PREPARING THE CO_2 ATLAS OF PAKISTAN VIA SATELLITE OBSERVATIONS

BY

MALEEHA JAMAL
NUST201261046MSCEE65212F

Institute of Environmental Sciences and Engineering (IESE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST)
(2015)

PREPARING THE CO_2 ATLAS OF PAKISTAN VIA SATELLITE OBSERVATIONS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE

IN

ENVIRONMENTAL SCIENCE

BY

MALEEHA JAMAL
NUST201261046MSCEE65212F

Institute of Environmental Sciences and Engineering (IESE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

CERTIFICATE

This dissertation submitted by **Ms. Maleeha Jamal** is accepted in its present form, by the Institute of Environmental Sciences and Engineering (IESE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST), Islamabad as satisfying the requirement for the degree of Masters of Environmental Science.

Supervisor:____________________

Dr. Fahim Khokhar
Assistant Professor

Member: ________________________

Professor Dr. Imran Hashmi
Associate Dean
IESE, SCEE, NUST

Member: ________________________

Dr. Yousuf Jamal
Assistant Professor
IESE, SCEE, NUST

External Member: ____________________

Dr. Imran Shahid
Assistant Professor
Institute of Space Technology, Islamabad

This thesis is dedicated to my Parents!

For every fiddlestick of their love and care

ACKNOWLEDGEMENTS

It would not have been possible to write this thesis without the support of many people. First of all, the one above all of us, the beholder, the omnipresent **Allah**, for answering my prayers and who enabled me to complete this study.

I am thankful to my supervisor **Dr. M. Fahim Khokhar** who was abundantly helpful and offered invaluable assistance, support and guidance. I would also like to thank my external member **Dr. Imran Shahid** for cooperation. This thesis would not have been possible without the support and assistance of my committee members **Professor Dr. Imran Hashmi** and **Dr. Yousuf Jamal**.

I am grateful to the staff and students of **IESE, NUST** as they were very helpful and supportive during this research.

Maleeha Jamal

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AJK	Azad Jammu and Kashmir
CDIAC	Carbon dioxide Information Analysis Center
CO_2	Carbon dioxide
ENVISAT	Environmental Satellite
FATA	Federally Administered Tribal Area
GOSAT	Greenhouse Gases Observing Satellite
KPK	Khyber Pakhtunkhwa
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
SD	Summer Decrease
WI	Winter Increase

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Study of spatial distributions of different greenhouse gases by using satellite instruments has been largely improved since past thirty years. It has given new dimensions to the monitoring of atmospheric composition not only at the global scale but also at the regional and even at local scale. This is an important step forward to acquire the knowledge about composition and evolution of the atmosphere around the globe. Increase in CO_2 concentrations, an important greenhouse gas, plays a vital role in altering the climatic conditions. This study proposes to investigate temporal and seasonal variations in CO_2 concentrations over Pakistan during the period of seven years (2003-2009). Main emphasis was made on the hotspot regions where concentration of CO_2 has risen to the level above global averages. Results showed a temporal increase of about 3.32% in the amount of CO_2 over seven years (2003 - 2009). Both maxima and minima in CO_2 concentrations have shown an increasing trend. This increase may be attributed to increase in the fossil fuel combustion during the suggested period. It has also been observed that regions in the KPK and the Gilgit-Baltistan provinces of Pakistan have shown marked increase in the concentrations of CO_2. The increase may be attributed to increase in deforestation and land use change.

Chapter 1

INTRODUCTION

1.1 Background

Human activities are linked to current increase in the concentration of various green house gases which are said to affect the climate by altering various factors such as temperature, precipitation, sea level rise etc. Within the scientific community this increase in the concentration of green house gases is considered as a major concern at global level (Stocker et al., 2013). Since the pre-industrial era, anthropogenic greenhouse gas emissions have increased and attributed to economic and population growth. This has caused an increase in the atmospheric concentrations of methane, nitrous oxide and carbon dioxide. Effects of these anthropogenic emissions have been detected throughout the climate system and are considered to be the dominant cause of the observed warming since the mid-20th century (Pachauri et al., 2014**).** For instance global average CO_2 concentration measured over South Pole and Mauna Loa increased to 395 ppm in 2014 from 315 ppm in 1958. During this period, the airborne fraction of CO_2 due to industrial emissions (fossil fuel plus cement) accounts for 57% (Rafelski et al., 2009).

1.1.1 Global Climatic Changes

The climatic effects due to anthropogenic changes in the last three decades have led to successively warmer temperatures at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, the period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years. The globally averaged temperature data for both land and ocean surface show a warming of 0.85 (0.65 to 1.06)°C over the period 1880 to 2012. Similarly the Greenland and Antarctic ice sheets have been losing mass over the period 1992 to 2011 and at a larger rate over 2002 to 2011. It has been observed that around the world the glaciers have continued to shrink and snow cover has continued to decrease in the Northern Hemisphere. Arctic sea-ice has also shown a decrease over the period 1979 to 2012, with a rate of 3.5 to 4.1% per decade. Global mean sea level rose by 0.19 (0.17 to 0.21) m over the period 1901 to 2010. Since the mid-19th century, the rate of sea level rise has been larger than the mean rate during the previous two millennia (Pachauri et al., 2014). All these climatic effects pose a serious challenge to life on earth and merits implementation of an effective mitigation plan in order to address these changes.

1.1.2 Climate Change in South Asia

South Asia is considered to be the most disaster prone region in the world and is home to over one fifth of the world's population. The vulnerability of the region to climatic impacts is due to continuing high rates of poverty and food insecurity, high rates of population growth and natural resource degradation. Climate variability in South Asia may be marked by increasing air temperatures, increasing trend in the intensity and frequency of extreme events over the last century. Recent modelling experiments indicate significant warming in arid regions of Asia and Himalayan Highlands including the Tibetan Plateau (Shivakumar et al., 2011).

1.1.2.1 Extreme Events

In many countries of South Asia there have been significantly longer heat waves with several cases of severe heat waves (Shivakumar et al., 2011). Similarly, in many parts of Asia, the frequency of more intense rainfall events has increased, causing landslides, severe floods and debris/mud flows (Team, C.W et al., 2007). At the same time, the rain has been concentrated in few days and the total amount of rainfall has decreased. In South Asia, the linear trends for decrease in the rainfall for 1900–2005 were 7.5% (Shivakumar et al., 2011). Besides that, the droughts have increased in the frequency and intensity in this region since the 1970s (Team, C.W et al., 2007). The vulnerability of coastlines of South Asia to cyclones has increased along with coastal flooding, which has resulted in fatalities and substantial economic losses (Shivakumar et al., 2011).

1.2 Atmospheric Chemistry

1.2.1 Green House Gases

Solar Energy drives Earth's climate. The process mainly involves absorption of some of the energy while radiating the rest back towards the space. However, greenhouse gases in the atmosphere absorb some of the energy radiated from the Earth thus acting as a blanket, warming the Earth's surface. This is known as "greenhouse effect" which occurs naturally to sustain life. But as a result of human activities in the past century, the amount of greenhouse gases has increased substantially in the atmosphere trapping more heat and leading to changes in the Earth's climate.

The major anthropogenic greenhouse gases emitted into the atmosphere are carbon dioxide, methane, nitrous oxide, and fluorinated gases. These can remain in the atmosphere for tens to hundreds of years after being released. Various factors determine the way a greenhouse gas will affect the Earth's climate. These include length of time for which the gas remains in the atmosphere. Another factor is the ability of a gas to absorb energy. These factors determine the gas's global warming potential when compared to an equivalent mass of CO_2 which has been assigned a standard global warming potential equal to 1 as shown in the table below (Green House Gases, 2012).

Green House Gas	Mode of Production	Average Lifetime in the Atmosphere	100 – Year Global Warming Potential
Carbon Dioxide	Emitted through Burning of Fossil Fuels (Oil, Natural Gas and Coal), Solid Waste, Changes in Land, Deforestation	Moves in the Ocean – Atmosphere - Land System. Some is absorbed but some remain for Thousands of years	1
Methane	Emitted during the transport and production of Coal, Natural Gas and Oil. It is also emitted from livestock, agricultural practices and decay of Organic waste	12 Years	21
Nitrous Oxide	Emitted during agricultural and industrial activity and as well as from combustion of fossil fuels and solid waste	114 Years	310
Fluorinated Gases	Hydrofluorocarbons, Perfluorocarbons, Sulfur Hexafluoride. These gases are emitted form Industrial, Commercial and household usage. These do not occur naturally	A few weeks to Thousands of Years	Varies (Highest is Sulfur hexafluoride at 23,900)

Table 1.1: Major Green House Gases

1.2.2 Carbon dioxide: Major Green House Gas

CO_2 naturally occurs in the Earth's atmosphere causing natural Greenhouse Effect. As mentioned earlier that the main source of emission of CO_2 is burning of fossil fuels along with changes in land use, solid waste and deforestation. Ice core measurements confirm the increasing trend followed by CO_2 since industrial era (Ehhalt et al., 2001).

1.2.2.1 Natural Fixation

CO_2 is absorbed by plants through the process of diffusion from stomata into leaves and later to the sites of photosynthesis. Almost one-third of all the CO_2 in the atmosphere is dissolved in the leaf water which is equivalent to about 270 PgC/yr (Farquhar et al., 1993; Ciais et al., 1997). The amount of CO_2 which does not participate in photosynthesis is diffused out from the leaf surface. Gross Primary Production (GPP) is the amount of CO_2 that is fixed from the atmosphere and is converted into carbohydrates through the process of Photosynthesis. This fixed amount of CO_2 has been estimated to be 120 PgC/yr (Ciais et al., 1997) however, the other half is released back into the atmosphere by autotrophic respiration (Lloyd and Farquhar, 1996; Waring et al., 1998).

1.2.2.2 Land Use Changes

Amount of carbon in plant biomass and soils is also affected by Changes in land use. Comparison of maps of natural vegetation in the absence of human intervention to the maps of current vegetation derived from satellite data 1987 shows the carbon loses of 180 to 200 PgC due to changes in land us (de Fries et al., 1999). Since 1850, almost 90% of the estimated emissions due to land-use change were caused by deforestation resulting in 20% decrease in the global forest area (Houghton, 1999).

1.2.2.3 Fossil Fuel Emissions

Accelerating increase in the atmospheric CO_2 is primarily caused by emissions from the burning of fossil fuels (Raupach et al., 2007). Approximately 337 billion metric tonnes of carbon have been released to the atmosphere since 1751 from the consumption of fossil fuels and cement production (Boden et al., 2010) fossil-fuel combustion accounts for 90% of total CO_2 emissions whereas emissions from cement clinker production is the largest source of non-combustion-related CO_2 emissions which contributes about 4% to the global total (Olivier et al., 2012).

1.3 Present Study

This study proposes to extract and analyze CO_2 concentrations over Pakistan during the 2003-2009 with main emphasis on major districts of Pakistan. This will help in identification of the potential sources of CO_2, seasonal cycle and temporal and spatial evolution of CO_2 over Pakistan.

1.3.1 Justification of the Study

In order to have better understanding of climate change, weather extremities, a better understanding of atmospheric composition and the dynamics driving these phenomena is essential. Carbon dioxide is the most important anthropogenic greenhouse gas and taking into account the role of CO_2 in climate change, long-term data of atmospheric composition of CO_2 is therefore needed to evaluate temporal variations and trends in climate extremes. Unfortunately, no such record of atmospheric composition over Pakistan exists. This poses a major obstacle in examining the climatic extremes especially in developing countries like Pakistan. This study is part of the efforts to eliminate these obstacles and to prepare scientific base line information of atmospheric CO_2 concentration during 2003-2009 over Pakistan.

1.3.2 Benefits of the Study

This study will provide information on evolution of CO_2 over in Pakistan during 2003-2009. This study will result in creation of a CO_2 database which may act as baseline information for further research in this field and region. This study will facilitate in identification of hotspot areas where levels of CO_2 have reached maximum levels in Pakistan. This study may help policy-makers and decision-makers to design relevant adaptation and mitigation strategies.

1.4 Objectives

- To prepare database of CO_2 concentrations over Pakistan during the time period 2003-2009 using satellite observations.
- To analyze the evolution of CO_2 concentrations over Pakistan.
- To compare the level of CO_2 in various Districts of Pakistan.

Chapter 1 deals with introduction and aim and objectives of this study. Chapter 2 deals with the Literature that has been reviewed before and during the execution of this study. Chapter 3 consists of description of study area and data sets with complete methodology that was used to conduct this study. The results obtained from this study are given in Chapter 4 and in the end conclusion with recommendations are presented in Chapter 5.

Chapter 2

LITERATURE REVIEW

2.1 Carbon Cycle

2.1.1 Stages

Atmospheric CO_2 constitutes only a tiny fraction of the carbon in the earth system. Major portion of the carbon is part of the reservoirs in that system. Human intervention however, is changing this natural balance by making carbon from fossil fuel emissions part of the atmospheric CO_2 cycle. Fossil fuel reserves and land use change are two important contributing factors in changing the dynamics of the natural cycle. Archer and Brovkin, (2008) has shown time scale of thousands of years to remove anthropogenically emitted carbon from the atmosphere by natural processes as shown in the table below.

Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O$ + photons $\rightarrow C_6 H_{12} O_6 + 6O_2$ $C_6 H_{12} O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + heat
Ocean invasion: Seawater buffer	$10–10^3$	$CO_2 + CO_3^{-2} + H_2O \rightarrow 2HCO_3^{-1}$ $\leftarrow$
Reaction with calcium carbonate	$10^3–10^4$	$CO_2 + CaCO_3 + H_2O \rightarrow Ca^{+2} + 2HCO_3^{-1}$
Silicate weathering	$10^4–10^6$	$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$

Table 2.1: Natural Removal of CO_2

The above mentioned reactions are part of the natural flow of carbon in the terrestrial, oceanic and atmospheric systems but the balance created by these systems is changing with time and depends on the level of emissions. Ciais et al. (2014) studied the relationship between natural cycle and its adjustment to human induced emissions which can be divided into three stages.

For several decades of emissions, almost third to half of CO_2 gets absorbed into the terrestrial ecosystem and the ocean while rest of it goes into the atmosphere. Within few centuries, it existed as inorganic carbonate in the oceans thereby decreasing the pH. Eby et al. (2009) and Joos et al. (2013) has analyzed the increase in atmospheric fraction of CO_2 with the decrease in carbonate buffer capacity of the ocean.

The second stage pertains to restoring the original balance of carbon in the oceans. Within next few thousand years pH of the ocean that was decreased in stage 1 is restored by the reaction of dissolved CO_2 in the ocean with that of calcium carbonate ($CaCO_3$) present in the sea floor sediments which restore the balance by drawing down atmospheric CO_2 into the oceans. After about 10,000 years, this stage decreased the remaining atmospheric CO_2 fraction down to 10 to 25% of the original CO_2 amount.

In this stage, within several hundred thousand years, silicate weathering played its role in CO_2 removal from the atmosphere which is a very slow process and involves reaction between CO_2 and calcium silicate ($CaSiO_3$) and other minerals of igneous rocks (Sundquist, 1990; Walker and Kasting, 1992).

In this way CO_2 circulated between different systems maintaining a balance among them. These long time processes of CO_2 removal from the atmosphere however, does not allow to designate fix atmospheric lifetime to CO_2.

2.2 Annual Increase

Keeling et al. (1976) reported that the concentration of atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii is reported for the years from 1964 to1971 in order to observe the effects of combustion of fossil fuels on the distribution of CO_2 in the atmosphere. The data led to the findings that between 1959 and 1971the annual average CO_2 concentration rose to 3.4% with decline in the mid-1960's. These changes have also been observed at the South Pole making it a global phenomenon.

