EFFECTS OF INFRASTRUCTURE DEVELOPMENT ON THE CLIMATE OF ISLAMABAD

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This thesis is dedicated to my parents for their unconditional love and support;

And to all the experts who made this possible, especially to my supervisor Mr Khubaib Abuzar for his guidance at every step

Abstract

Climate change is one of the most important phenomenon occurring all over the world. Pakistan is not exempted from these changes as the clear sign and symptoms are being observed over the recent years like extreme weather conditions, increase in the average temperatures as well as maximum temperatures and changes intensity, frequency and patterns of precipitation. Over the years, Pakistan has faced rapidly growing economy and population, resulting in urbanization. The lack of urban planning in various cities has taken a heavy toll on natural resource management resulting in the distortion of the natural balance of the environment. Islamabad is one of the most cosmopolitan cities and is the Federal Capital of the country. The urbanization of Islamabad has increased dramatically since it was developed in the 1960s. The urbanization of Islamabad and its effects on the climate has been studied with the help of temperature and precipitation analysis over the past 30 years. Further, the classification of Landsat MSS satellite images have been carried out to show temporal and spatial changes. Results have shown an increase of urban development by 44% mainly due to the increase in population and economic constraints to accommodate this increasing population. The microclimate of Islamabad has also changed with annual rainfall shifts showing extremes in drought and rainfall.

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ABBREVIATIONS

CO_2	Carbon dioxide
CH_4	Methane
EPA	Environment Protection Agency
ESRL	Earth Systems Research Laboratory
GIS	Geographic Information Systems
GHG	Greenhouse Gases
NARC	National Agriculture Research Centre
NOAA	National Oceanic and Atmospheric Administration
N2O	Nitrous Oxide
O_3	Ozone
PE	Precipitation Effective Index Unit
PMD	Pakistan Meteorological Department
PPM	Parts Per Million
PARC	Pakistan Agriculture Research Council
SPOT	Systeme Pour Observation Terre
SPM	Suspended Particulate Matter
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

CHAPTER 1

Introduction

1. INTRODUCTION

1.1 Background of the study

Climate change is one of the most important phenomenons being carried out all over the world. It is proved as being the amalgamation of various anthropogenic and natural factors resulting in the deterioration of the environment in many countries. Similarly, Pakistan is experiencing many climatic changes, such as extreme weather conditions, increase in average temperatures and changes in precipitation patterns.

There has been a noticeable change in the climate of the region in which Pakistan is located, but instead of a general warming of about 0.1 to 0.3^{0}C and lowering of rainfall, a reverse trend has been observed. The meteorological data available from 11 observatories in Pakistan indicate a general cooling by 0.1 to 0.3^{0}C at the stations of rural towns and a warming of 0.7^{0}C at the stations of the cities during the last four decades. Precipitation has in general increased at a number of locations by 10 to 30% during the same period. 'Abrupt' climate change, like 'dangerous' climate change, has been much discussed, but infrequently defined and only superficially analyzed. (Hulme, 2003)

The main cause of climate change is believed to be unplanned and rapid urbanization, often referred to as the ‘urban sprawl’. In today's globalized world, cities no longer stand apart as islands. They are the centre of commerce, gateways to the world knotted together in a widespread network of communication and transportation systems. Cities are concentrations of energy in a global field.(Nations, 2001)

1.2 Land use and Climate Change

Climate change and its relationship with land use continue to be a controversial debate. However, many factors such as deforestation, agriculture, urban sprawl and many human influences have fragmented the climate. The 1992 United Nations Framework Convention on Climate Change (UNFCCC) defines “climate change” as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere. . . ” On the other hand, the Intergovernmental Panel for Climate Change describes it in the more broader sense by including land use change as a major factor. Many studies showing the changes in the forest cover have had various consequences in the climate of a region, for example in the Amazon Basin.(Marland, 2003)

Pakistan over the years has faced rapidly growing economy and population, resulting in urbanization. The lack of urban planning in cities has taken a toll on the natural resources and caused severe deterioration of the natural balance of the environment. These consequences are only evident during the time of climate stresses, such as extended droughts or disastrous floods. This lack of management of natural resources and urban planning along with high growth in population is the main causes for the deterioration of Pakistan’s natural resources. (Arfan, 2008)

1.3 Study Area

Islamabad one of the most cosmopolitan city of the country is the Federal Capital of the Islamic Republic of Pakistan. The city was built between 1960 - 1970 by the vision of President Ayub Khan (1907–1974) to make the capital of Pakistan approachable, safe and well planned with equal distribution of development. Hence, Islamabad, a new capital of Pakistan was conceived in 1959, planned from 1959 to 1963 by a Greek architect-planner C. A. Doxiadis, and started implementation in

1961.(Imran, 2006) Islamabad is one of the greenest and most well-planned cities of South Asia.(city of Islamabad 2010)

Geographically, Islamabad is located in the north east of Pakistan on the Potohar Plateau, covering a total area of 906.5 km^2 (from 33°40'N to 73°10'E) at the foothills of the Himalayas 1600-1900 ft above sea level. Moreover, set along side are the beautiful Margalla hill range, giving Islamabad not only aesthetic beauty but a very pleasant climate.

