	-1.21	.385	-.731	.348
10 P	.065	.215	-.202	.171	-.019	.869	.051	.281	-.921	.383	-.378	.313
11 P	.025	.365	-.284	.153	-.157	.169	.036	.449	-1.25	.199	-1.09	.227
12P	-.019	.492	-.209	.178	-.089	.467	-.094	.248	-1.28	.425	-.797	.330

Sabt-Alalaya (Schist.)

Table 16: Rainfall (May to Oct)

Model	Linear Regression						Ordinal Logistic					
	Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality		Rainfall only		Rainfall with seasonality		Rainfall with auto correlation and seasonality	
	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P	Cof.	P
0 P	-.104	.785	.027	.817	.068	.448	-.133	.154	-.762	.110	-.535	.219
1 P	-.113	.785	-.06	.956	.004	.962	-.155	.622	-.985	.602	-.882	.597
2 P	-.099	.624	-.075	.522	-.060	.513	-.138	.206	-1.0	.202	-.641	.190
3 P	-.045	.259	.149	.206	.215	.180	-.070	.152	-.313	.266	1.33	.073
4 P	.016	.516	.126	.286	.018	.844	.000	.990	-.272	.324	-.047	.919
5 P	.079	.2871	.156	.189	.074	.428	.066	.179	-.316	.253	-.272	.532
6P	.120	.658	.041	.731	-.058	.533	.119	.119	-.151	.585	.177	.697
7P	-.022	.758	-.116	.697	-.066	.790	-.06	.668	-1.06	.099	-.519	.662
8 P	-.015	.869	-.356	.462	-.375	.348	-.019	.913	-1.02	.298	-.469	.267
9 P	-.105	.590	-.692	.137	-.236	.576	-.234	.541	-1.76	.083	. 178	.450
10P	-.040	.913	-.178	.655	.300	.389	-.190	.130	-2.48	.114	-.118	.587
11 P	.112	.506	.175	.629	.358	.232	-.329	.329	-1.98	.227	-.321	.518
12P	.039	.707	.160	.465	.132	.666	-.073	.719	-1.03	.176	-.211	.386