Schimel (1995) stated that the carbon cycle involves flow of carbon among four main reservoirs: the oceans, the terrestrial biosphere, fossil carbon and the atmosphere. The findings of his work involve measurement of carbon flux during 1980s where emissions of fossil carbon averaged 5.5 Gt y^{-1} while the atmosphere gained 3.2 Gt C y^{-1}. Cias et al. (2014) has assessed global anthropogenic CO_2 budget, averaged over the 1980s, 1990s, and 2000s until 2011. The negative land or ocean to atmosphere CO_2 flux depicts gain of carbon by these reservoirs.

FACTORS	1980-1989 PgC yr^{-1}	1990-1999 PgC yr^{-1}	2002-2011 PgC yr^{-1}
Atmospheric increase	3.4 ± 0.2	3.1 ± 0.2	4.3 ± 0.2
Fossil fuel combustion and cement production	5.5 ± 0.4	6.4 ± 0.5	8.3 ± 0.7
Ocean-to-atmosphere flux	–2.0 ± 0.7	–2.2 ± 0.7	–2.4 ± 0.7
Land-to-atmosphere flux Partitioned as follows	–0.1 ± 0.8	–1.1 ± 0.9	–1.6 ± 1.0
Net land use change	1.4 ± 0.8	1.5 ± 0.8	0.9 ± 0.8
Residual land sink	–1.5 ± 1.1	–2.6 ± 1.2	–2.5 ± 1.3

Table 2.2: Global Anthropogenic CO_2 budget

The global anthropogenic CO_2 budget indicates increase in the concentration of carbon dioxide since 1980s whereas there is constant decrease in the land and ocean flux to the atmosphere.

Sirignano et al. (2010) analyzed atmospheric CO_2 concentrations from 2000 until 2005 from the coastal stations Mace Head (MHD), Ireland and Lutjewad (LUT), The Netherlands and observed an average increase in CO_2 concentration in the atmosphere of about 1.7 ± 0.2 ppm y^{-1} which is mainly attributed to human activities, particularly fossil fuel burning.

2.3 Seasonal Oscillations

Seasonal pattern of CO_2 refers to interannual variation in the levels of CO_2 which can be attributed to changes in CO_2 absorption and release alternatively in summer and winter seasons respectively. A study carried out by Bacastow et al. (1985) showed that a seasonal pattern is exhibited by atmospheric carbon dioxide at Mauna Loa Observatory that repeats with a specific regularity. It was observed that the seasonal amplitude, increased per year from 1958 to 1982 at an average rate of about 0.7% with high statistical significance. It was argued that the seasonal cycle of CO_2 in the northern hemisphere is considered to be due to the metabolic activity of terrestrial vegetation.

Kane and De Paula (1996) determined that seasonal variation in atmospheric CO_2 indicates maxima during May and minima during September or October at Mona Loa. Dettinger and Ghil (1998) observed that the seasonal cycle of CO_2 depends upon the local absorption and release of CO_2. This shows that seasonal levels of CO_2 differ from place to place as were determined at both South Pole and Mona Loa.

Sirignano et al. (2010) determined the seasonal difference in the concentration of CO_2 in summer (minima) and winter (maxima) which was 14.4 and 16.1 ppm at Mace Head and Lutjewad, respectively.

Bergeron and Strachan (2011) investigated CO_2 flux over a suburban and an urban residential area in the Montreal region for a two-year period. The suburban area contributed about 50 t CO_2 ha^{-1} $year^{-1}$,whereas urban area contributed about 200 t CO_2 ha^{-1} $year^{-1}$.The results indicated that biological sources and sinks (vegetation) was a dominant component of the net CO_2 flux at suburban site, specifically in summer, while human activity dominantly affect CO_2 fluxes at the urban site. Therefore, the major factors affecting CO_2 exchange over Montreal residential areas were vegetation, fuel combustion for heating and vehicular traffic emissions, along with air temperature and incoming light levels.

Shim and Wang (2013) examined spatial and temporal variability of CO_2 over East Asia through nested modeling and GOSAT satellite retrievals. Their findings indicated that seasonal changes in the atmospheric levels of CO_2 are largely caused by northeastern forest uptake.

2.4 Temperature and Carbon dioxide

Alexiadis (2007) has suggested complexity in the relation between CO_2 concentration and temperature. He stated that carbon dioxide is a greenhouse gas and directly affects the thermal balance of the planet while, as a result of subsequent warming, various feedback mechanisms affect the concentration and exchange of CO_2 in various sources and sinks of carbon (photosynthesis, respiration, marine CO_2 pump e.t.c). The results of the study show that the anthropogenic CO_2 is the main driving force in increasing global temperatures even if the emissions decrease for a certain time.

Liu and Rodríguez (2005) reported that with the doubling of CO_2 the temperature change lies between 2.15 and 3.4 ^{0}C which coincides with the previous report of the IPCC (2001) using 15 different general circulation models.

Ghommem, et al. (2012) quantified the coupling between global temperature and carbon-cycle utilizing general circulation model (GCM) and investigated how sequestration of anthropogenic CO_2 would impact the lowering the rate of increase in global temperatures. Their findings indicated that in order to impact global warming CO_2 emissions would have to be sequestered on large scale. They concluded that about 25 % of these emissions can be removed from direct absorption or land use management.

Rafelski, et al. (2009) explained warming-induced release of CO_2 from the land biosphere to the atmosphere. They elaborated that multi decadal variation in temperature, possibly through processes such as fires and temperature-dependent respiration, cause variations in the land CO_2 sink.

2.5 Fossil Fuel Emissions

Siegenthaler and Sarmiento (1993) indicated the relation between atmospheric increase of CO_2 between Northern Hemisphere and the Southern Hemisphere. They stated in Northern Hemisphere which accounts for almost 95% of fossil fuel emissions, the annual mean concentrations of CO_2 has exceeded the Southern Hemisphere's concentrations and these inter hemispheric differences can be attributed to fossil fuel emissions of CO_2.

Cias et al. (2014) studied that fossil fuel combustion and cement production contributed 5.5 ± 0.4 PgC yr^{-1} to global CO_2 emissions during 1980–1989. These reached to the levels of 6.4 ± 0.5 PgC yr^{-1} during 1990–1999 whereas during 2000–2009 these emissions were equal to 7.8 ± 0.6 PgC yr^{-1} on the average. This showed an increase of 3.2% yr^{-1} on average during the decade 2000–2009 compared to 1.0% yr^{-1} in the 1990s and 1.9% yr^{-1} in the 1980s.

Sawa et al. (2012) studied CO_2 measurements from 5224 flights from commercial airliners during 2005-2010 and observed through surface CO_2 measurements that about half of the CO_2 produced by cement production and fossil fuel combustion and has stayed in the atmosphere while the remainder has been absorbed by various natural sinks on land and in the ocean.

2.6 Deforestation

Van der Werf et al. (2009) suggested that after fossil fuel combustion, deforestation is the second largest anthropogenic source of CO_2 to the atmosphere. House et al. (2002) studied the impact of land use changes over increase and decrease of CO_2 in the atmosphere. This study showed an increase of 90 ppm of CO_2 between the pre-industrial era and year 2000 in the atmosphere due to land-use changes (mostly deforestation) and fossil fuel emissions.

DeFries et al. (2002) estimated carbon fluxes from deforestation for the 1980s and 1990s using satellite in combination with a terrestrial carbon model. The results indicated that the clearing rate of tropical forest increased ≈10% from the 1980s to 1990s, specifically in Southeast Asia. This led to an increase in mean annual carbon fluxes to an average 0.6 and 0.9 Pg yr^{-1} for 1980s and 1990s, respectively.

Pakistan is also affected by similar situation. Ali et al. (2005) assessed that forest in Basho Valley in the Western Himalayas of Pakistan has been reduced by at least 50%. Tariq et al. (2014) studied the climatic impacts in Dir Kohistan region of KPK Pakistan indicating increase in the temperature by 0.33°C besides the decrease in rainfall and humidity which can be regarded as an outcome of forest degradation in Dir Kohistan.

2.7 Climate Change Impacts

Solomon et al. (2009) discussed the irreversibility of climatic changes for 1000 years due to increase in the concentration of CO_2 in the atmosphere. The irreversible impacts would be expected if the levels of CO_2 increased to 450–600 ppmv from current levels. These impacts include reductions in dry season rainfall reductions and inexorable rise in sea level. It was further explained that global average sea level rise of at least 0.4–1.0 m is expected if CO_2 concentration exceeds 600 ppmv.

Sajjad et al. (2010) analyzed that rapid urbanization, population and vehicles growth and industrialization played a critical role in the consumption of fossil fuels in Karachi during 1947 to 2008. It was also observed that emission of CO_2 increased from 39 million metric tons in 1980 to 151 million metric tons in 2007 which was in consonance with the increase in the consumption of oil and petrol, natural gas and coal which showed an increase of about 219, 365 and 287%, respectively during the same period.

Mustafa (2011) in view of the current status of climate change indicated that Pakistan will have to face environmental, social and economic impacts. Pakistan is frequently exposed to natural hazards like droughts, floods and cyclones. The agriculture sector is most vulnerable to climate change which affects and changes cropping and productivity negatively impacting poor rural communities of the country. With problems relating to water shortages and high temperatures arid and semi-arid regions are most vulnerable. Therefore in Pakistan, this vulnerability is high because of economic dependence on primary natural resources.

Chapter 3

METHODOLOGY

3.1 Study Area

Pakistan stretches between 61-78 ^{0}E and 23.6-38 ^{0}N with an area of 796,096 square kilometers. The surface elevation ranges from Arabian Sea (in the south) to the world's second highest (8,611 m) peak of K-2 in the North (Chaudhry et al., 2009). Pakistan shares its borders with India on the East, Iran on the West, China in the North and with Afghanistan on the NorthWestern side with coastline of 1100 km in the South.

3.2 General Methodology

Following Methodology was followed in this research

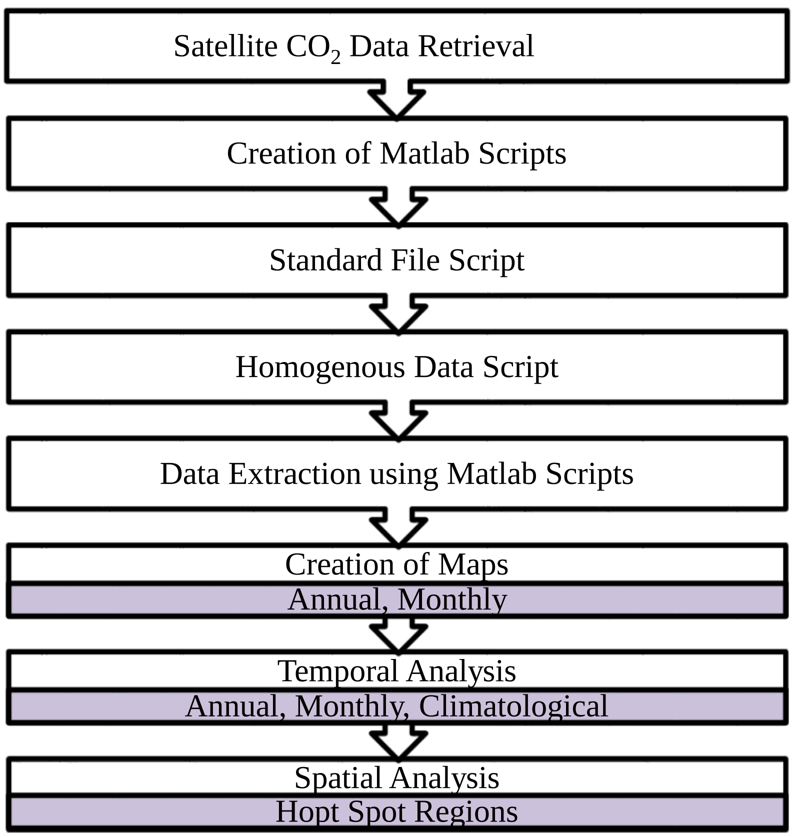

Figure 3.1: General Methodology

3.3 Satellite CO_2 Data Retrieval

In order to analyze the CO_2 distribution over Pakistan, SCIAMACHY data product (Version 2.3, Level 3) was used. Data from 2003 to 2009 was downloaded. Specifications of the satellite are given below.

PROPERTIES	SCIAMACHY
Spatial resolution	60 x 30 Km^2
Swath width	960 km
Temporal resolution	6 days
Temporal coverage	2002 to 2012
Red and NIR bands	-
Spectral range	240 to 2380 nm
Data quality assessment	70% Accurate

Table 3.2: Satellite Sensors and their Properties

3.4 Data Extraction

Current study covers the geographical area of Pakistan. Sciamachy data was global data; which was to be extracted over the region of Pakistan. To obtain Pakistan specific data Matlab scripts were created. These scripts extracted monthly data of Pakistan from 2003 to 2009 creating 84 Pakistan specific files for 7 years.

3.4.1 Script for Standard File Creation

Purpose of this script was to create a standard file which covers the region of Pakistan. This script was used to extract Pakistan specific data from the global files.

```
function [] = create_file
fid=fopen('standard_latlong_paknc17.txt', 'w');

a=[];
b=[];
n=23.75;
s=60.25;
n1=51.25
s1=102
k=1;
length_of_a=0;
length_of_b=0;

for i=n: n1
    for j=s:s1
a(k)=n;
b(k)=s;

  s=s+0.5;
  k=k+1;
end
s=60.25;
 n=n+0.5;
end


length_of_a=length(a)
length_of_b=length(b)

for z=1 :length_of_a
    fprintf(fid,'\r\n%f\t\t\t\t %f',a(z),b(z));
end
fclose(fid);
```

Figure 3.2: Matlab Script for Standard File Creation

After the script is executed on Matlab, following standard file was created. Left column indicate latitude values and right column indicate longitude values.