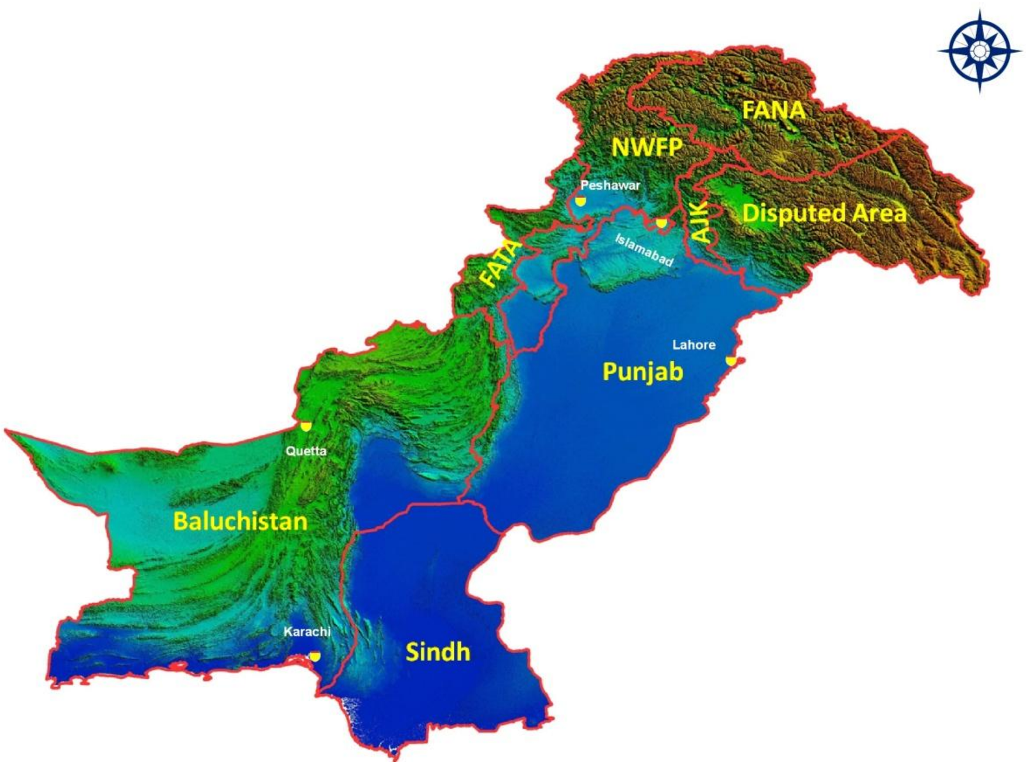

Figure 1.1: Location map of the Study area; Islamabad

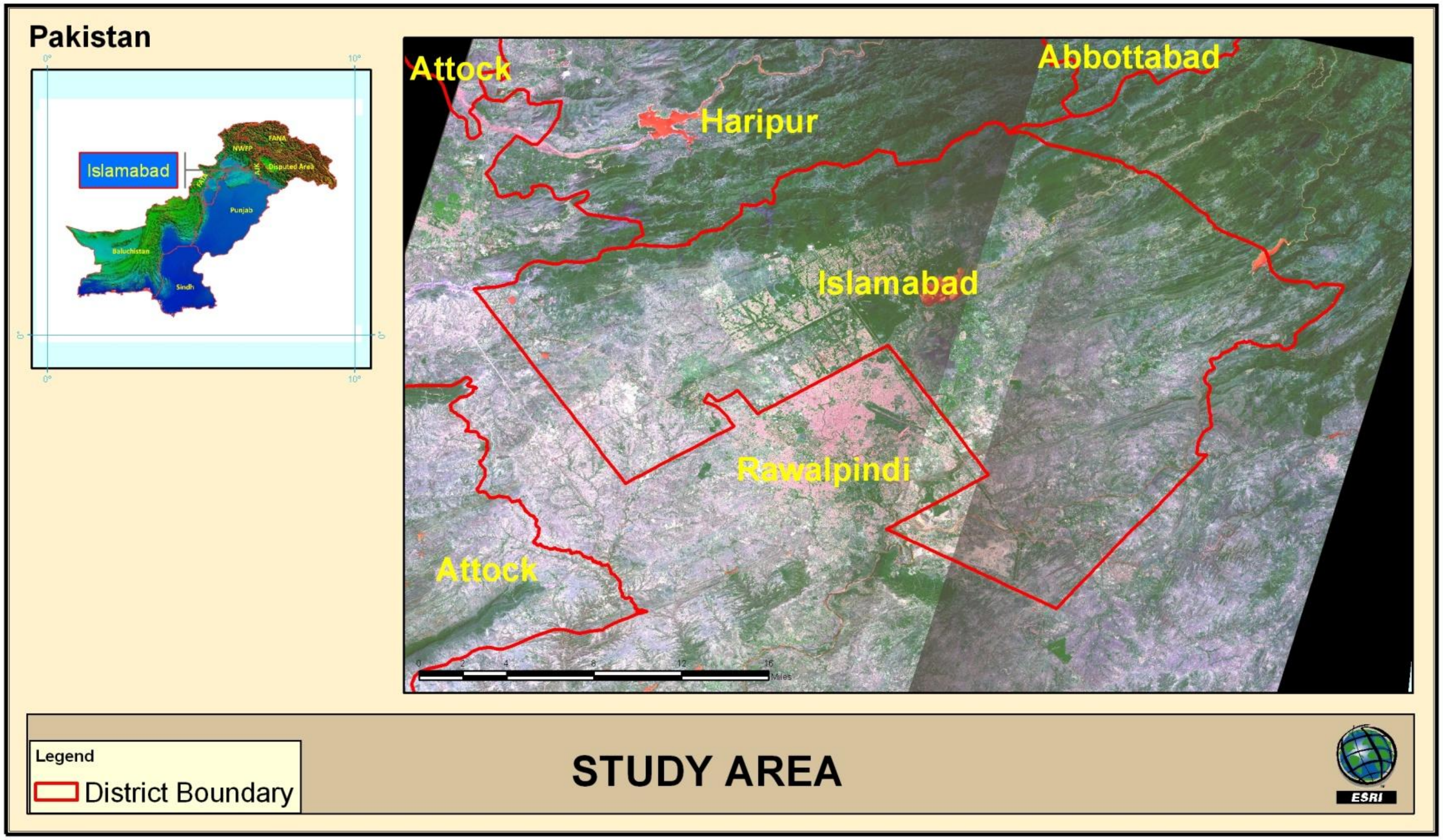

Figure 1.2: Study Area (Islamabad)

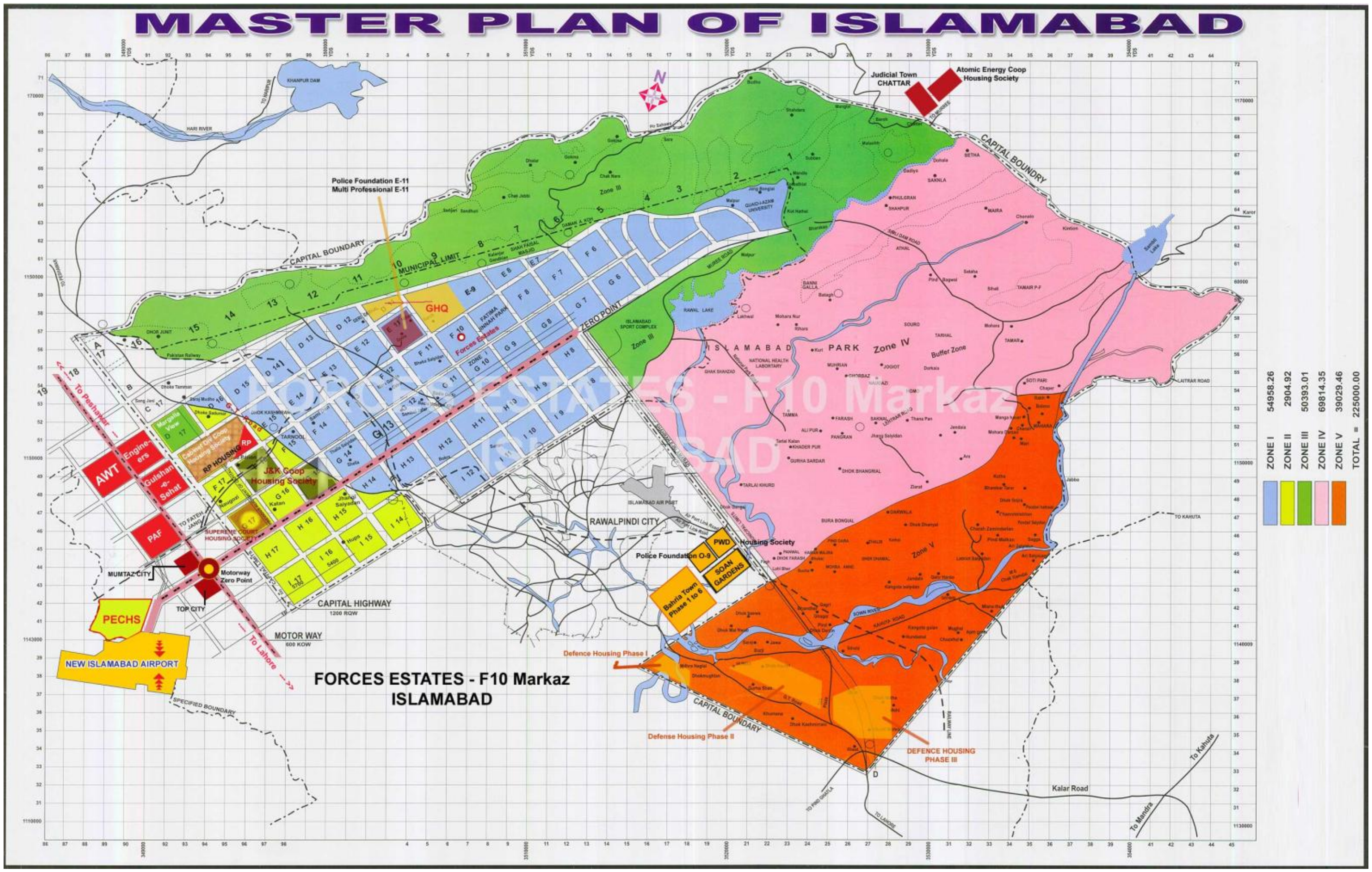

Figure 1.3:- Master Plan of Study Area

1.4 Climate of the chosen area

The geographic positioning of Pakistan on the globe, above the tropic of cancer blesses it with seasonal variations throughout the year.

According to the journal published by Pakistan Meteorological Department (PMD), “Detection of Urban Growth in Islamabad and its Climatic Impacts Using RS and GIS” the analysis of Precipitation- Effectiveness (PE) index values and maps it may be concluded that Pakistan is divided into following climate zones:(Faisal & Sadiq, July 2009)

1. Rain Forest (wet) where PE index value is greater than or equal to 50

2. Forest (humid) where PE index value ranging between 34-49

3. Partly Forest (less humid) PE index values ranging between 20-33

4. Arid (dry) less than 20

Islamabad is present in the Rain Forest zone and due to its geographical position in the northern part of Pakistan experiences cooler climate than the other developed cities of the country. Islamabad is situated approximately 1000 miles from the Arabian Sea, therefore the summers are hotter and winters are cooler. Overall, the city has extreme weather patterns, with hot summers with maximum temperatures reaching 47 C (117 F) in June, heavy monsoon rainfalls from July to August and moderately cold winters, with a minimum of -4C (25 F) in January. (Jamil, 2009)

1.5 Population statistics

According to the population census, the population of Islamabad in 1951 was 95,940 .However, numbers have now shot to 972, 669 in the year 2010.(Nizami, 2009-2010) This is greatly due to the urban expansion and development taking place at a rapid scale. The construction of industries, government offices, private enterprises and residential areas have played a major part in making the community of Islamabad what it is today. In the 50 years of its development, Islamabad has gone from a small under developed area, where only Saidpur Village had a small community structure to a large city with all sorts of enterprises within its vicinity. All these factors have caused a detrimental effect on the environment of Islamabad. Air pollution has started to become an evident concern in the environment of Islamabad, as day by day number of vehicles emitting air pollutants increases. Studies report that the increase in driving will overwhelm the improved fuel efficiency of new vehicles and the lower carbon fuel content. (Leslie, 2009)

According to (Haider, 2006) the year 2030 will serve as a landmark in Pakistan's history. Over the next 25 years, the urban population in Pakistan is likely to increment by 140%. This will add another 80 million to the urban population in Pakistan, bringing the total urban population to a 130 million people. For the first time in 83 years, the urban population in Pakistan will constitute 50% of the total population. From nearly 50 million urbanites today, Pakistan will be home to a massive urban population of 130 million, with one of the largest urban centers in the world.

Moreover, the construction of new roads, highways and buildings have also taken the place of many trees and developed urban heat islands which has altered the microclimate of the city. The number of Suspended Particulate Matter (SPM) at two sample points in Islamabad (Abpara Chowk and I-9) summed up to an average day data of 520 SPM. ((PAK-EPA, 2001)

A comprehensive collection of temporal data about the effects of urban development on climate and meteorology of cities is important so that further developmental efforts can be appropriately planned.