Latitude	Longitude
24.25000000000	67.75000000000
24.25000000000	68.25000000000
24.25000000000	68.75000000000
24.25000000000	69.75000000000
24.75000000000	67.75000000000
24.75000000000	68.25000000000
24.75000000000	68.75000000000
24.75000000000	69.25000000000
24.75000000000	69.75000000000
24.75000000000	70.25000000000
24.75000000000	70.75000000000
25.25000000000	66.75000000000
25.25000000000	67.25000000000
25.25000000000	67.75000000000
25.25000000000	68.25000000000
25.25000000000	68.75000000000
25.25000000000	69.25000000000
25.25000000000	69.75000000000
25.25000000000	70.25000000000
25.25000000000	70.75000000000
25.75000000000	63.75000000000
25.75000000000	64.25000000000
25.75000000000	64.75000000000
25.75000000000	65.25000000000
25.75000000000	65.75000000000
25.75000000000	66.25000000000
25.75000000000	67.25000000000
25.75000000000	67.75000000000
25.75000000000	68.25000000000
25.75000000000	69.25000000000
25.75000000000	69.75000000000
25.75000000000	70.25000000000
26.25000000000	63.25000000000
26.25000000000	63.75000000000
26.25000000000	65.75000000000
26.25000000000	66.25000000000

Figure 3.3: Standard Pakistan Lat Long File

3.4.2 Script for Data Extraction

This Matlab script was created to extract CO_2 data from the global file based on the latitude and longitude present in the standard file. This script resulted in Pakistan specific files having latitude, longitude and CO_2 concentrations.

```
function [] = find_latlong
%fid=fopen('PAK_SCIA_XCO2_WFMDv23_200912.txt', 'w');
fid=fopen('PAK_2009dec.txt', 'w');
%fid=fopen('test.txt', 'w');
%fprintf(fid, '%6s %6s %6s\r\n', 'LATITUDE          LONGITUDE        CO2');
d=[];
lat=[];
long=[];
g=0;
length_of_d=0;
length_of_n=0;
file1 = sprintf( 'standard_latlong_paknc17.txt');
%file1 = sprintf( 'pak.txt');

data1= load(file1);
%file2 = sprintf( 'SCIA_XCO2_WFMDv23_200912.grid');
file2 = sprintf( 'Export_Output_2009_12_attribute_table.prn');
%file2 = sprintf( 'global.txt');


data2= load(file2);
lat1 = data1(:,1);
long1 = data1(:,2);
lat2 = data2(:,1);
long2 = data2(:,2);
%c = data2(:,6);
c = data2(:,3);
a=length(lat1)
b=length(long1)
e=length(lat2)
f=length(long2)
s= length(data2)
h=0;
k=0;
n=[];
%lat1
%lat2
%long1
```

Figure 3.4: Matlab Script for Data Extraction

This script created following files

Latitude	Longitude	CO_2 [ppm]
24.2500000000	67.7500000000	387.8455000000
24.2500000000	68.2500000000	388.4410000000
24.2500000000	68.7500000000	388.6603300000
24.2500000000	69.7500000000	388.5134900000
24.7500000000	67.7500000000	388.7600000000
24.7500000000	68.2500000000	388.3874000000
24.7500000000	68.7500000000	387.8550000000
24.7500000000	69.2500000000	387.0746700000
24.7500000000	69.7500000000	387.8740000000
24.7500000000	70.2500000000	388.3179900000
24.7500000000	70.7500000000	388.3179900000
25.2500000000	66.7500000000	387.9750100000
25.2500000000	67.2500000000	386.8182500000
25.2500000000	67.7500000000	387.3296000000
25.2500000000	68.2500000000	389.4527500000
25.2500000000	68.7500000000	389.4635000000
25.2500000000	69.2500000000	388.0913400000
25.2500000000	69.7500000000	388.0665100000
25.2500000000	70.2500000000	387.9364300000
25.2500000000	70.7500000000	388.1535000000
25.7500000000	63.7500000000	390.6560100000
25.7500000000	64.2500000000	390.6560100000
25.7500000000	64.7500000000	389.8299900000
25.7500000000	65.2500000000	389.8299900000
25.7500000000	65.7500000000	390.0130000000
25.7500000000	66.2500000000	390.0130000000
25.7500000000	67.2500000000	386.9385000000
25.7500000000	67.7500000000	386.5981400000
25.7500000000	68.2500000000	388.4750100000
25.7500000000	69.2500000000	388.3030100000
25.7500000000	69.7500000000	388.2845100000
25.7500000000	70.2500000000	387.8581700000
26.2500000000	63.2500000000	390.1030000000
26.2500000000	63.7500000000	390.1030000000
26.2500000000	65.7500000000	390.0130000000
26.2500000000	66.2500000000	390.0130000000

Figure 3.5: Pakistan Specific Files

3.5 Creation of Maps

In order to analyze the data graphically, annual and monthly maps of Pakistan were created presenting the variation in the amount of CO_2. These maps were created in ArcGIS.

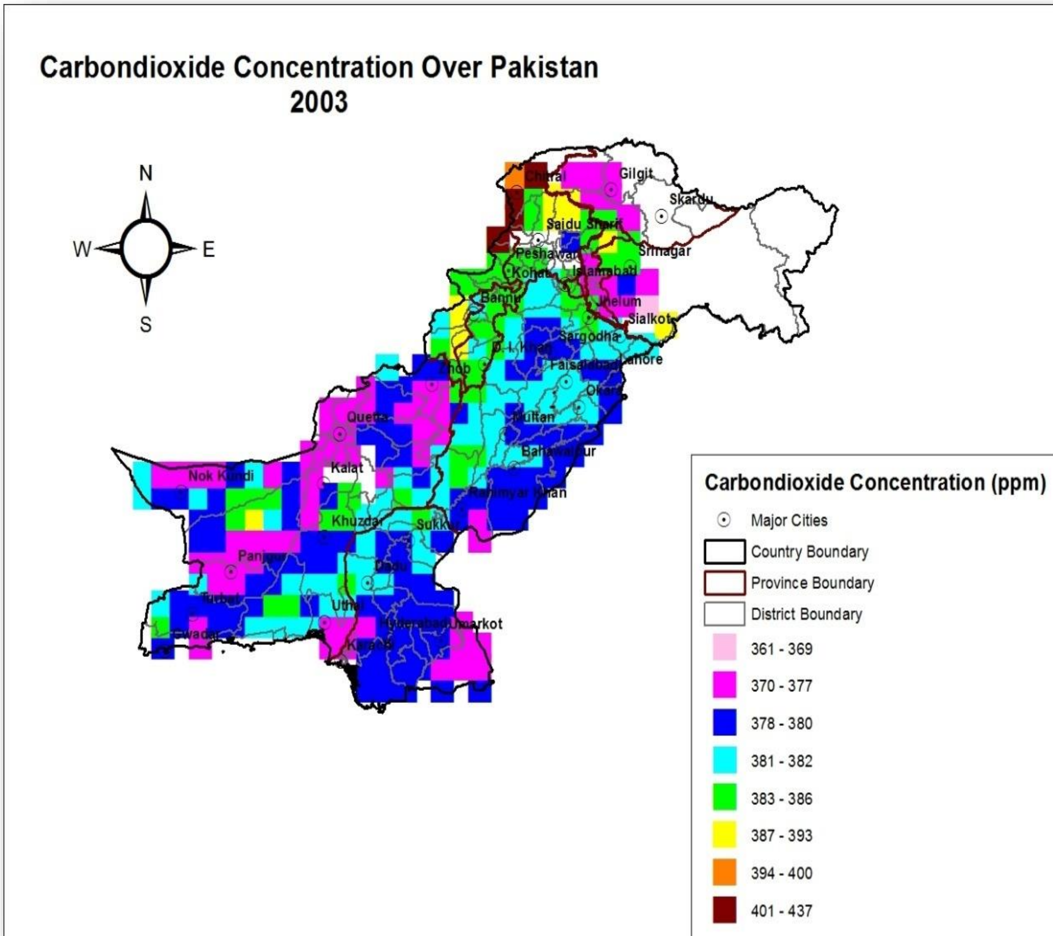

Figure 3.6: Annual mean map of Pakistan showing concentrations of CO_2

3.6 Temporal Data Analysis

Temporal data analysis presented the annual, monthly and climatological variation in the concentrations of CO_2 over Pakistan during 2003 – 2009. This was performed using excel. In excel, monthly and annual means for the seven year’s data were calculated. Different graphs indicating the annual, monthly and climatological trend of CO_2 over Pakistan were created. Besides that analysis of fossil fuel data and calculation of coefficient of correlation was also performed in excel.

3.7 Spatial Data Analysis

This was performed in order to determine the hotspot regions with respect to CO_2 concentration over Pakistan in ArcGIS. In ArcGIS, carbon dioxide concentrations in various districts of Pakistan were determined and selected concentrations i.e ranging between 391 ppm and 400 ppm and above 400 ppm were extracted using SQL queries and was exported in the excel files.

FID_1	OBJECTID	Lat	Lon	Mean	FID_2	PROV_NAME	DIST_NAME	PR	DIST_	AFFE	HUB	ET_IC	SCALE	CS_CHE
287	288	35.2500000000	72.2500000000	399.7369290000	75	N.W.F.P.	Upper Dir	16	2077	No			0	
292	293	35.7500000000	71.7500000000	399.2562620000	63	N.W.F.P.	Chitral	16	2065	No			0	
294	295	35.7500000000	72.7500000000	396.6885810000	74	N.W.F.P.	Swat	16	2076	No			0	
288	289	35.2500000000	72.7500000000	396.6348410000	67	N.W.F.P.	Kohistan	16	2069	Yes	Batagram	05	0	
295	296	36.2500000000	71.7500000000	396.4466720000	63	N.W.F.P.	Chitral	16	2065	No			0	
149	150	29.2500000000	67.7500000000	395.0062970000	11	Balochistan	Bolan	11	2013	No			0	
278	279	34.2500000000	72.2500000000	395.0001680000	73	N.W.F.P.	Swabi	16	2075	No			0	
163	164	29.7500000000	67.7500000000	394.7135790000	30	Balochistan	Sibi	11	2032	No			0	
293	294	35.7500000000	72.2500000000	394.6013890000	75	N.W.F.P.	Upper Dir	16	2077	No			0	
23	24	25.7500000000	61.7500000000	393.5828170000	14	Balochistan	Gwadar	11	2016	No			0	
291	292	35.2500000000	74.2500000000	393.1477200000	34	F.A.N.A.	Diamir	13	2036	No			0	
245	246	32.7500000000	70.2500000000	392.6008200000	48	F.A.T.A.	North Waziristan Agency	14	2050	No			0	
275	276	33.7500000000	75.2500000000	392.2379440000	32	Disputed Area	Disputed Area	12	2034	No			0	
255	256	32.7500000000	75.7500000000	392.0859980000	32	Disputed Area	Disputed Area	12	2034	No			0	
279	280	34.2500000000	74.2500000000	391.9449770000	32	Disputed Area	Disputed Area	12	2034	No			0	
233	234	32.2500000000	70.2500000000	391.0611010000	58	N.W.F.P.	Tank	16	2060	No			0	
277	278	34.2500000000	71.7500000000	390.9760130000	62	N.W.F.P.	Charsadda	16	2064	No			0	
256	257	33.2500000000	70.2500000000	390.4968520000	48	F.A.T.A.	North Waziristan Agency	14	2050	No			0	
289	290	35.2500000000	73.2500000000	390.2758450000	67	N.W.F.P.	Kohistan	16	2069	Yes	Batagram	05	0	
276	277	34.2500000000	71.2500000000	390.0844330000	45	F.A.T.A.	Khyber Agency	14	2047	No			0	
232	233	32.2500000000	69.7500000000	389.6469750000	50	F.A.T.A.	South Waziristan Agency	14	2052	No			0	
270	271	33.7500000000	71.7500000000	389.5462820000	38	F.A.T.A.	Tribal Area adj Peshawar	14	2040	No			0	
280	281	34.2500000000	74.7500000000	389.5380000000	32	Disputed Area	Disputed Area	12	2034	No			0	
269	270	33.7500000000	71.2500000000	389.4979750000	49	F.A.T.A.	Orakzai Agency	14	2051	No			0	
246	247	32.7500000000	70.7500000000	389.3758640000	59	N.W.F.P.	Lakki Marwat	16	2061	No			0	
127	128	28.7500000000	67.7500000000	389.3691270000	11	Balochistan	Bolan	11	2013	No			0	
283	284	34.7500000000	74.2500000000	389.2473230000	131	P.A.K.	Neelum	10	2133	Yes	Muzaffarabad	09	0	
244	245	32.7500000000	69.7500000000	389.2146920000	48	F.A.T.A.	North Waziristan Agency	14	2050	No			0	
223	224	31.7500000000	70.2500000000	389.0418360000	64	N.W.F.P.	D. I. Khan	16	2066	No			0	

Figure 3.7: District Data for Carbon dioxide values between 391 ppm and 400 ppm

In this research above mentioned tools and processes were used in order to analyze the data of CO_2 over Pakistan and its districts during 2003 – 2009.

Chapter 4

RESULTS AND DISCUSSION

4.1 Temporal Analysis of Carbon dioxide over Pakistan

4.1.1 Annual Analysis

The current research aims at analyzing the levels of carbon dioxide in the atmosphere over Pakistan. The analysis of the data starting from 2003 till 2009 shows that the amount of carbon dioxide has increased linearly to 3.32% in seven years over Pakistan. Average concentration of carbon dioxide in 2003 was 378 ppm whereas in 2009 it reached to the level of 391.2 ppm. Globally the amount of carbon dioxide has increased from 270 ppm in 1750 to 390.5 ppm in 2011 (Ciais et al., 2014) which verifies the increasing trend of carbon dioxide over Pakistan reaching to an average amount of 391.2 ppm in 2009 as shown in the figure 4.1.

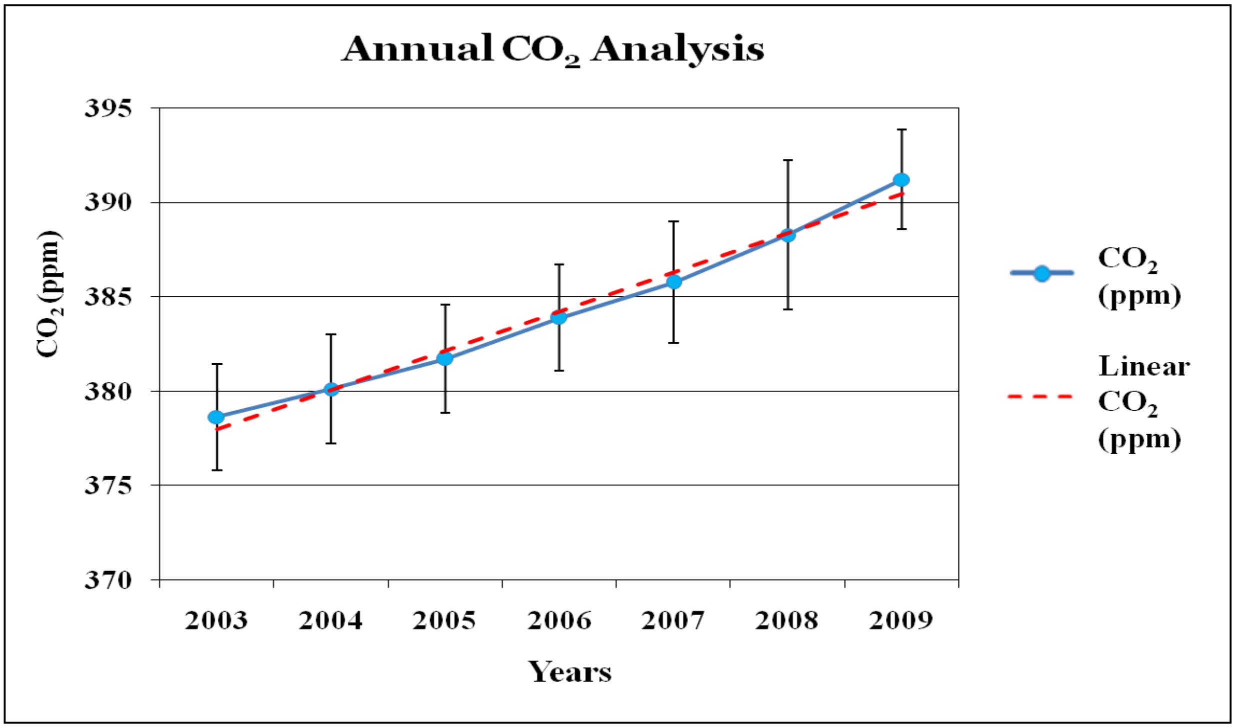

Figure 4.1: Annual Carbon dioxide Analysis (2003-2009)

Annual variations in the levels of carbon dioxide over Pakistan clearly show substantial increase in its concentration from 2003 – 2009. This was graphically verified by creating annual maps in ArcGIS Software.