1.6 Environment

Islamabad is a considerable green city but over the past year the microclimate of Islamabad has deteriorated. The weather is mostly pleasant with temperatures ranging from 3.95 to 38.4^{o}C at an average through out the year. The city overall has an extreme climate with hot summers with monsoon rains occurring during July and August, and fairly cold winters.

1.7 Urbanization of Islamabad

The urbanization of Islamabad has increased dramatically since it was developed in the 1960s. Now Islamabad has become a metropolitan city with a growing population and various new projects are being implemented by the Capital Development Authority. Few of the recent projects included the development of three highways, overhead bridges and different underpasses connected the busiest areas of Islamabad to reduce the increasing traffic load in the city. Moreover, international investments in the form of “Centaurus” and business plazas have also lead to the rapid development of this small city. Along with the center of the city

(Blue Area) the outskirts have also faced rapid developments. The reconstruction of the Islamabad Highway became inevitable after the mushrooming of various housing societies along the highway and areas joining Rawalpindi. Loi Bher Forest is situated along Islamabad Highway and approximately 16 km away from Rawalpindi. A Survey of early 70'sindicates the total area of 1087 acres whereas in 2000 the forest area decreased to 594 acres only. (Naseem, Tubussum, & Shah, 2000)

CHAPTER 2
Literature Review

2. LITERATURE REVIEW

Considerable research has been carried on the effect of urbanization on climate, the relationship of vegetation and climate, and the overall changes in land use and land cover but temporal analysis specifically of Islamabad has not been extensively carried out.

According to the World Bank Development Report 2010(World Bank, 2010), the link between climate change and development must be thoroughly understood. These changes in climate have not only been faced by us today but in 2200 BC the reduction in Indian Monsoon rains and Mediterranean westerly winds caused a 300 year drought over the Aegean Sea and Indus River. This change in climate brought down Egypt's pyramid-building Old Kingdom and Sargon the Great's empire in Mesopotamia. Societies have always been dependent on climate but are now realizing that the climate is dependent on their actions. The increment in greenhouse gases since the Industrial Revolution has morphed the relationship between people and environment. Not only is climate dependent on development, but development is also dependent on climate.

The ill management of resources and planning for development will have a negative impact on countries in the near future. The earth will get warmer and impacts will be felt everywhere, especially in developing countries. Coastal areas from Florida to Bangladesh will face the trouble of increasing sea levels, inundating settlements and contamination of freshwater, Africa and semi arid areas will face extreme droughts, while the disappearing Himalayan and Andean glaciers will threat rural livelihoods and major food markets along with frequent floods at low areas. The window of opportunity to choose the right policies to deal with climate change and promote development is closing. The further countries go along current emissions trajectories, the harder it will be to reverse course and alter infrastructures, economies, and lifestyles.

2.1 Urban Sprawl

The migration of people from rural to urban areas has increased the demand for residential areas, hence causing an "urban sprawl". Urban sprawl is a consequence for the demand of space for the increasing population to form settlements on the outskirts of cities. During this, agricultural land and forests are consumed for the purpose of supporting societies threatening the ecosystem of the area. Due to these changes, the climate has started to change abruptly, with extreme temperatures and precipitation patterns. Such abrupt climatic changes have affected much of the earth with changes reaching to an astounding $10^{o}C$ in 10 years! Evidence shows that climate changes in the near future are expected and will affect societies and ecosystems the most. (Committee on Abrupt Climate Change, 2005)

One such example of an abrupt climatic change was the large change in precipitation experienced by the Sahel region of Africa during the middle decades of the twentieth century. There was a sudden increase in precipitation between the 1920s and 1950s followed by a decrease in precipitation by 30% from the 1960s to the 1980s. (Hulme, 2003)

Hence, the biggest question arises; can these societies cope with the abrupt climatic changes? According to Mike Hulme (Hulme, 2003) much discussion about climate change has been going on in the media, where the connection between human perturbation of the climate system and climate change has not been much focused on except for those who want early mitigation methods. Surprisingly, very less work has been done for the evidence of human influences on the environment, however, recent studies by Gbnopolski & Rahmstorf has shown that greenhouse gas emissions by humans has potentially triggered climatic changes. Quoting a study by Rahmstorf, Mike Hulme writes that “abruptness” should be defined as the non linear behavior of climate and related to threshold limits rather than being defined by rate of change or magnitude. However, this definition cannot be used to analyze social and ecological impacts caused through anthropogenic means.

2.2 Abrupt Climate Change and Vegetation

Another example of abrupt climate change was the severe flood on Central Europe in 2002. It affected large areas of Southeastern Germany, Czech Republic and Hungary(Hulme, 2003). Floods are undoubtly the consequence of Thermohaline Circulation but are also propagated by the changes in temperature, precipitation, melting of glaciers and increase in solar radiation. The collapse of Thermohaline Circulation can have adverse effects on the earth, by destroying ecosystems, fisheries and decreasing agricultural yields(Hulme, 2003).

Climate change has a detrimental effect on the existing forests and small vegetation. According to the objective of the United Nations Framework Convention on Climate Change (UNFCCC) greenhouse gases due to anthropogenic activities have to be stabilized to a level which is harmless to the existing global system(Marko Scholze, 2006) . The world’s forests affect the climate physically, biologically and chemical with the help of various natural processes which keep the natural balance of the system by controlling planetary energetic, hydrological cycles and atmospheric compositions. Tropical forests mitigate warming through evaporative cooling, but the low albedo of boreal forests is a positive climate forcing. Tropical forests also maintain soil moisture, soil humidity, reduce sunlight intensity, weaken harsh winds and inhibit anaerobic soil conditions.(PIELKE, June 2002)

However, now due to rapid deforestation, the natural sinks for atmospheric pollutants have been reduced alarmingly.

Moreover, it has been stated that changes in the land cover provides a major forcing towards climate change. Major global radioactive forcing takes place due to release of anthropogenic aerosols, greenhouse gases and solar variation. Changes in vegetation can change the surface heat flux directly.

2.3 Greenhouse Gases

Recent greenhouse gas (GHG) emissions have placed the Earth close to dramatic climate change that could run out of our control. Carbon dioxide (CO_2) being the greatest gas promoting a positive climate forcing along with other trace gases such as Nitrous oxide(N_2O), ozone (O_3) and methane (CH_4). Methane is the second largest greenhouse gas being emitted by human activities and works in the same way as CO_2 in trapping heat underneath the Earth's atmospheric layers and is the principal cause of tropospheric ozone; the third largest GHG.(Hansen, 2007)

Carbon dioxide is emitted in numerous ways and in millions of tons every second on Earth. Its primary sources consist of fossil fuel burning for the production of energy in factories, industries and automobiles. Naturally it is emitted in the carbon cycle, a very essential balance of nature. Carbon dioxide can be removed in the atmosphere by the oceans, dense forests and through animal respiration which act as natural carbon sinks. After the industrial revolution in 1700s, the production and release of carbon dioxide into the atmosphere accelerated immensely, a trend that is still seen today and because of which the climate of the Earth is changing dramatically. (U.S. Environmental Protection Agency) The current levels of carbon dioxide has been measured to 390.9 ppm (parts per million) in July 2010 by Earth Systems Research Laboratory (ESRL) / National Oceanic and Atmospheric Administration (NOAA)

(CO2now). These measurements have also been supported by NASA which have shown graphically a steep increment of carbon dioxide levels from 1950 (280ppm) to 2010 (390 ppm).

2.4 Urbanization and Its Effects

Landuse or urbanization has become a considerable issue for the environment. In order to cater for the ever increasing population of the Earth, many croplands, farmland, water ways, forests and green pastures have been converted into built areas to provide shelter to more than six billion people(Foley, 2005).

A case study carried out in Kaduna Town in Nigeria by Ishaya, S. *et.al* showed the use of GIS and remote sensing as a tool to represent the changes in landuse and landcover due to development in the form of urbanization in the town. According to the study, Urbanization has lead to the birth of various problems in cities such as, congestion, poor housing, and crowded transportation, lack of basic services, ill health, low educational status and high unemployment. Moreover, these have been accelerated due to the ill planning of town planners, poor urban planning and uncontrolled landuse, lack of financial resources and inadequate investment in environmental management is leading to the increase urban area coverage causing more impact on the environment. Activities of man such as farming, logging, grazing, hunting, urbanization and other development activities induced by the rapidly increasing population have together reduced natural vegetation cover to patches on the surface of the earth. The loss of natural vegetation has great implications such as destruction of wildlife habitat, depreciation or outright wiping off of genetic pool, loss of food and medicinal herbs and promotion of desertification and drought among others, building up of green house gasses. The study revealed that there has been a rapid transformation of green land to built up area in Kaduna, Vegetation is lost at a rate of 297.5 ha and built up area increased at 167.86 ha annually(Ishaya, 2008).

The human domination of the Earth is growing substantially with one third to one half of the Earth's land surface transformed by humans for use. The main cause for this transformation is the demand of the increasing population for food and shelter. Agriculture, fishery, building of cities, industry and international commerce has altered the major biogeochemical cycles and added and removed many species on Earth. These changes then bring about a global change effect in the form of climate change and loss of biodiversity. (P.M, 2008)

2.5 Urban Climate

It is estimated that by 2030, 60 percent of the Earth's population would be living in cities, mainly because cities today will have expanded to cater to the increasing population. These will bring about changes in the environment and urban climate. Urban climate is defined as the difference in climate of the city and its adjoining surroundings. The features of urban climate include higher air and surface temperatures, low humidity, changes in radiation balance (solar intensity), and limited atmospheric exchange which will cause a build up of air pollutants. These effects can be local or regional and may even reach to global scales due to the persistence of some substances.

The causes of urban climate include:-

1. Replacement of natural soil by built up areas and sealed surfaces, such as roads, foot paths and pavement etc
2. Reduction in low wave emission by street canyons
3. Reduction in land covered by natural vegetation

4. Release of air, water and land pollutants and heat waves generated by machinery and factories.

However, most importantly the regional and local situation of an area, the infrastructure and local economic structures all contribute in altering the climate.

Materials used in the construction of sealed surfaces and buildings affect the thermal behavior of the sealed surface. The thermal behavior of the sealed surface is determined by the density, heat capacity, thermal conductivity, thermal diffusivity and thermal admittance coefficient of the material used.

The large use of impermeable materials (asphalt, polypropylene and polyester used in construction of roads) in sealing of urban surfaces obstructs the drainage of water from precipitation and run off almost completely, the water collected in storm drains are transferred to underground water sewers in urban cities preventing evaporation, thus reducing the release of heat and making more energy available for low wave emissions, sensible heat flux and conduction to subsurface.

The structure of the urban atmosphere also affects the wind conditions in the area. The roughness of the surfaces effects the wind directions, i.e. the horizontal and vertical wind vectors. Disturbances in the near surface boundary layers can be measured up to 500 m in the urban atmosphere, 400m in suburbs and 300m in the surrounding areas.

The urban atmosphere is formed by four distinct layers;

1. **Urban boundary layer-** Local to meso-scale phenomenon affected by the urban surface, formed when air flows over the city. During the day the total thickness of the layer can reach several hundred meters, however at night the layer is only a few decameters thick.

2. **Urban canopy layer-** The layer of air beneath the mean height of the buildings produced by microscale processes in streets, it is a mixture of different microclimates produced due to the surrounding areas.
3. **Urban plume-** Rising air in the lower altitudes due to urban areas being warmer than surrounding areas
4. **Rural boundary layer-** Air flow over the less developed rural areas produces this layer.

As the wind blows over the rural areas the wind speed is usually lower, on reaching the suburban area, the wind is thrust upwards due to the urban canopy layer and congested building which do not allow the free flow of air in the city (Urban Heat Islands). This thrust of the wind causes an urban plume which rises towards the atmosphere, carrying with it heat and air pollutants, thus creating a local/regional effect of warming. Surface level wind speed is usually higher during the night and in cloudless and cool weather conditions when urban heat islands are high. This phenomenon known as the country breeze and is generated by difference in thermal energy between cities and country side areas. This wind system is very important if applied to urban planning, the effect of urban heat islands can be reduced if air is allowed to circulate freely within the cities (Kuttler, 2008).

2.6 Urban Heat Island and Global Warming

According to the glossary of meteorology, urban heat island (UHI) are defined as areas which are warmer than their surroundings due to human disturbances, for example towns and cities. Heat islands consists of “cliffs” at the urban-rural fringe and a “peak” in the most built up area of the city (Society, 2000)

Urban Heat Island formation takes place due to an amalgam of various driving forces. The changes in natural land covers in the area can alter the rate of evapotranspiration, a mechanism by which heat energy is used by plants to change water into water vapors promoting a cooling effect in the surroundings. An important positive forcing of UHI is the effect of the emission and waste energy by automobiles, industries and buildings. Air conditioning systems also expel waste energy into the atmosphere. All these driving forces result in the increase in the average urban temperature. Urban Heat Island effect depends largely on the area in relevance to its climatological region, urban population and nature of the rural hinterlands.(Ruth, 2006)

2.7 Consequences

Urban heat islands have meteorological and socioeconomic impacts which can be beneficial or detrimental. In winters and cold climates, urban heat islands will reduce the need for heating, decreasing the amount of fuel consumed. The closer the houses the more they protect each other against the weather. However, this advantage is out weighted by the amount of air conditioning required in the summers. (H.E, 1981)

2.8 Geographical Information System (GIS) and Application

Conventional, manual survey methods do not provide the flexibility and cost effective environment guaranteed by geographical information systems. (Gautam, 2002). GIS, integrated with remotes sensing, provides a simple framework for entering, analyzing and displaying data from diverse data sets for activities involving database development, change detection and landscape feature identification(Weng, 2010). A great deal of research trends depend on remote sensing for objective data and GIS for more comprehensive and subjective data for planning and decision making.

While a number of studies have been conducted analyzing the spatial spread of activities such as grazing and crop spread, spatial and temporal analysis particularly depend on the instruments offered by GIS.(Hudak, 1997) One example is the analysis of spatial and temporal changes in landuse between 1978 and 1992 in a typical watershed covering 543 km2 in the Middle Hills of Nepal. The data sets used were landuse maps of 1978 data sets of ground verified aerial photographs of the scale of 1: 50,000 from Land Resources Mapping Project (LRMP) and 1992 data from topographic maps (1:25,000) compiled from 1:50,000 ground-verified aerial photographs. Digitization was performed by ARC INFO. Change layers to observe spatial changes from 1978-1992 were done by overlaying the two map layers. The only constraints to the analysis were the lack of mapping of forestry in the area. As the purpose of the study was to describe the advantages and success of community forestry, forested area between the two time periods was easily shown by GIS map overlay and the limitation of the data did not act as a significant detriment.(Gautam, 2002)

Remote sensing has allowed scientists to analyze the changes in the ecology, landuse and land cover over spatial and temporal changes by using different satellite images having different resolution. It provides information locally and globally for conducting various types of studies. Remote sensing is a widely used source of information which is used to study the effects of many parameters on the landcover of the Earth. Along with this GIS in collaboration with sophisticated software make it possible to pan out a visual representation of changes and provide statistics. Similarly, Remote Sensing and GIS play a very important role in the monitoring of the environment. With the help of these techniques, scientists can study in the changes in weather and climate patterns, location of biodiversity, flora and fauna.

CHAPTER 3

Methodology

3. METHODOLOGY

3.1 Data Acquisition

To carry out the comparative analysis of the effect of infrastructure development on the climate of Islamabad a variegate of satellite images were required. National Agriculture Research Council (NARC) provided Landsat 30m resolution data for the years 1992 and 2000 to carry out this study.

Moreover, the pattern of precipitation and average temperature changes were obtained by the journals of Pakistan Meteorological Department in Islamabad and National Agriculture Research Council. Temperature and precipitation records were taken from year 1954 to 2006. Data for 2007-2009 was provided on a per day basis for each year.

Software used

1. ArcGIS 9.2
2. ERDAS Imagine 8.6

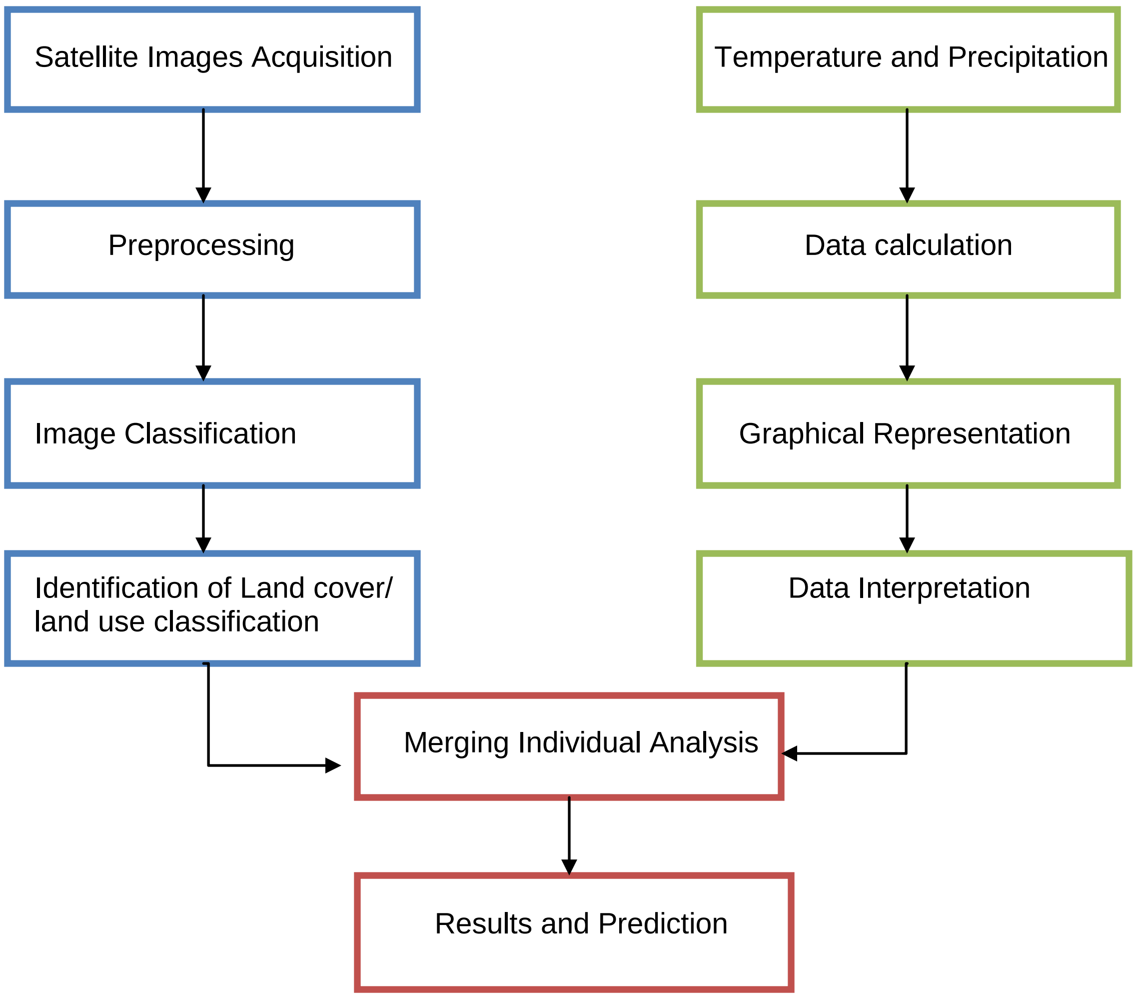

Figure 3.1: Conceptual Diagram of Methodology

3.2 Demarcation of Study Area

The whole of Islamabad was considered in this study and demarked using tehsil boundary of Pakistan.