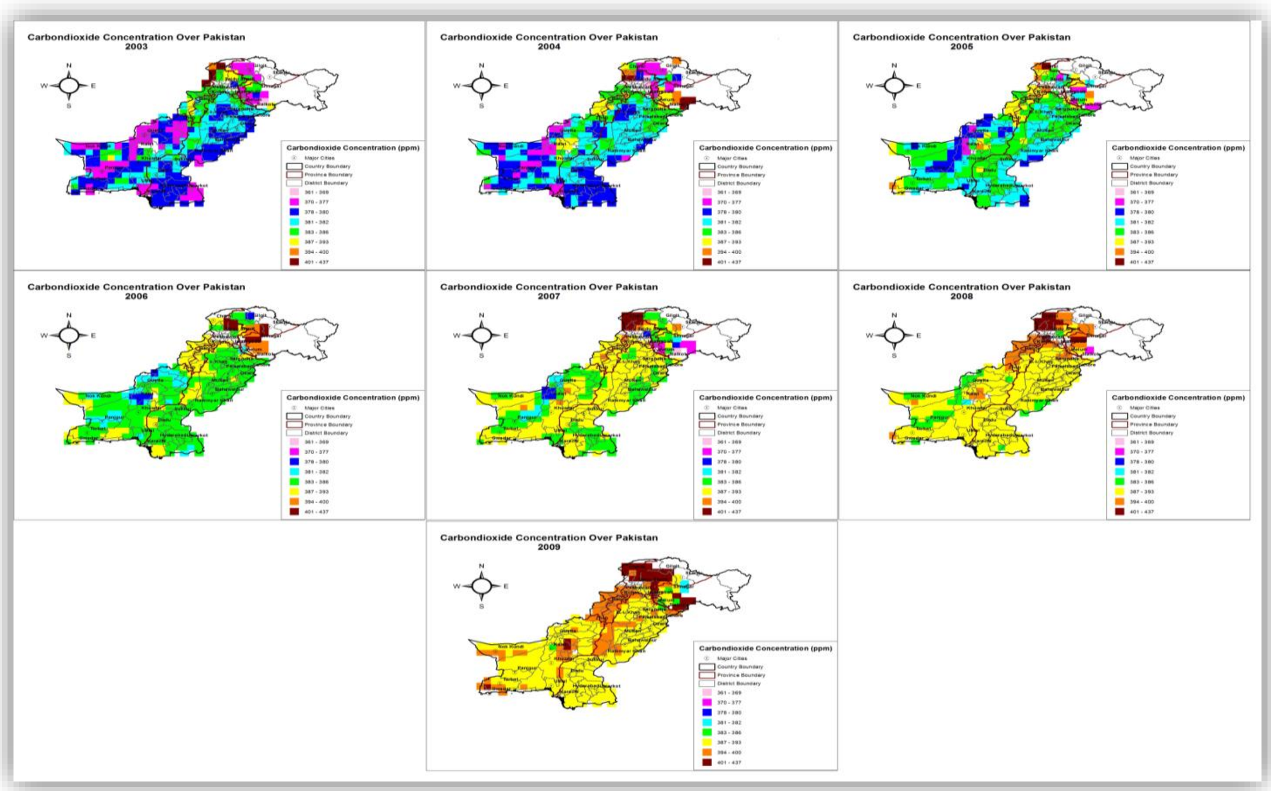

Figure 4.1 a: Mean Maps of CO_2 Concentration over Pakistan (2003 - 2009)

The annual mean maps clearly show the annual increase in the levels of carbon dioxide with the maximum levels reaching in 2009 as indicated by the yellow, orange and red color range. Yellow colour depicts the range of 387 – 393 ppm, orange colour represents concentration of 394 – 400 ppm, whereas maroon colour range represents 401 – 437 ppm concentration of carbon dioxide. As mentioned above that the maximum average concentration of carbon dioxide was 391.2 ppm in 2009 which falls in yellow colour range. The maps therefore, also indicate regions of Pakistan where concentration of carbon dioxide is more than 391.2 ppm. These regions are shown by orange and maroon colour range which mostly falls in the KPK province of Pakistan.

4.1.2 Monthly Analysis

4.1.2.1 Change in Maxima and Minima

Monthly analysis of carbon dioxide over Pakistan not only depicts increase in the concentration of CO_2 as mentioned earlier but also gives information about the seasonal increase in concentration of carbon dioxide over seven years as shown in the graph below. The curve shown below is termed as the keeling curve. Peaks in the curve are termed as maxima whereas depths are termed as minima. Minima and maxima correspond to the minimum and maximum concentration of carbon dioxide during winter and spring respectively.

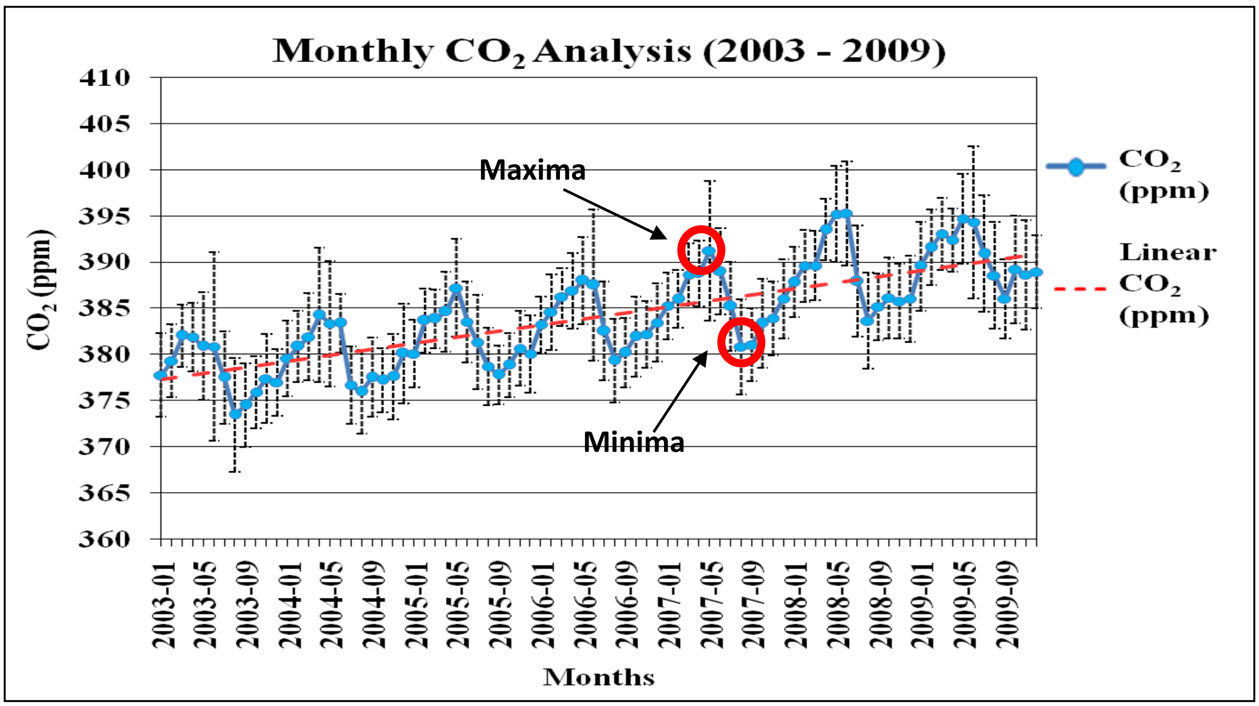

Figure 4.2: Monthly Carbon dioxide Cycle (2003-2009)

From the analysis of satellite data it has been observed that in 2003 the minima was at the concentration of approximately 374.6 ppm whereas in 2009 it reached at 387.9 ppm. Similarly in

2003 the maxima was approximately at 381.4 ppm, which reached to the concentration of 393.8 ppm in 2009. This shows an absolute increase of 13.3 ppm in minima and 12.4 ppm in maxima regarding the concentration of carbon dioxide during the period of 7 years over Pakistan as shown in figure 4.3,4.4and 4.5.

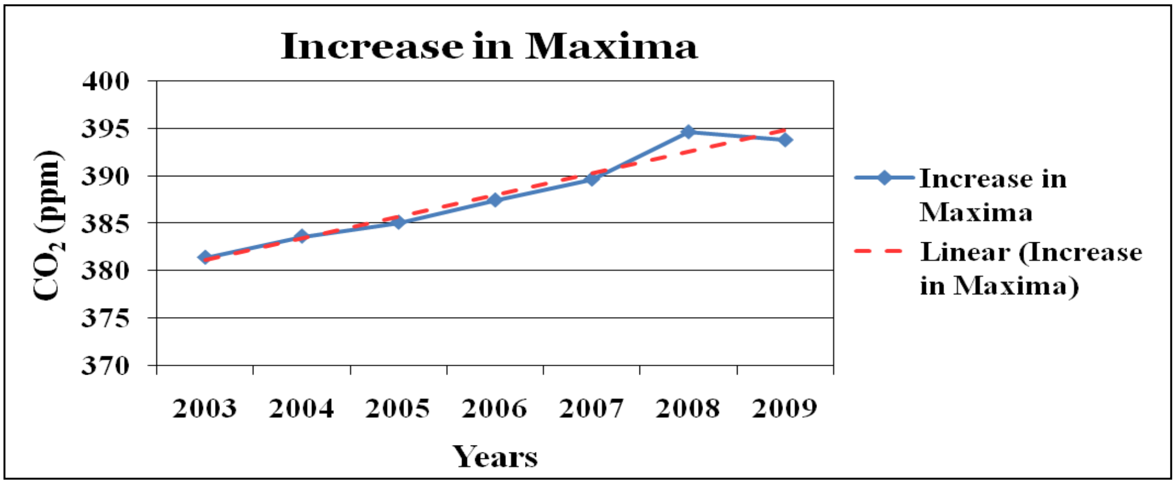

Figure 4.3: Increase in Maxima

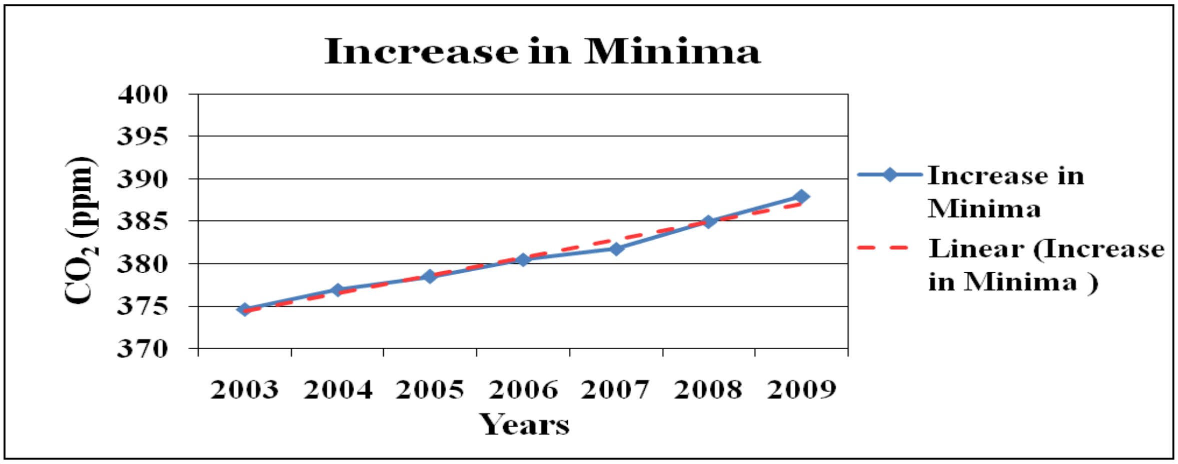

Figure 4.4: Increase in Minima

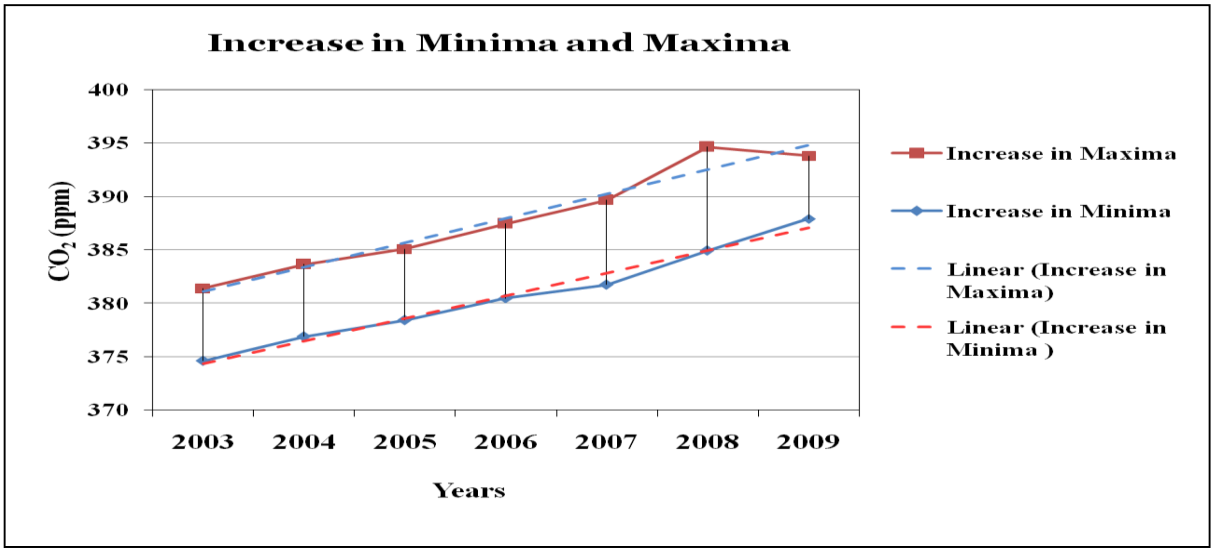

Figure 4.5: Combined increase in Maxima and Minima

4.1.2.2 Increase in Amplitude of the Monthly Cycle of Carbon dioxide

The analysis of monthly cycle reveals concentration of carbon dioxide has experienced change in the amplitude in winters and summers. Winter Increase (WI) corresponds to the increase in the concentration of carbon dioxide in the atmosphere in winter season as a result of decline in carbon fixation (as elaborated in the climatological analysis explained in the following section). However, Summer Decrease (SD) corresponds to the decrease in the amount of carbon dioxide in the atmosphere in summers due to increase in the rate of carbon fixation by plants (as elaborated in the climatological analysis explained in the following section). It has been observed that during the period of seven years the amplitude with respect to these two indicators i.e WI and SD has increased over Pakistan as shown in figure 6.