3.3 Development of a Location Map

A location map was created by digitizing a topographic sheet of raster data using ArcGIS 9.2. Features such as water bodies, roads, sectors and natural parks were marked.

3.4 Image Processing

The images obtained from NARC and PMD were rectified and geometrically corrected. After which a visual interpretation was carried out to get an average estimation about the changes in greenery and development of the city. After this a proper analysis consisting of supervised and unsupervised classification was carried out under the guidance of expertise.

Basically, two images were acquired for the study. One was taken of the year 1992 and the other of 2000.

The images are LANDSAT and each image was classified through a unsupervised classification after which the bands formed were merged and corrected leading to a supervised classification of the image. Both images were classified using five classes;

1. Water
2. Urban development
3. Bare soil
4. Rocks
5. Vegetation

3.5 Demographic Analysis

The urban growth over a period of 30 years was analyzed by the images classified and results were prepared by the comparative analysis of the images processed. Population growth of Islamabad was evaluated by the information provided on the official website of Population Census Organization.

REGION	POPULATION					
Islamabad	1951	1961	1972	1981	1998	2010
Rural	95,940	117,669	160,908	135,922	276,055	_
Urban	_	_	76,641	204,364	529,180	_
Total	95,940	117,669	237,549	340,286	805,235	1,335,000

Table 3.2: Population statistics over 50 years of Islamabad (Statisics Division)

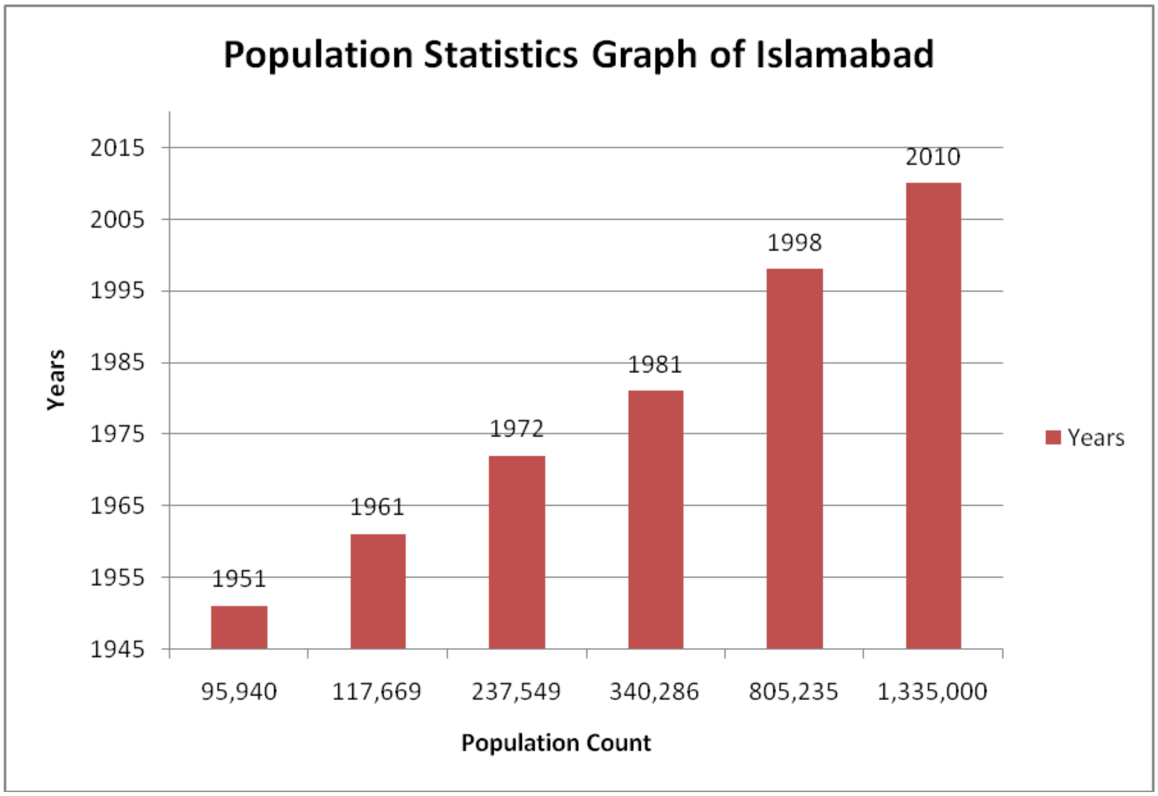

Figure 3.1: - Graphical representation on population increase in Islamabad

3.6 Meteorological Analysis

Effects of infrastructure development were directly linked with changes in precipitation and temperature patterns in this study. An increase in urbanization applies a stress in the atmosphere by the increment of greenhouse gases in the atmosphere. The loss of vegetation cover to accommodate the increasing population causes the urban heat island effect which in return also disturbs the natural flora and fauna of the region.

The temperature and precipitation patterns were taken of different time periods, from 1954 to 2010. An average of both the parameters yearly were plotted as line graphs on excel sheets. Data from three stations in Islamabad were taken:

1. NARC (Murree station) Data compiled with the help of PMD
2. PARC (Satrameel station)
3. Pakistan Meteorological Department (PMD); Islamabad

3.7 Expected Data Output

The aim of this study was to allow the easy comparison of graph and image data to provide a better understanding of how urbanization has affected our climate over the last 40 years.

3.8 Data Limitations

Some of the problems faced in retrieving data was the lack of proper resolution data of satellite images. Moreover, getting an image bigger than 10km by 10 km was difficult for a student at the undergraduate level. Therefore, the most of the images available has been made. SPOT images of the area were very costly and early time SPOT images were not even available, LANDSAT was the best alternative option although it may not have as much accurate results because of low resolution. Google earth was also used to provide a boundary map of Pakistan as it was the easiest and fastest data available on the internet. During literature review, a lot of the articles were posted under memberships and could not be opened. These data restrictions are the biggest hindrances in helping research students conduct proper case studies.

CHAPTER 4
RESULTS

4. RESULTS

4.1 Objective

The main objective of this study was to show temporal changes in the climate of Islamabad due to urbanization. The following results have been organized in the form of line charts, images and tables to serve the purpose of the objective.

4.2 Temperature Data Analysis

According to the climatic data analyzed by Pakistan Meteorological Department; Punjab (Bahawalpur, Faisalabad, Islamabad, Jhelum, Khanpur, Lahore, Multan, Murree, Sialkot, and Sargodha) has experienced an average increase in the Heat Index. In summer high temperatures have been recorded in this region of Pakistan. The increasing trends can be shown by the graph below:

The total increase calculated was 3.5^{o}C (277k) and is claimed by PMD with 95% confidence on statistics. This overall rise in temperature is not only going to affect the humans but also the flora and fauna in the region.(Zahid & Rasul, January 2010)

The variability of temperatures was studied by using available historical data of major meteorological stations in the region. Data was acquired from NARC (Murree station and satrameel) and PMD. The trend in variability in temperature showed a mild stability with slight upward trends from April to September, proving to be hotter than the rest of the year. Moreover, the average maximum temperatures after 1999 showed a stable increase. The mean minimum temperatures also showed a sustained increase after 1999.

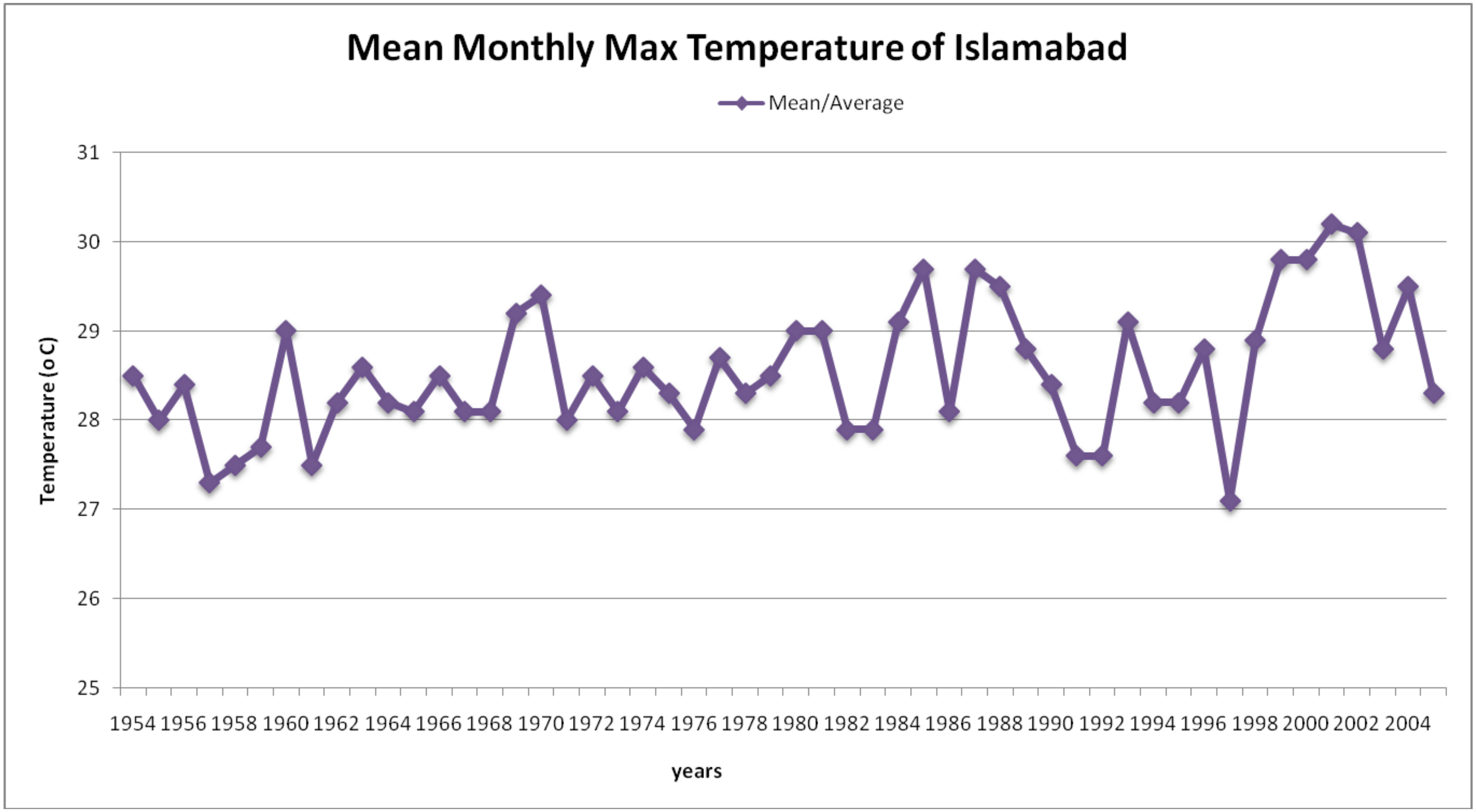

Figure 4.1: - Average Monthly Maximum Temperature Variation in Islamabad

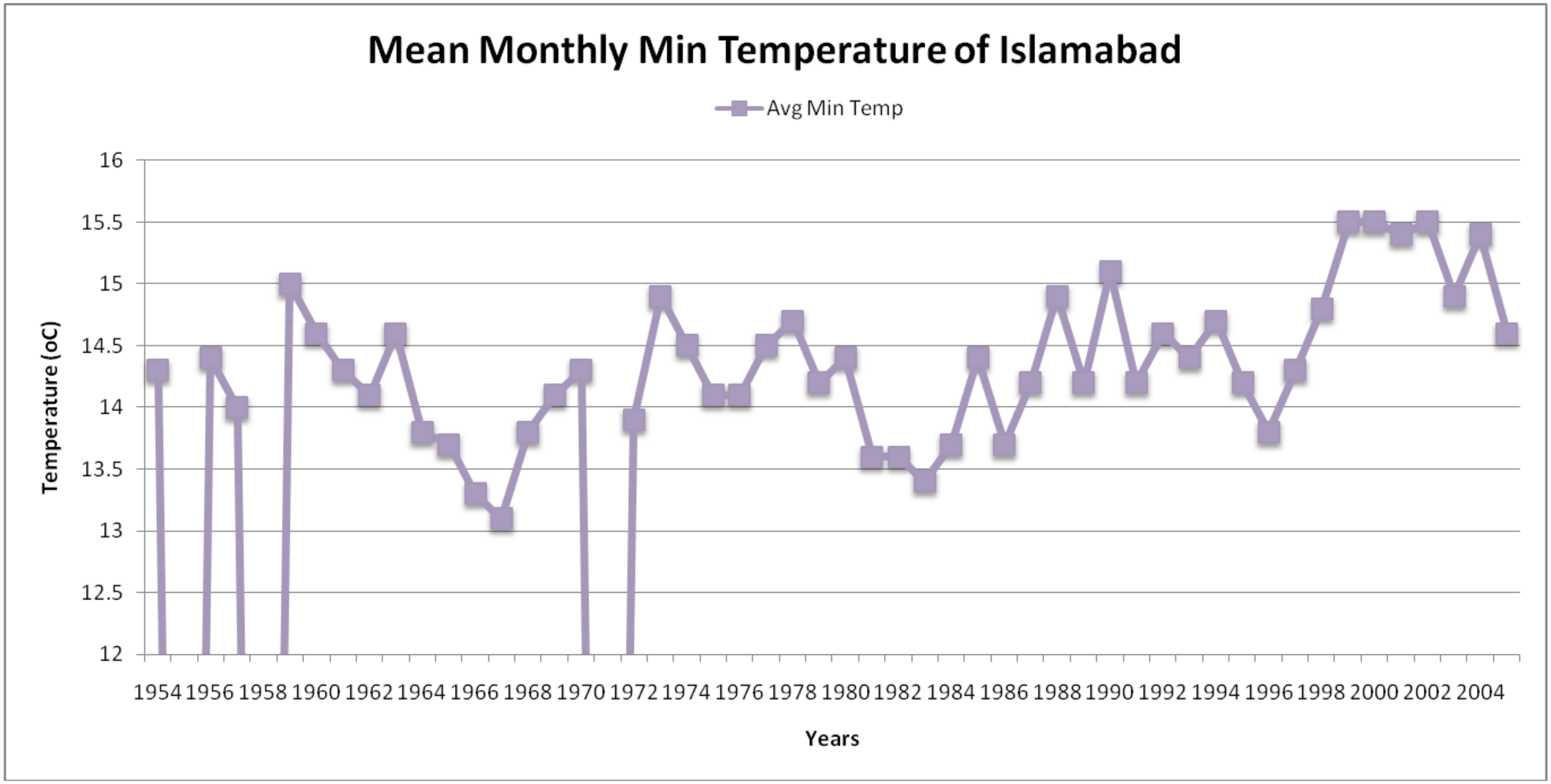

Figure 4.2: - Average Monthly Minimum Temperature Variation in Islamabad

4.3 Precipitation Data Analysis

The spatial and temporal climatic variability of precipitation was observed through the historical climate data (from 30-40 years). As in temperature analysis, data was also obtained from the same sources and an average precipitation variability graph was drawn to estimate the changes in precipitation patterns. It was observed that with a drop in precipitation, there would be a peak in the following years. The precipitation patterns therefore seemed to be unpredictable and drastic for the extremes. Precipitation patterns showed a general increase with Islamabad receiving an average rainfall of 1000mm.