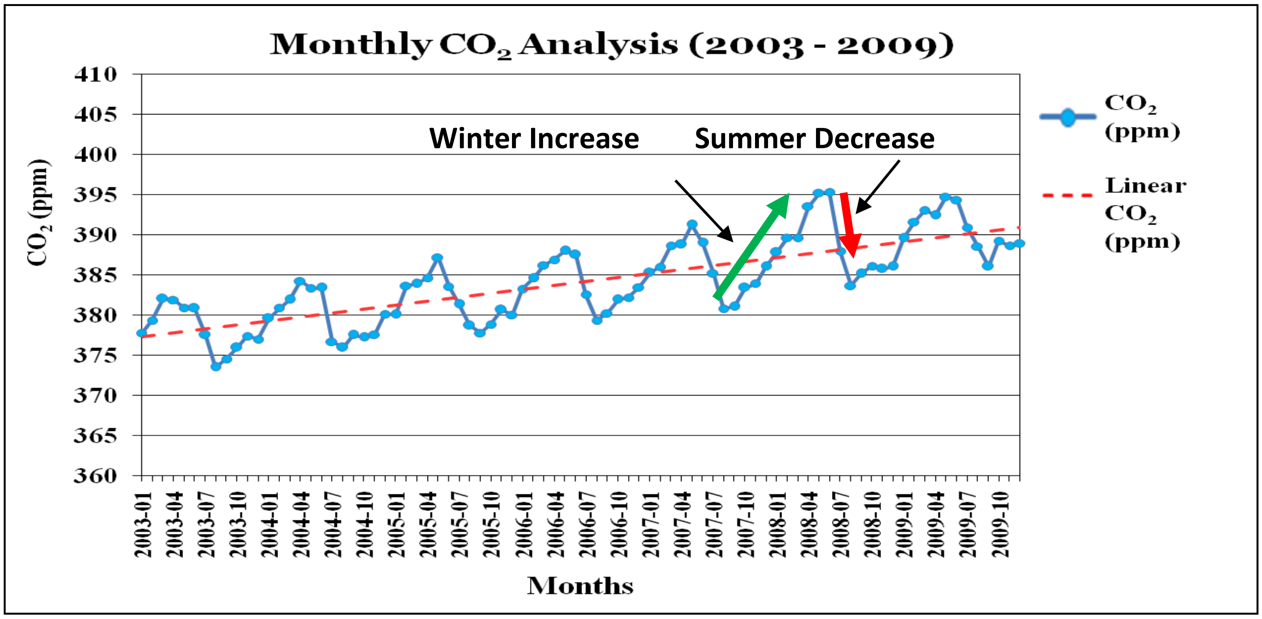

Figure 4.6: Monthly CO_2 Analysis (2003 - 2009)

WI is calculated from minima of the previous year to the maxima of the following year whereas; SD is calculated from the maxima to the minima of the same year.

$$WI = Y_{x+1\ (max)} - Y_{x\ (min)} \quad \textbf{Eq.1}$$

$$SD = Y_{(max)} - Y_{(min)} \quad \textbf{Eq.2}$$

The results show an increase in the amplitude of WI from approximately 9.01 ppm in 2003 to 12.91 ppm in 2008 whereas average increase during 2003 – 2009 is **9.538035 ppm** . The results also indicate and increase in SD which was 6.7 ppm in 2003 and 9.7 ppm in 2008 and the average increase during 2003 – 2009 is **7.242806 ppm**. Decrease in amplitude of WI and SD in the year 2009 may be attributed to decrease in CO_2 emissions due to fossil fuel burning as a result of Global economic recession (Olivier et al., 2010)

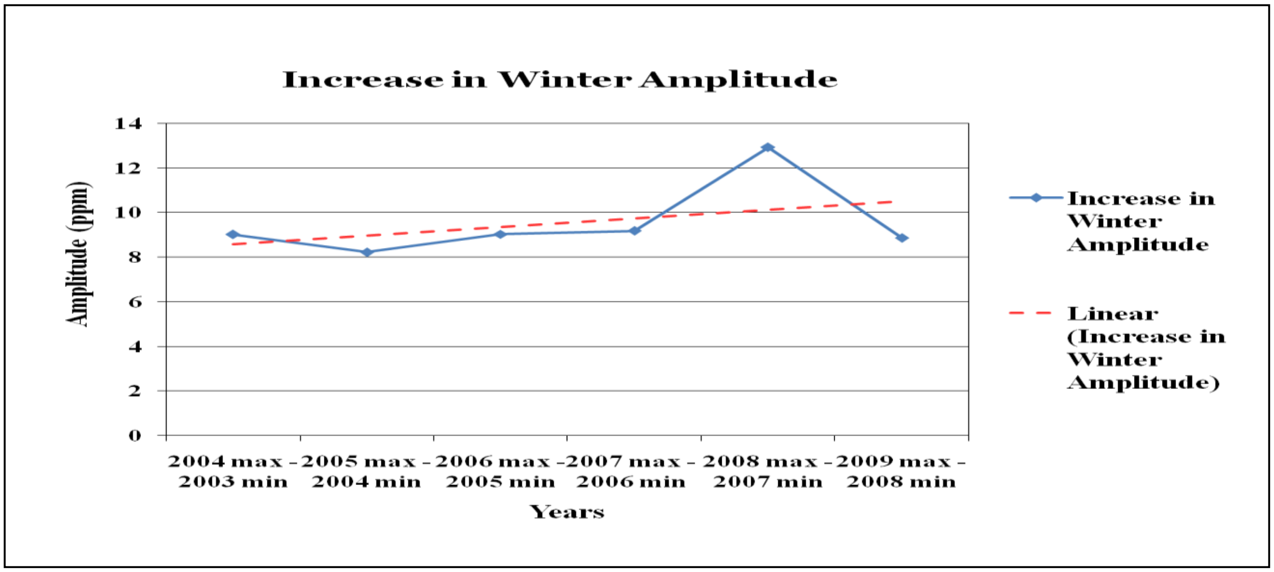

Figure 4.7: Increase in Winter Amplitude

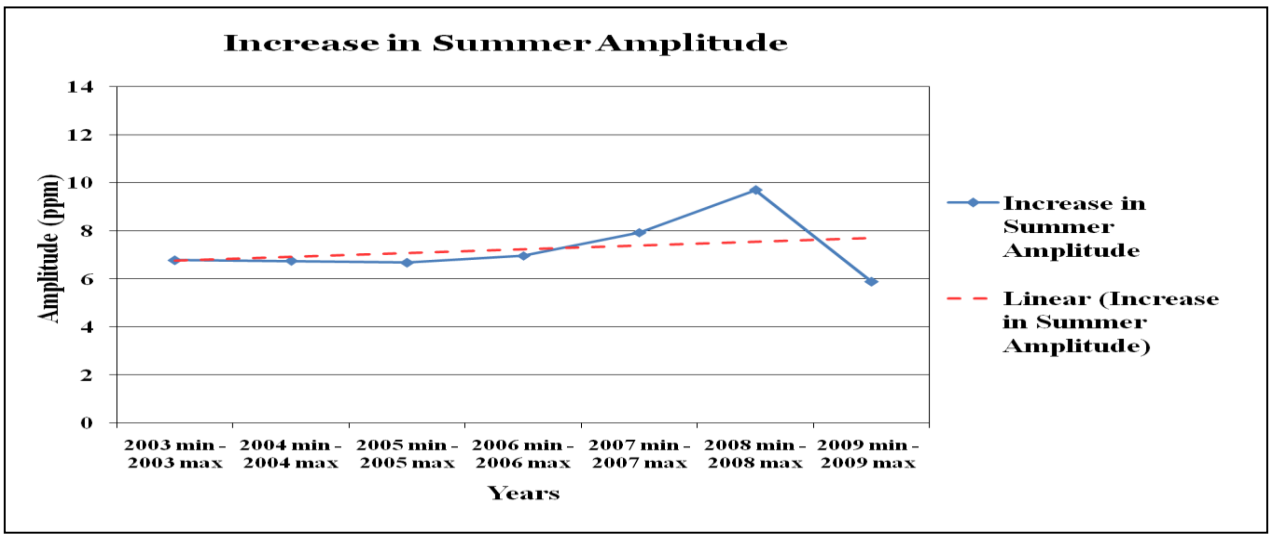

Figure 4.8: Increase in Summer Amplitude

This change in seasonal amplitude of carbon dioxide can be explained by the shift in the seasonal timing of heterotrophic respiration (Soil Respiration) and Net Primary Productivity (The rate at which plants incorporate atmospheric carbon through photosynthesis) (Randerson et al., 1997, Idso et al., 1999, Kumar et al., 2014). Moreover, seasonal cycle of carbon dioxide is primarily affected by two major human activities which include consumption of fossil fuel and burning of forests and grassland (Randerson et al., 1997). In addition to that it has been suggested that the rising temperatures may have played a central role in increasing the amplitude of seasonal cabon dioxide cycle (Idso et al., 1999).

4.2 Climatological Analysis of Carbon dioxide over Pakistan

Climatological analysis involves study of variation in the concentration of carbon dioxide from January till December during 2003 to 2009. The analysis reveals a pattern of decrease in the concentration of CO_2 in summers and increase in winters.

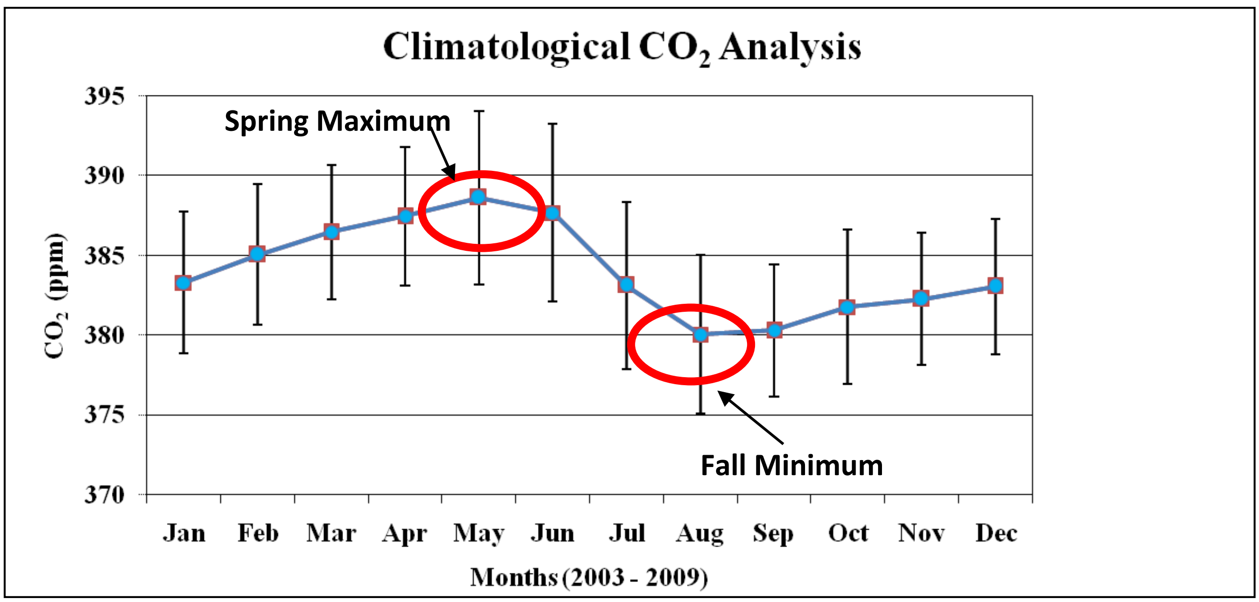

Figure 4.9: Climatological Analysis of Carbon dioxide (2003-2009)

As observed from the satellite analysis over Pakistan, the amount of CO_2 starts increasing in the month of January till it reaches its maximum level in the months of April and May. The maximum point is known as **Spring Maximum**. After that it starts decreasing till it reaches its minimum level in the months of August and September. The minimum point is known as **Fall Minimum**. This trend is in consonance with the one measured in **Mauna Loa,** Hawaii (Kane et al., 1996). The increasing trend in the atmospheric CO_2 in winters can be attributed to the end of growth season in plants. During winters the rate of photosynthesis in plants decreases and that of respiration increases thereby decreasing the uptake of CO_2 by plants and increasing the concentration of CO_2 in the atmosphere. Whereas in summers when the growth season is at its peak, the rate of photosynthesis increases as compared to the rate of respiration in plants, thereby decreasing the amount of CO_2 in the atmosphere resulting in greater CO_2 fixation by plants (Dettinger et al., 1998). This shows that biotic component plays an important role in the variation levels of CO_2 in the atmosphere as strong correlation exists between and inter annual variability in CO_2 and the biological activity (Adams et al., 2005, Idso et al., 1999)

As depicted in figure 4.9a and 4.9b, the yellow and orange scheme shows concentration of CO_2 greater than 386 ppm. The maroon scheme shows the amount of CO_2 greater than 400 ppm. The colour scheme shows greater amount of atmospheric CO_2 in Spring season as compared to that of Fall season.

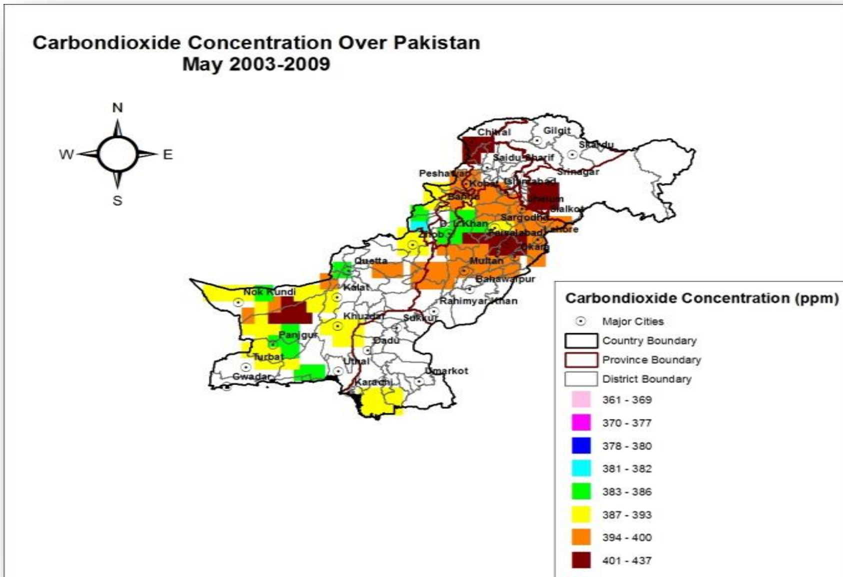

Figure 4.9 a: CO_2 Concentration over Pakistan in Spring Season (2003 - 2009)

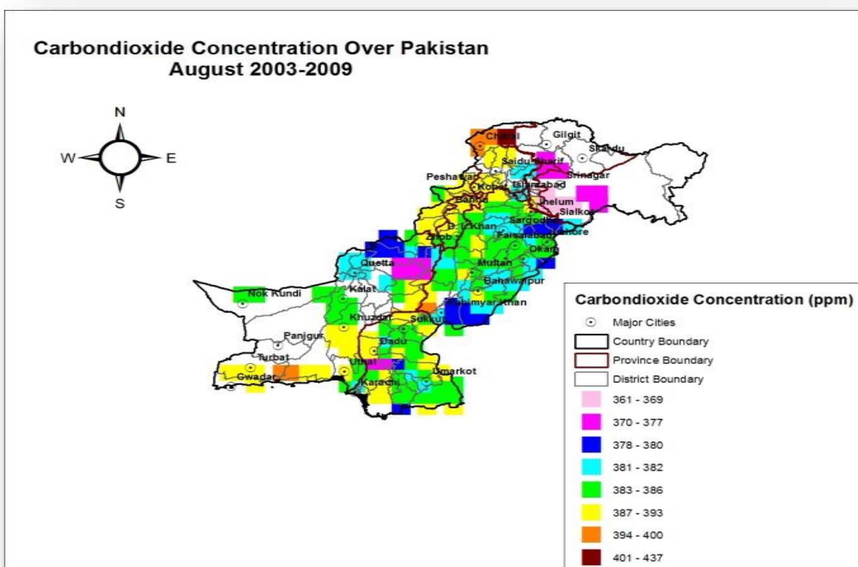

Figure 4.9 b: CO_2 Concentration over Pakistan in Fall Season (2003 - 2009)

4.3 Correlation Analysis of Temperature and Carbon dioxide

4.3.1 Temporal Analysis

4.3.1.1 Annual Analysis

Annual analysis of carbon dioxide and Temperature delineates the increasing trend with positive correlation of 0.32 during the years 2003 – 2009 as shown in figure 4.10.