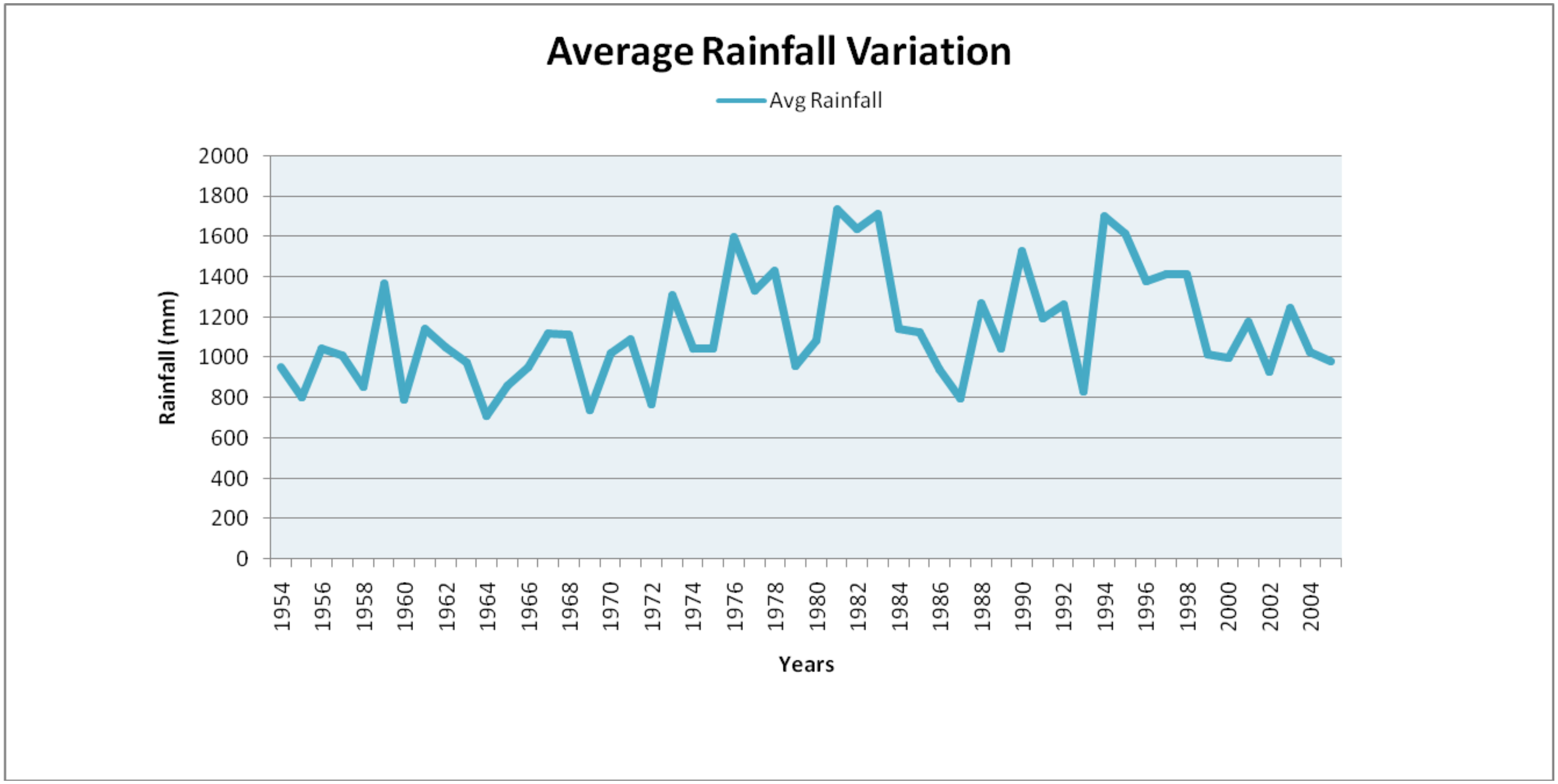

Figure 4.3: - Average Rainfall Variability from PARC/PMD

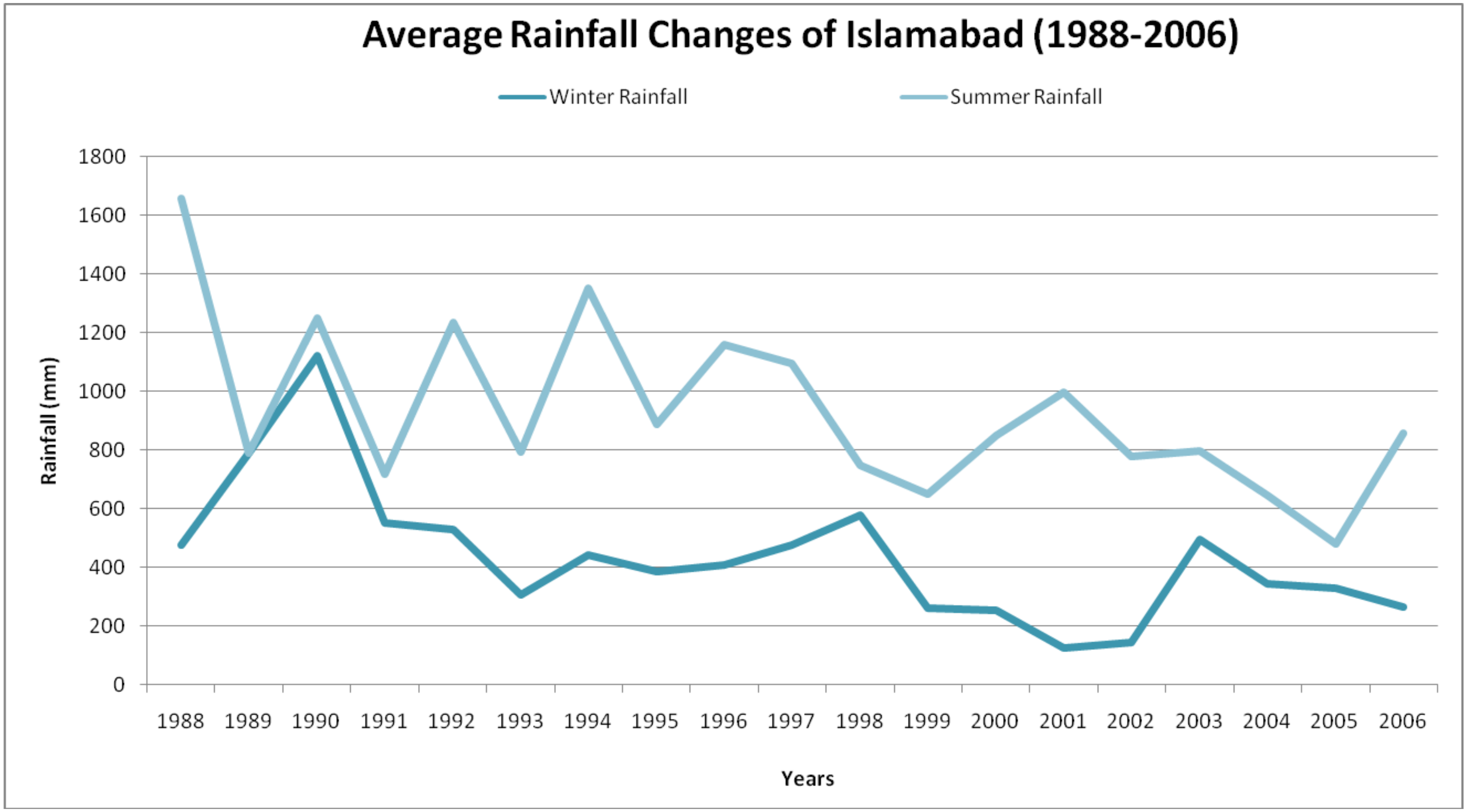

Figure 4.4: - Comparison of Winter and Summer Rainfall changes

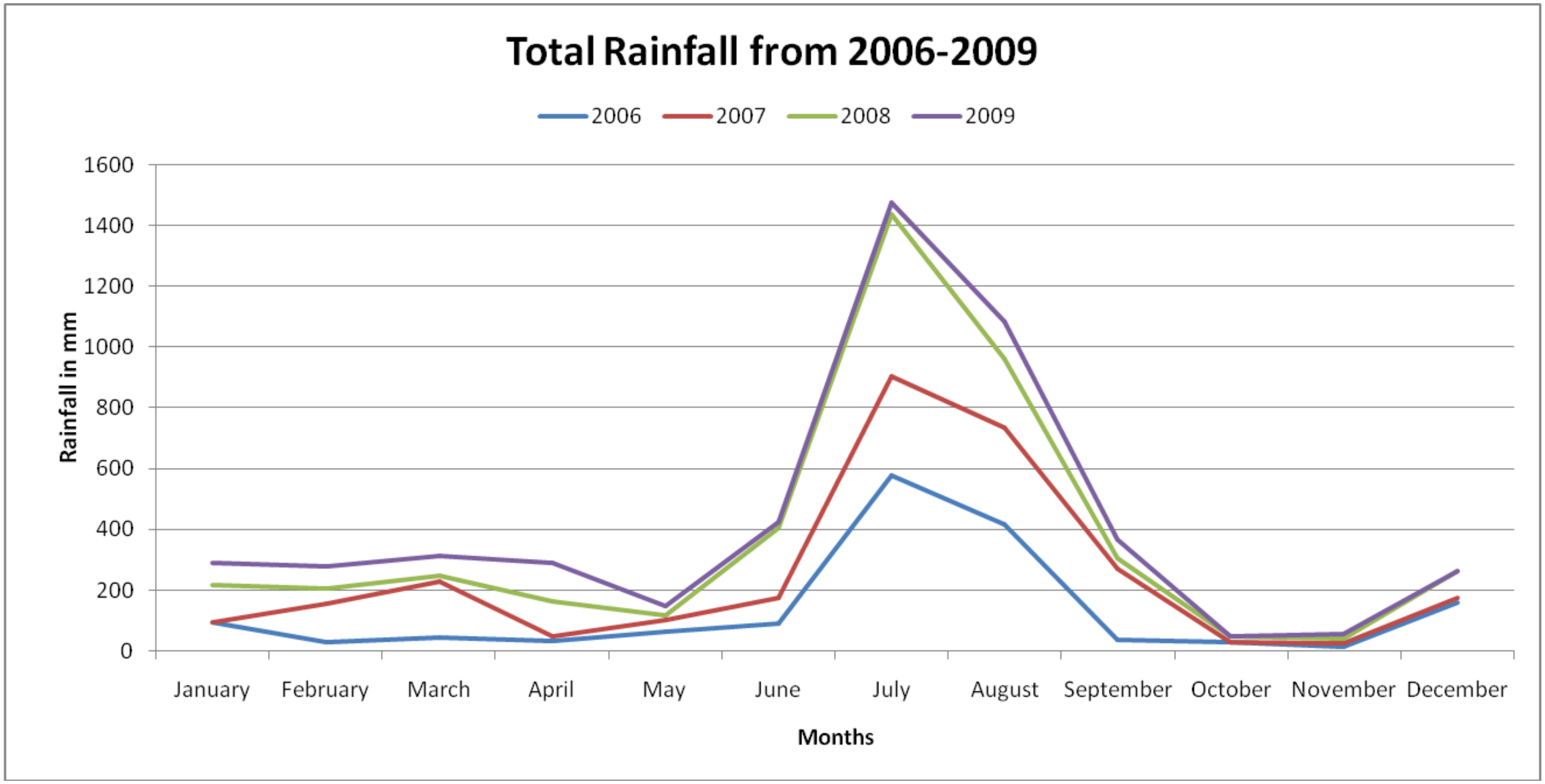

Figure 4.5: Total Rainfall from 2006 to 2009

4.4 Landuse/ Landcover Analysis

Landuse and landcover analysis was carried out by the comparison of two satellite images obtained of Islamabad. One image was of 1992 and the other of 2000.