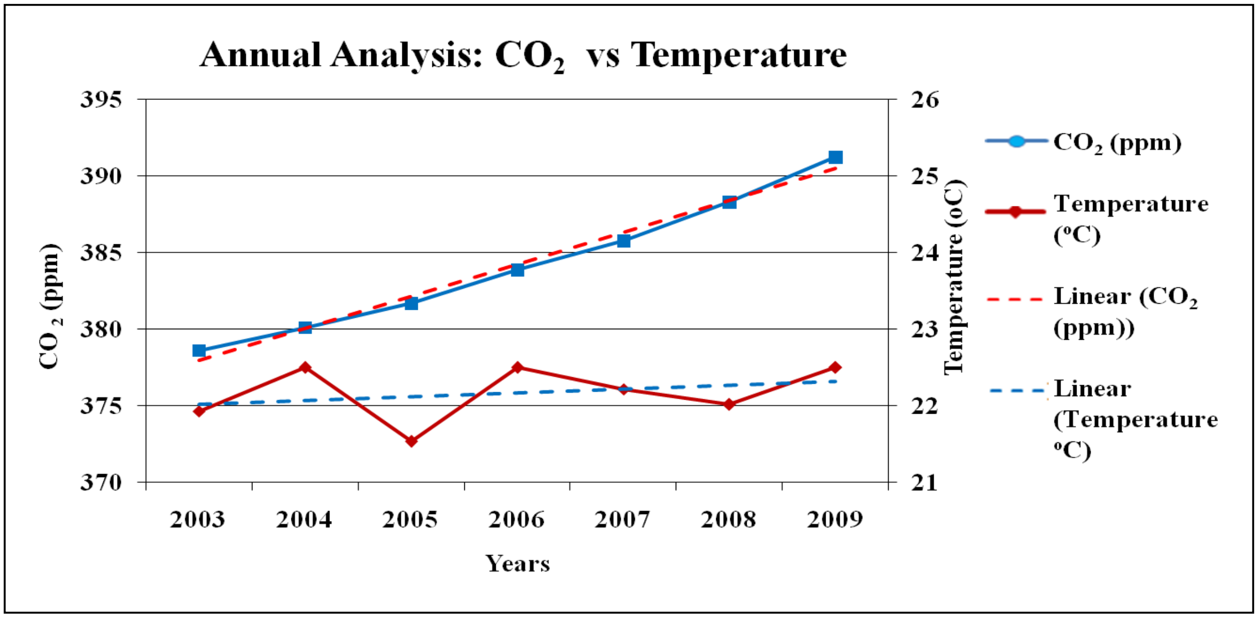

Figure 10: Annual Analysis: CO_2 vs Temperature (2003-2009)

The increasing trend in both the variables reinforces the climatic impacts of increased carbon dioxide concentration in the atmosphere manifesting as an increase in the surface temperatures thus causing global warming. Increase in temperature due to CO_2 over Pakistan during 2003 – 2009 is in harmony with the increase in observed global average surface temperature. The reported increase in the global average surface temperature during the period of 100 years from 1906 to 2005 is of 0.74 ± 0.18°C (Ciais et al., 2014, Sivakumar et al., 2011) where as in Pakistan, since early 1900s it is 0.16 – 1.0°C in the coastal areas (Sivakumar et al., 2011).

4.3.1.2 Monthly Analysis

Figure 4.11 depicts the monthly variation in carbon dioxide and temperature during the years 2003 – 2009. This time series is determined from monthly means of CO_2 and temperature over Pakistan. Data analysis reveals positive correlation of 0.054 between both the variables indicating an increasing trend during the period from 2003 till 2009 over Pakistan. The graph also delineates the seasonal oscillations between carbon dioxide and temperature as will be elaborated in the climatological analysis.

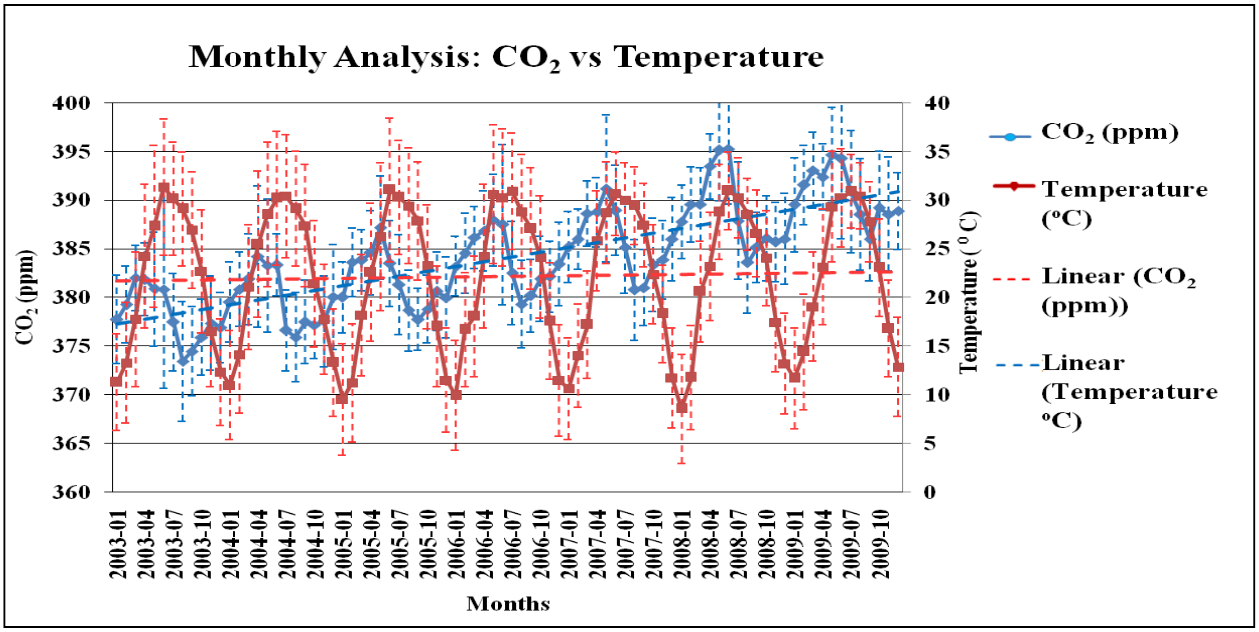

Figure 4.11: Monthly Analysis: CO_2 vs Observed Temperature (2003-2009)

4.3.2 Climatological Analysis

Climatological analysis of carbon dioxide and temperature shows seasonal interaction of both the variables. In the month of June when temperature is maximum and growing season is at its peak (Zimov et al., 1999) the process of photosynthesis dominates the process of respiration and causes a reduction in the carbon dioxide concentration. Soon after the monsoon season, as the temperatures starts decreasing, the process of respiration in plants dominates the process of photosynthesis and carbon dioxide is released into the atmosphere (Dettinger and Ghil, 1998). This shows alternating relationship between the monthly temperatures and the amount of carbon dioxide in the atmosphere as depicted in the figure 4.12.

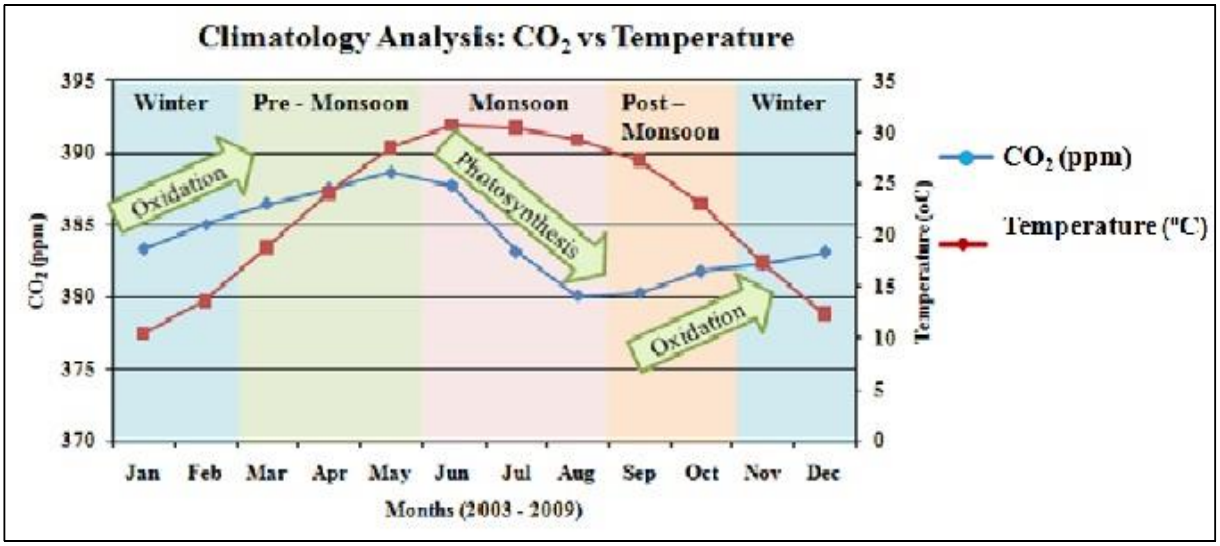

Figure 4.12: Climatological Analysis: CO_2 vs Temperature

4.4 Spatial Analysis

4.4.1 Identification of Hot Spot Regions in Pakistan w.r.t Carbon dioxide Concentrations

Spatial analysis of carbon dioxide concentration reveals variation in the distribution pattern in its amount over the entire region. Mean distribution during 2003 – 2009 indicates that the concentration of CO_2 between 391 ppm and 400 ppm lies in the provinces of KPK, Balochistan, FATA and disputed area. The concentration of carbon dioxide greater than 400 ppm can be observed in the district Gilgit, province of KPK as shown in the table 4.1 and table 4.2.

PROVINCE NAME	DISTRICT NAME	CO_2 (ppm)
KPK	Upper Dir	399.74
KPK	Chitral	399.26
KPK	Swat	396.69
KPK	Kohistan	396.63
KPK	Chitral	396.45
Balochistan	Bolan	395.01
KPK	Swabi	395.00
Balochistan	Sibi	394.71
KPK	Upper Dir	394.60
Balochistan	Gwadar	393.58
F.A.N.A.	Diamir	393.15
F.A.T.A.	North Waziristan Agency	392.60
Disputed Area	Disputed Area	392.24
Disputed Area	Disputed Area	392.09
Disputed Area	Disputed Area	391.94
KPK	Tank	391.06

Table 4.1: Hotspot Regions having CO_2 between 391 ppm and 400 ppm

PROVINCE NAME	DISTRICT NAME	CO_2 (ppm)
KPK	Chitral	406.42
KPK	Chitral	401.54

Table 4.2: Hotspot Regions having CO_2 greater than 400 ppm

The map below shows mean distribution pattern of CO_2 concentrations in the years 2003 – 2009 in various provinces of Pakistan. It may be observed that in the KPK province the concentration of CO_2 reaches the level greater than 391 ppm whereas, in the Gilgit district of KPK it is more than 400 ppm.

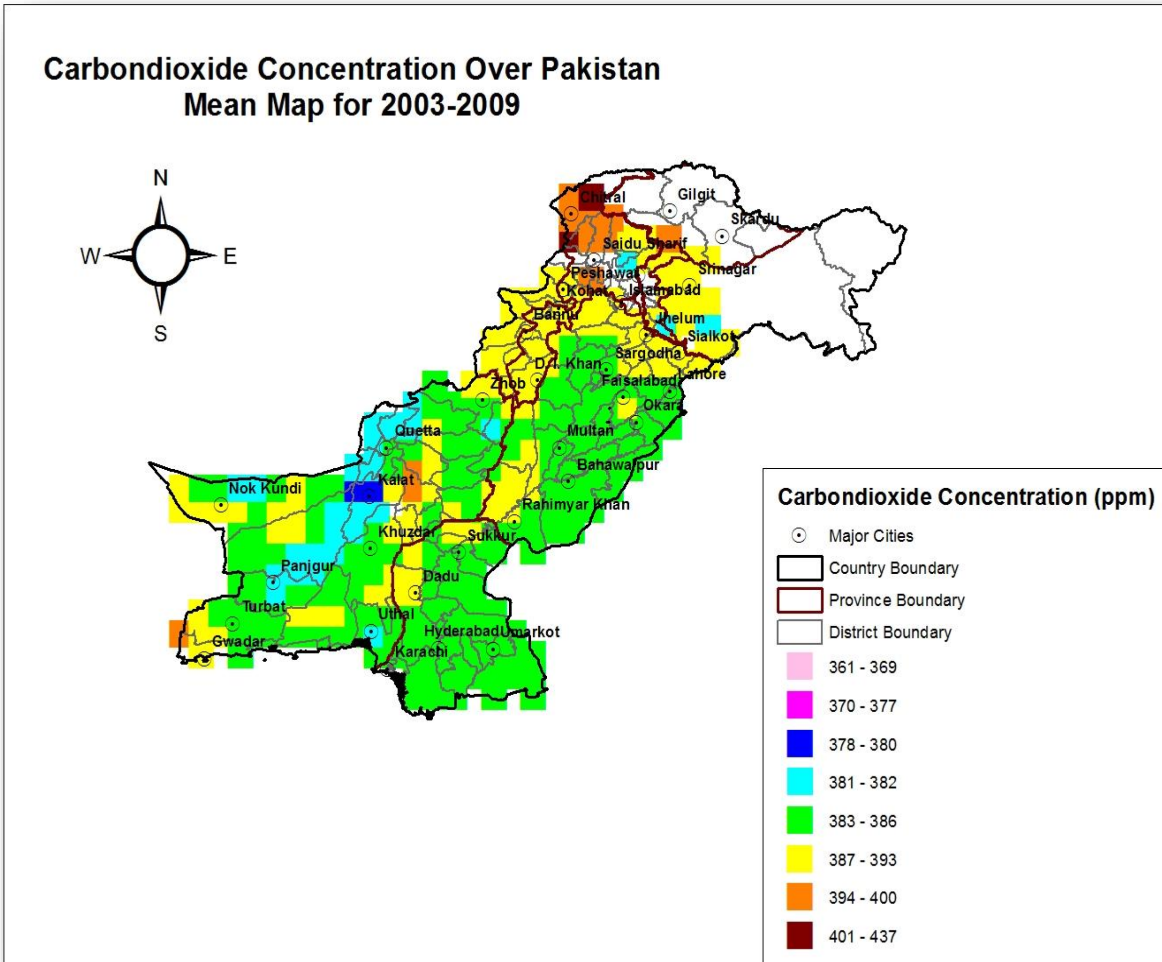

Figure 4.13: Mean Map of CO_2 Concentration (2003 – 2009)

Like Pakistan, increase in the CO_2 concentration in the northern region of India was also observed in the study conducted during 2004 – 2011 (Kumar et al., 2014).

4.5 Fossil Fuel Emissions and Carbon dioxide: Analysis

4.5.1 Sectoral Distribution of CO_2 Emissions

Fossil fuel combustion is considered one of the major sources of anthropogenic carbon dioxide emissions. According to 5th IPCC report, between 1750 and 2011, Anthropogenic CO_2 emissions to the atmosphere were 555 ± 85 PgC where fossil fuel combustion and cement production contributed 375 ± 30 PgC. IPCC Report also mentions CO_2 emissions from fossil fuel burning as one of the dominant cause of the observed increase in atmospheric CO_2 concentration. Therefore, Emissions to the atmosphere of carbon dioxide from fossil-fuel combustion are of concern because of their growing magnitude, the resulting increase in atmospheric concentrations of CO_2, the concomitant changes in climate, and the direct impact of increased atmospheric CO_2 on ecosystems and energy demand (Andres et al., 2012).

Fossil fuel data analysis shows the sector wise distribution of 1809009 Kt CO_2 emissions in Pakistan during 2003 – 2009 (Fossil Fuel data over Pakistan during 2003 - 2009 was obtained from carbon dioxide Information Analysis Center **(CDIAC)**). In Pakistan almost **24.38%** emissions of CO_2 are due to gaseous fuel consumption, **20.43%** due to Liquid fuel consumption, **16.14%** due to Manufacturing Industries and Construction, **15.36%** due to electricity and heat production, whereas transport sector contribute only to **11.31%** of total CO_2 emissions. Similarly in case of global fossil fuel CO_2 emissions, power generation and industry dominate the total mass of emissions (Andres et al., 2012).

Sectors	CO_2 Emissions (Kt)	CO_2 Emissions (%)
Electricity and heat production, total	277800	15.36
Gaseous fuel consumption	441000	24.38
Liquid fuel consumption	369567	20.43
Manufacturing industries and construction	292020	16.14
Other sectors, excluding residential buildings and commercial and public services	3420	0.19
Residential buildings and commercial and public services	96000	5.31
Solid fuel consumption	124612	6.89
Transport	204590	11.31
Total CO_2 Emissions	**1809009**	**100**

Table 4.3: Sector wise Distribution of Total CO_2 Emissions (Kt)

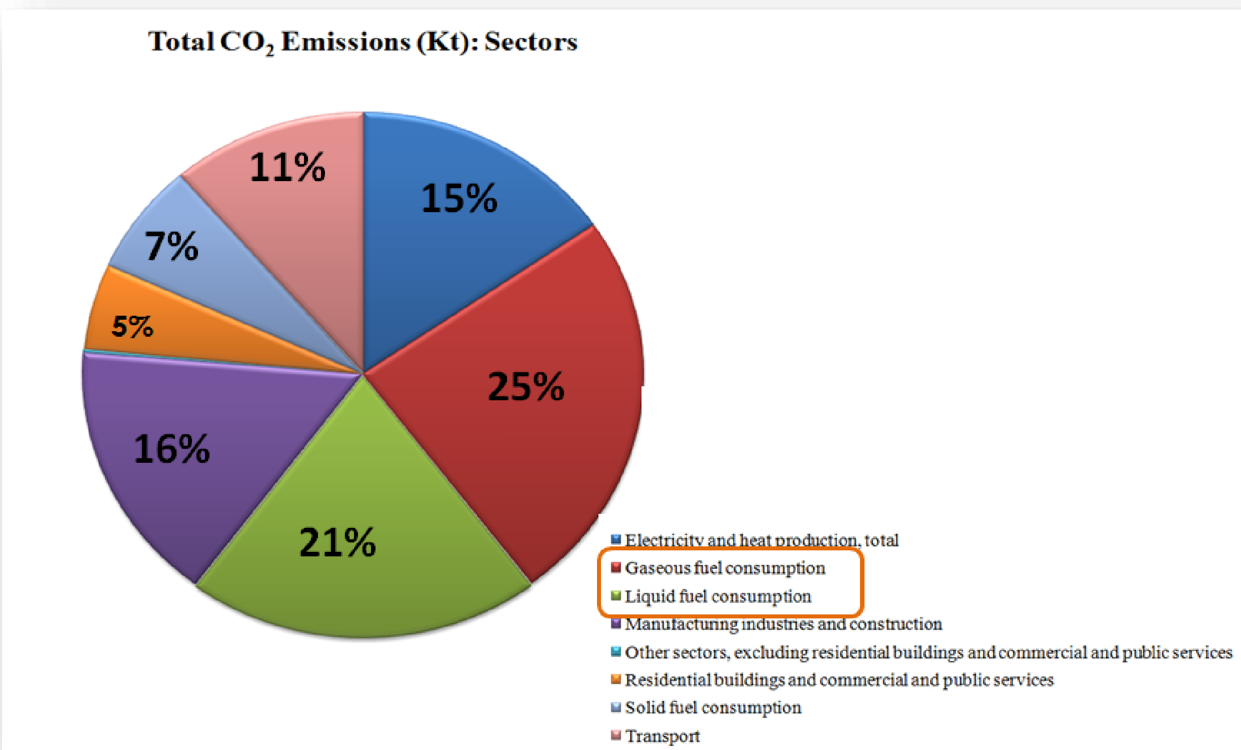

Figure 4.14: Sector wise Distribution of CO_2 Emissions

4.5.2 Comparison of Total Fossil Fuel Consumption and Total Carbon dioxide Emissions

Total CO_2 emissions in Pakistan during 2003 – 2009 were almost 1809009 Kt from various sectors as mentioned above. The graph below shows an increasing trend in CO_2 emissions during the suggested period.

Year	Total CO_2 Emissions (Kt)
2003	215962
2004	239559
2005	245977
2006	262854
2007	285181
2008	277225
2009	282251
Total	**1809009**

Table 4.4: Total CO_2 Emissions Kt (2003 – 2009)

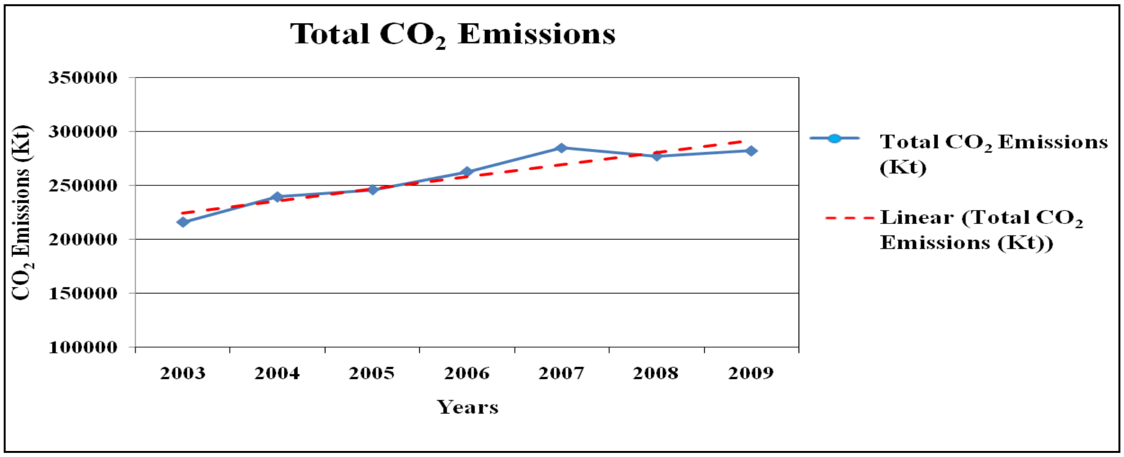

Figure 4.15: Total CO_2 Emissions (2003 - 2009)

According to **Economic Survey of Pakistan 2014**, total fossil fuel consumption during 2003 – 2009 in Pakistan was about 56370784.56 Kt

Year	Total Fossil Fuel Consumption (Kt)
2003	6085305.78
2004	7916422.79
2005	7737625.96
2006	7917601.33
2007	10135629.67
2008	8414517.96
2009	8163681.07
Total	**56370784.56**

Table 4.5: Total Fossil Fuel Consumption Kt (2003 - 2009)

The graph below indicates the increasing trend in the consumption of fossil fuel in Pakistan during 2003 - 2009.

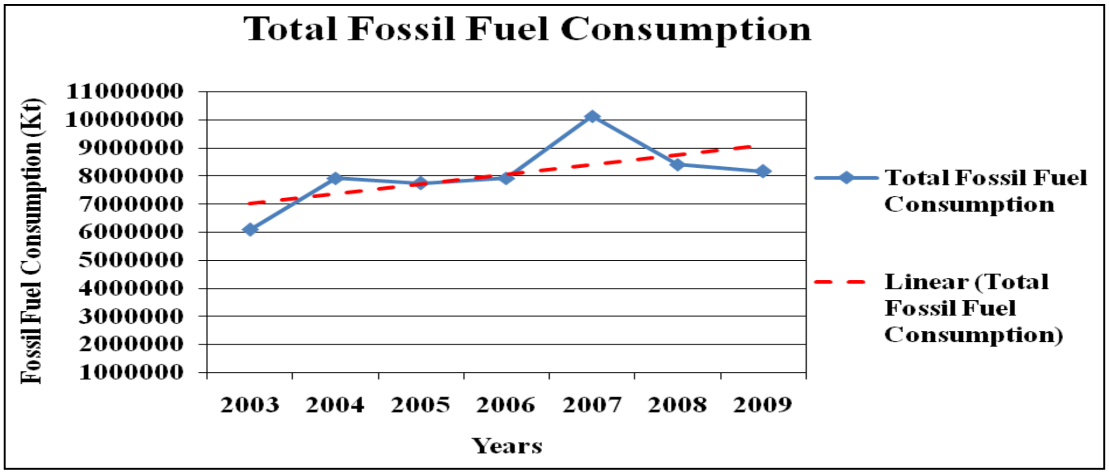

Figure 4.16: Total Fossil Fuel Consumption (2003 - 2009)

Comparison of total fossil fuel consumption and total CO_2 emissions show that during that period both the consumption and emissions increased linearly having correlation coefficient of 0.84 as shown in the figure 4.17. Similarly comparison of total CO_2 emissions, CO_2 emissions from fossil fuel and the atmospheric concentration of CO_2 through satellite analysis all showed positive correlation of 0.92 as indicated in the figures 4.18 and 4.19.

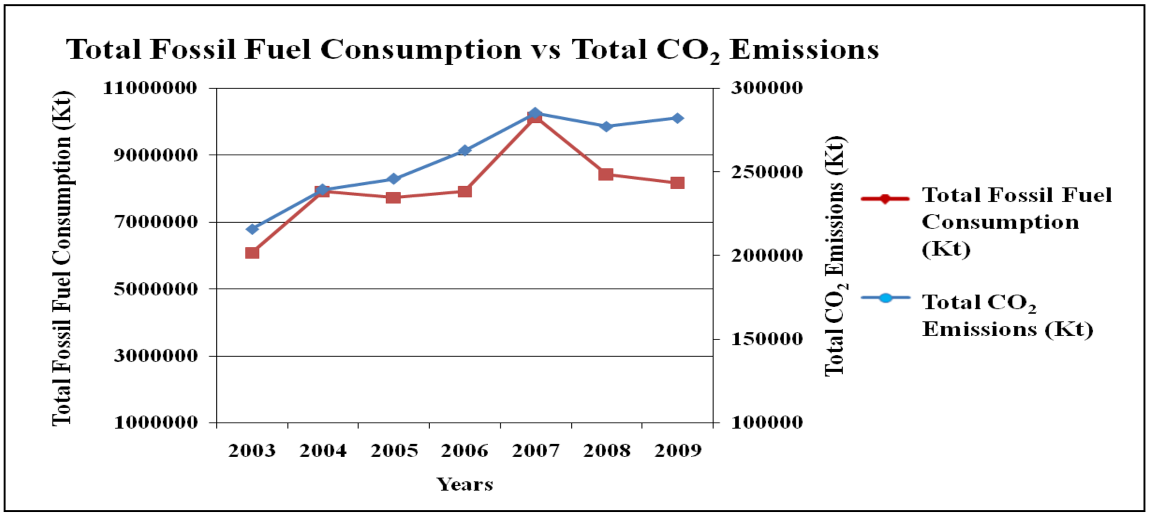

Figure 4.17: Total CO_2 Emissions vs Total Fossil Fuel Consumption (2003 - 2009)

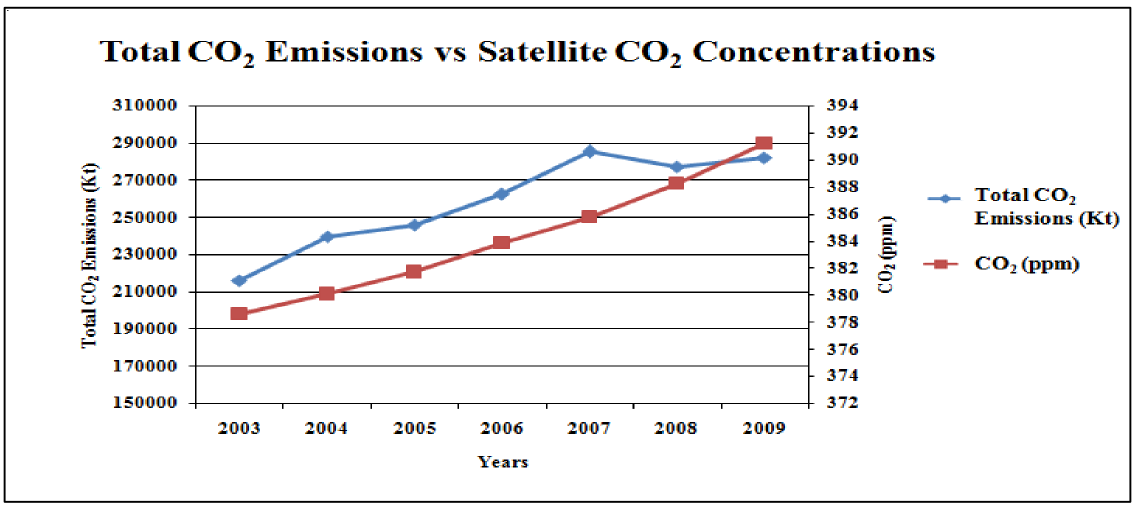

Figure 4.18: Total CO_2 Emissions vs Satellite CO_2 Concentrations (2003 - 2009)

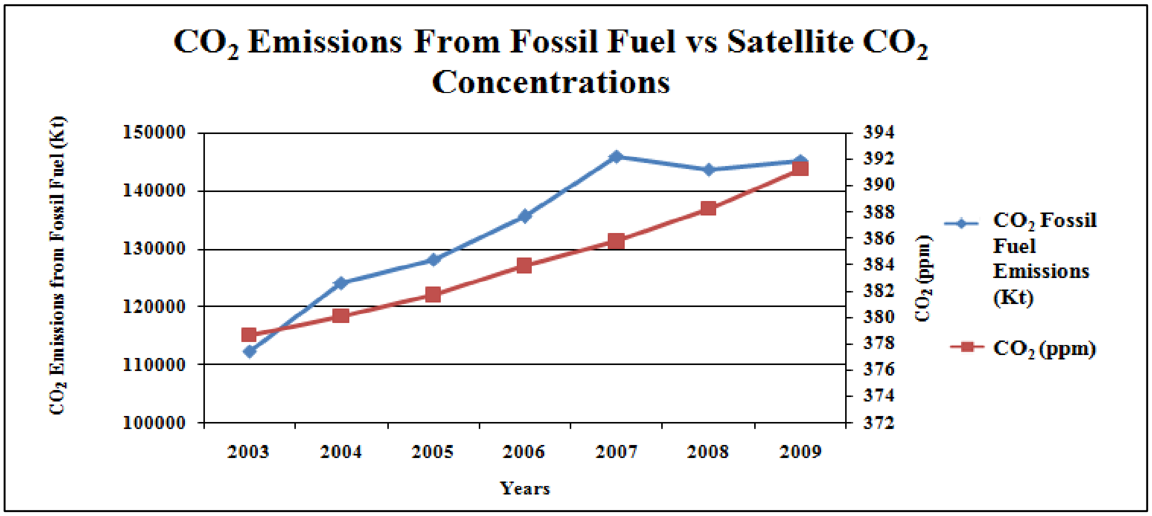

Figure 4.19: CO_2 Emissions from Fossil Fuel vs Satellite CO_2 Concentrations (2003 - 2009)

It is therefore justified that annual increase in CO_2 concentrations over Pakistan during 2003 – 2009 can be attributed to annual increase in the fossil fuel consumption and hence annual increase in the CO_2 emissions from the fossil fuel burning.

4.6 Deforestation and Increase in Carbon dioxide Concentrations

Forests play an important role in the uptake of carbon emissions. About 33% of CO_2 emissions are absorbed by the forests (Parry et al., 2007). Based on the recommendations of IPCC, besides lowering fossil fuel emissions, forest degradation and land use changes must be accounted for (Munawar et al., 2015). The analysis of hotspot regions in Pakistan clearly indicated marked increase in the amount of CO_2 in the KPK region of Pakistan from 2003 – 2009. This can be related to the rate of deforestation in that particular region. In Pakistan an area of almost 4.6 million hectares is occupied by the forests. Of this 40 % is found in the KPK province, 15.7% in Northern areas and 6.5 % in Azad Kashmir (Tariq et al., 2015). Pakistan is ranked second in terms of deforestation rate around the globe which is 4.6 % per annum and the conifer forests which are found in the KPK province, Azad Kashmir and Northern areas is declining at the rate of 1.27%

(Ahmad et al., 2012; Khan et al., 2009). A Study conducted in Pakistan shows that the major cause of extensive deforestation in Khyber Pukhtunkhwa is to meet household needs such as cooking and heating purposes, for making furniture, etc. Moreover black marketing and stake holders on these forests are also aggravating the situation. Meanwhile the ineffective management and ignorance of the forest department is another contributing factor in enhancing the rate of deforestation in that region apart from inefficient grazing patterns followed in the region. Therefore, deforestation which has reached to the level of 14.7% since 1990 till 2005, results in biomass burning of wood thus increasing the CO_2 concentrations in the atmosphere above those regions (Tahir et al., 2010).

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the above mentioned results and discussion it can be implied that during the period of 7 years from 2003 to 2009, the concentration of CO_2 increased with the absolute change of 13.2 ppm and total relative change of 3.32% over seven years. Monthly analysis delineates the increasing trend in seven years where average maxima lies at 391.2 ppm an average minima lies at 378 ppm of CO_2. It has been observed that the summer decrease and winter increase has also shown an increasing trend indicating increase in amplitude of the CO_2 concentration. Climatological analysis show the inter annual variation of carbon dioxide concentration where in spring season the maxima is reached in the months of April and May. After reaching maxima it starts declining and reaches the fall minima in the months of August and September. The results also indicate an absolute increase of 13.3 ppm in minima and 12.4 ppm in maxima with respect to concentration of CO_2 during the period of 7 years over Pakistan. The results show an increase in the amplitude of WI from approximately 9.01 ppm in 2003 to 12.91 ppm in 2008 whereas average increase during 2003 – 2009 is **9.538035 ppm**. The results also indicate and increase in SD which was 6.7 ppm in 2003 and 9.7 ppm in 2008 and the average increase during 2003 – 2009 is **7.242806 ppm**.

Variation of CO_2 and Temperature show increase in annual concentration of both indicated by the positive correlation of 0.054. This confirms the warming effect caused by the CO_2 emissions in the atmosphere. Monthly comparisons also present seasonal oscillations between both the variables which can be closely observed in the climatological cycle.

It was found that the annual increase in the amount of CO_2 over Pakistan from 2003 - 2009 was linked to the increase in fossil fuel emissions during the suggested period. Comparison of total fossil fuel consumption and total CO_2 emissions show that during that period both the consumption and emissions increased linearly having correlation coefficient of 0.84. Similarly comparison of total CO_2 emissions, CO_2 emissions from fossil fuel and the atmospheric concentration of CO_2 through satellite analysis all showed positive correlation of 0.92.

The hotspot analysis of the districts of Pakistan revealed increased amounts of CO_2 in the province of KPK, northern areas and AJK. Particularly in the province of KPK, District Gilgit, concentration of carbon dioxide greater than 400 ppm was observed. Such an increase in the northern region can be attributed to deforestation as a result of biomass burning thus releasing CO_2 in the atmosphere. This also causes reduction in the sinks available for CO_2 fixation.

5.2 Recommendations

Following are the recommendations which can be observed in order to expand the current research:

- The analysis can be further expanded by retrieving data post 2009.
- Data sets from different satellites like with that of GOSAT can also be compared.
- Land use change pattern including change in vegetation and deforestation can also be analyzed in detail using satellite datasets to find out its impact on the increasing concentration of CO_2.

Chapter 6

REFERENCES

Adams, J. M., & Piovesan, G. (2005). Long series relationships between global interannual CO_2 increment and climate: Evidence for stability and change in role of the tropical and boreal-temperate zones. Chemosphere, 59(11), 1595-1612.

Ahmad, S. S., Abbasi, Q., Jabeen, R., & Shah, M. T. (2012). Decline of conifer forest cover in Pakistan: a GIS approach. Pak. J. Bot, 44(2), 511-514.

Alexiadis, A. (2007). Global warming and human activity: A model for studying the potential instability of the carbon dioxide/temperature feedback mechanism. Ecological Modelling, 203(3), 243-256.

Ali, J., Benjaminsen, T. A., Hammad, A. A., & Dick, Ø. B. (2005). The road to deforestation: An assessment of forest loss and its causes in Basho Valley, Northern Pakistan. Global Environmental Change, 15(4), 370-380.

Andres, R. J., Boden, T. A., Bréon, F. M., Ciais, P., Davis, S., Erickson, D., ... & Treanton, K. (2012). A synthesis of carbon dioxide emissions from fossil-fuel combustion. Biogeosciences.

Archer, D., & Brovkin, V. (2008). The millennial atmospheric lifetime of anthropogenic CO2. Climatic Change, 90(3), 283-297.

Bacastow, R. B., Keeling, C. D., & Whorf, T. P. (1985). Seasonal amplitude increase in atmospheric CO_2 concentration at Mauna Loa, Hawaii, 1959–1982. Journal of Geophysical Research: Atmospheres (1984–2012), 90(D6), 10529-10540.

Bergeron, O., & Strachan, I. B. (2011). CO_2 sources and sinks in urban and suburban areas of a northern mid-latitude city. Atmospheric Environment, 45(8), 1564-1573.

Boden, T.A., G. Marland, and R.J. Andres. (2010). Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

Chaudhry, Q. U. Z., Mahmood, A., Rasul, G., & Afzaal, M. (2009). Climate change indicators of Pakistan. Pakistan Meteorological Department, Islamabad. Technical Report No. PMD-22/2009, 1-43.

Ciais, P., Denning, A. S., Tans, P. P., Berry, J. A., Randall, D. A., Collatz, G. J., ... & Heimann, M. (1997). A three-dimensional synthesis study of δ18O in atmospheric CO_2: 1. Surface fluxes. Journal of Geophysical Research: Atmospheres (1984–2012), 102(D5), 5857-5872.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., ... & Thornton, P. (2014). Carbon and other biogeochemical cycles. In Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 465-570). Cambridge University Press.

Collins, M., Knutti, R., Arblaster, J., Dufresne, J., Fichefet, T., Friedlingstein, P., ... & Wehner, M. (2013). Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Long-term Climate Change: Projections, Commitments and Irreversibility, Cambridge Univ. Press, Cambridge, UK, and New York.

DeFries, R. S., Field, C. B., Fung, I., Collatz, G. J., & Bounoua, L. (1999). Combining satellite data and biogeochemical models to estimate global effects of human-induced land cover change on carbon emissions and primary productivity. Global Biogeochemical Cycles, 13(3), 803-815.

DeFries, R. S., Houghton, R. A., Hansen, M. C., Field, C. B., Skole, D., & Townshend, J. (2002). Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. Proceedings of the National Academy of Sciences, 99(22), 14256-14261.

Dettinger, M. D., & Ghil, M. (1998). Seasonal and interannual variations of atmospheric CO_2 and climate. Tellus B, 50(1).

Eby, M., Zickfeld, K., Montenegro, A., Archer, D., Meissner, K. J., & Weaver, A. J. (2009). Lifetime of anthropogenic climate change: millennial time scales of potential CO_2 and surface temperature perturbations. Journal of Climate, 22(10), 2501-2511.

Economic Survey of Pakistan 2014.

Edward R. Long,Longhill Technologies inc.A Study of Mauna Loa Seasonal Variation of CO_2 Concentration. Available at virginiaclimate.polyrad.net/AStudyOfMLOSeasonalVariationOfCO2Concentration.

Ehhalt, D., Prather, M., Dentener, F., Derwent, R., Dlugokencky, E. J., Holland, E., ... & Pickering, K. (2001). Atmospheric chemistry and greenhouse gases (No. PNNL-SA-39647). Pacific Northwest National Laboratory (PNNL), Richland, WA (US).

Farquhar, G. D., Lloyd, J., Taylor, J. A., Flanagan, L. B., Syvertsen, J. P., Hubick, K. T., ... & Ehleringer, J. R. (1993). Vegetation effects on the isotope composition of oxygen in atmospheric $C0_2$. Nature, 365, 368.

Ghommem, M., Hajj, M. R., & Puri, I. K. (2012). Influence of natural and anthropogenic carbon dioxide sequestration on global warming. Ecological Modelling, 235, 1-7.

Green House Gases. (2012). www.epa.gov/climatechange/pdfs/CI-greenhouse-gases-2012.pdf.

Houghton, R. A. (1999). The annual net flux of carbon to the atmosphere from changes in land use 1850–1990. Tellus B, 51(2).

House, J. I., Colin Prentice, I., & Le Quéré, C. (2002). Maximum impacts of future reforestation or deforestation on atmospheric CO_2. Global Change Biology, 8(11), 1047-1052.

Idso, C. D., Idso, S. B., & Balling, R. C. (1999). The relationship between near-surface air temperature over land and the annual amplitude of the atmosphere's seasonal CO_2 cycle. Environmental and Experimental Botany, 41(1), 31-37.

Joos, F., Roth, R., Fuglestvedt, J. S., Peters, G. P., Enting, I. G., Bloh, W. V., ... & Weaver, A. J. (2013). Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis. Atmospheric Chemistry and Physics, 13(5), 2793-2825.

Kane, R. P., & De Paula, E. R. (1996). Atmospheric CO_2 changes at Mauna Loa, Hawaii. Journal of atmospheric and Terrestrial Physics, 58(15), 1673-1681.

Keeling, C. D., Bacastow, R. B., Bainbridge, A. E., Ekdahl, C. A., Guenther, P. R., Waterman, L. S., & Chin, J. F. (1976). Atmospheric carbon dioxide variations at Mauna Loa observatory, Hawaii. Tellus, 28(6), 538-551.

Khan, B., & Baig, M. A. (2004). Pakistan: preliminary national greenhouse gas inventory. Journal of Applied Sciences and Environmental Management, 7(2), 49-54.

Khan, N. (2010). Marine resources in Pakistan: A tentative inventory. Market Report, 834.

Khan, S. R., & Khan, S. R. (2009). Assessing poverty–deforestation links: Evidence from Swat, Pakistan. Ecological Economics, 68(10), 2607-2618.

Kumar, K. R., Revadekar, J. V., & Tiwari, Y. K. (2014). AIRS retrieved CO_2 and its association with climatic parameters over India during 2004–2011.Science of the Total Environment, 476, 79-89.

Liu, H., & Rodríguez, G. (2005). Human activities and global warming: a co integration analysis. Environmental Modelling & Software, 20(6), 761-773.

Lloyd, J., & Farquhar, G. D. (1996). The CO_2 dependence of photosynthesis, plant growth responses to elevated atmospheric CO_2 concentrations and their interaction with soil nutrient status. I. General principles and forest ecosystems. Functional Ecology, 4-32.

Mustafa, Z. (2011). Climate Change and its impact with special focus in Pakistan. In Pakistan Engineering Congress, Symposium (Vol. 33).

Olivier, J. G. (2012). Trends in global CO_2 emissions: 2012 Report (p. 40). Hague: PBL Netherlands Environmental Assessment Agency.

Olivier, J. G. J., & Peters, J. A. H. W. (2010). No growth in total global CO_2 emissions in 2009. Netherlands Environmental Assessment Agency (PBL).

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & van Vuuren, D. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Rafelski, L. E., Piper, S. C., & Keeling, R. F. (2009). Climate effects on atmospheric carbon dioxide over the last century. Tellus B, 61(5), 718-731.

Randerson, J. T., Thompson, M. V., Conway, T. J., Fung, I. Y., & Field, C. B. (1997). The contribution of terrestrial sources and sinks to trends in the seasonal cycle of atmospheric carbon dioxide. Global Biogeochemical Cycles,11(4), 535-560.

Raupach, M. R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J. G., Klepper, G., & Field, C. B. (2007). Global and regional drivers of accelerating CO_2 emissions. Proceedings of the National Academy of Sciences, 104(24), 10288-10293.

Sajjad, S. H., Blond, N., Clappier, A., Raza, A., Shirazi, S. A., & Shakrullah, K. (2010). The preliminary study of urbanization, fossil fuels consumptions and CO_2 emission in Karachi. African Journal of Biotechnology, 9(13), 1941-1948.

Sawa, Y., Machida, T., & Matsueda, H. (2012). Aircraft observation of the seasonal variation in the transport of CO_2 in the upper atmosphere. Journal of Geophysical Research: Atmospheres (1984–2012), 117(D5).

Schimel, D. S. (1995). Terrestrial ecosystems and the carbon cycle. Global change biology, 1(1), 77-91.

Shim, C., Lee, J., & Wang, Y. (2013). Effect of continental sources and sinks on the seasonal and latitudinal gradient of atmospheric carbon dioxide over East Asia. Atmospheric Environment, 79, 853-860.

Siegenthaler, U., & Sarmiento, J. L. (1993). Atmospheric carbon dioxide and the ocean. Nature, 365(6442), 119-125.

Sirignano, C., Neubert, R. E. M., Rödenbeck, C., & Meijer, H. A. J. (2010). Atmospheric oxygen and carbon dioxide observations from two European coastal stations 2000–2005: continental influence, trend changes and APO climatology. Atmospheric Chemistry and Physics, 10(4), 1599-1615.

Sivakumar, M. V., & Stefanski, R. (2011). Climate Change in South Asia. In Climate change and food security in South Asia (pp. 13-30). Springer Netherlands.

Solomon, S., Plattner, G. K., Knutti, R., & Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. Proceedings of the National Academy of Sciences, 106(6), 1704-1709.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., ... & Midgley, B. M. (2013). IPCC, 2013: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.

Sundquist, E. T. (1990). Influence of Deep-Sea Benthic Processes on Atmospheric CO_2. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 331(1616), 155-165.

Tahir, S. N. A., Rafique, M., & Alaamer, A. S. (2010). Biomass fuel burning and its implications: deforestation and greenhouse gases emissions in Pakistan. Environmental Pollution, 158(7), 2490-2495.

Tariq, M., & Aziz, R. (2015). An overview of deforestation causes and its environmental hazards in Khyber Pukhtunkhwa. Journal of Natural Sciences Research, 5(1), 52-57.

Tariq, M., Rashid, M., & Rashid, W. (2014). Causes of deforestation and climatic changes in Dir Kohistan. Journal of Pharmacy and Alternative Medicine, 3(2), 28-37.

Team, C. W., Pachauri, R. K., & Reisinger, A. (2007). Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland.

Van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G., Kasibhatla, P. S., Jackson, R. B., ... & Randerson, J. T. (2009). CO_2 emissions from forest loss. Nature geoscience, 2(11), 737-738.

Walker, J. C., & Kasting, J. F. (1992). Effects of fuel and forest conservation on future levels of atmospheric carbon dioxide. Global and Planetary Change,5(3), 151-189.

Waring, R. H., Landsberg, J. J., & Williams, M. (1998). Net primary production of forests: a constant fraction of gross primary production?. Tree Physiology,18(2), 129-134.

Zimov, S. A., Davidov, S. P., Zimova, G. M., Davidova, A. I., Chapin, F. S., Chapin, M. C., & Reynolds, J. F. (1999). Contribution of disturbance to increasing seasonal amplitude of atmospheric CO_2. Science, 284(5422), 1973-1976.