According to calculations it was noted that the urban development of Islamabad has increased from 43% to 45% and vegetation has decreased from 47% to 44%. The results show that the vegetation in Islamabad is decreasing at a faster rate than the increment in urbanization.

Class	Percentile
Urban Development	43%
Water	1%
Rocks	8%
Bare soil	1%
Vegetation	47%

Table 4.1: Landuse/Landcover (%) year 1992

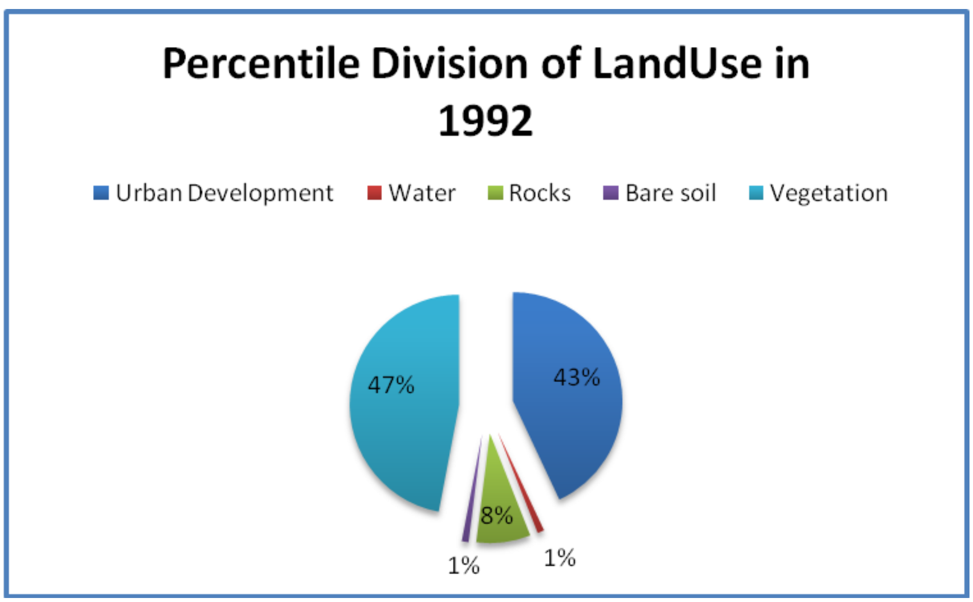

Figure 4.7: Percentile division of Landuse/Landcover in 1992

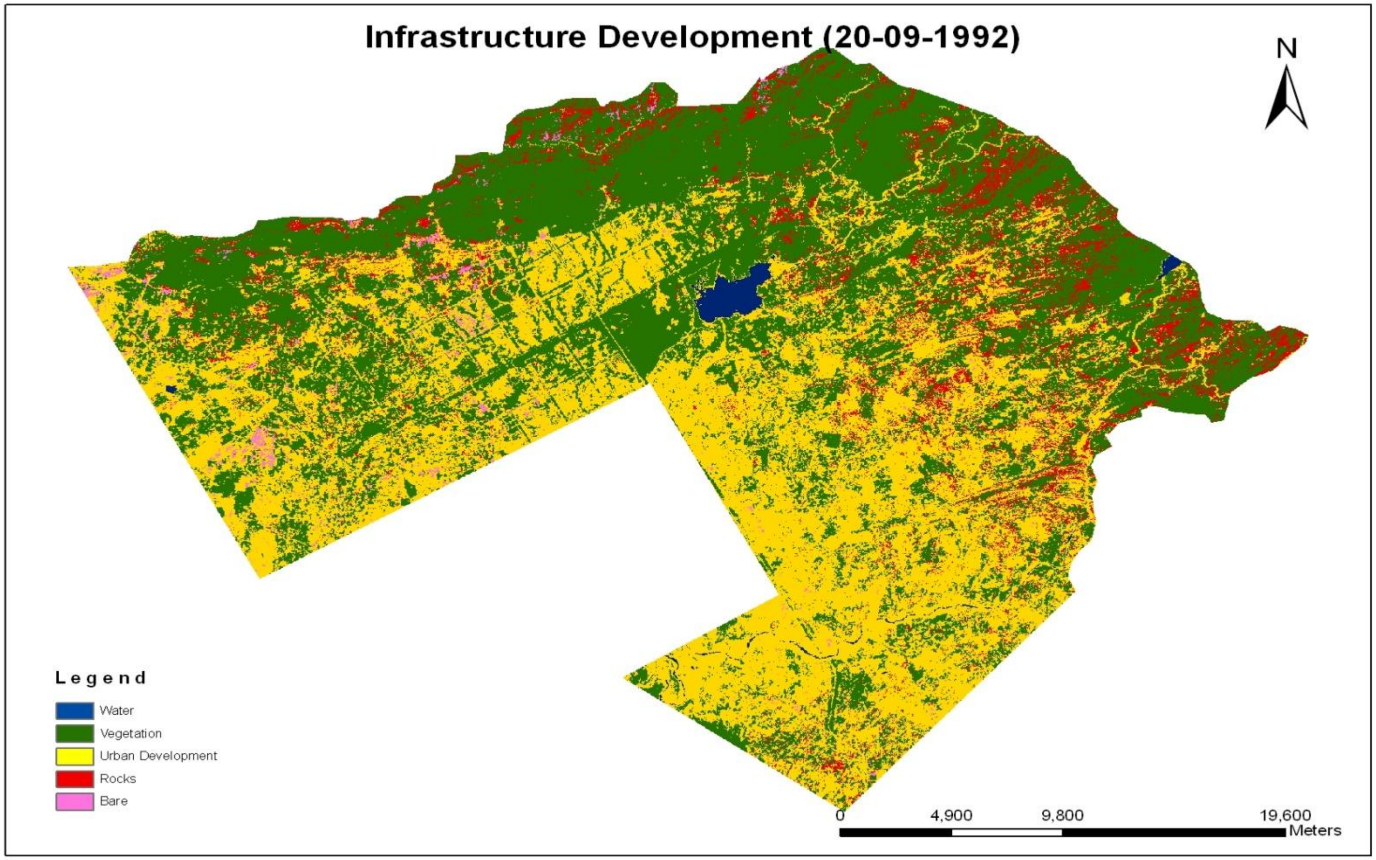

Figure 4.8: Supervised Classification of Satellite Image of Islamabad (1992)

Class	Percentile
Urban Development	45%
Water	3%
Rocks	3%
Bare soil	5%
Vegetation	44%

Table 4.2: Landuse/Landcover classes (%) year 2000

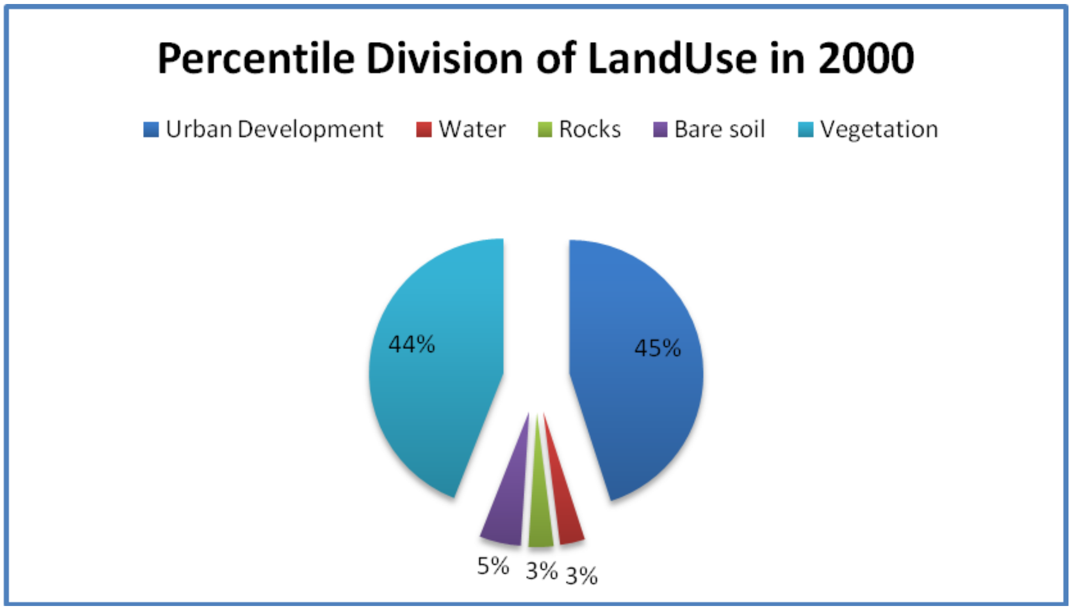

Figure 4.9: Percentile division of Land Use in 2000

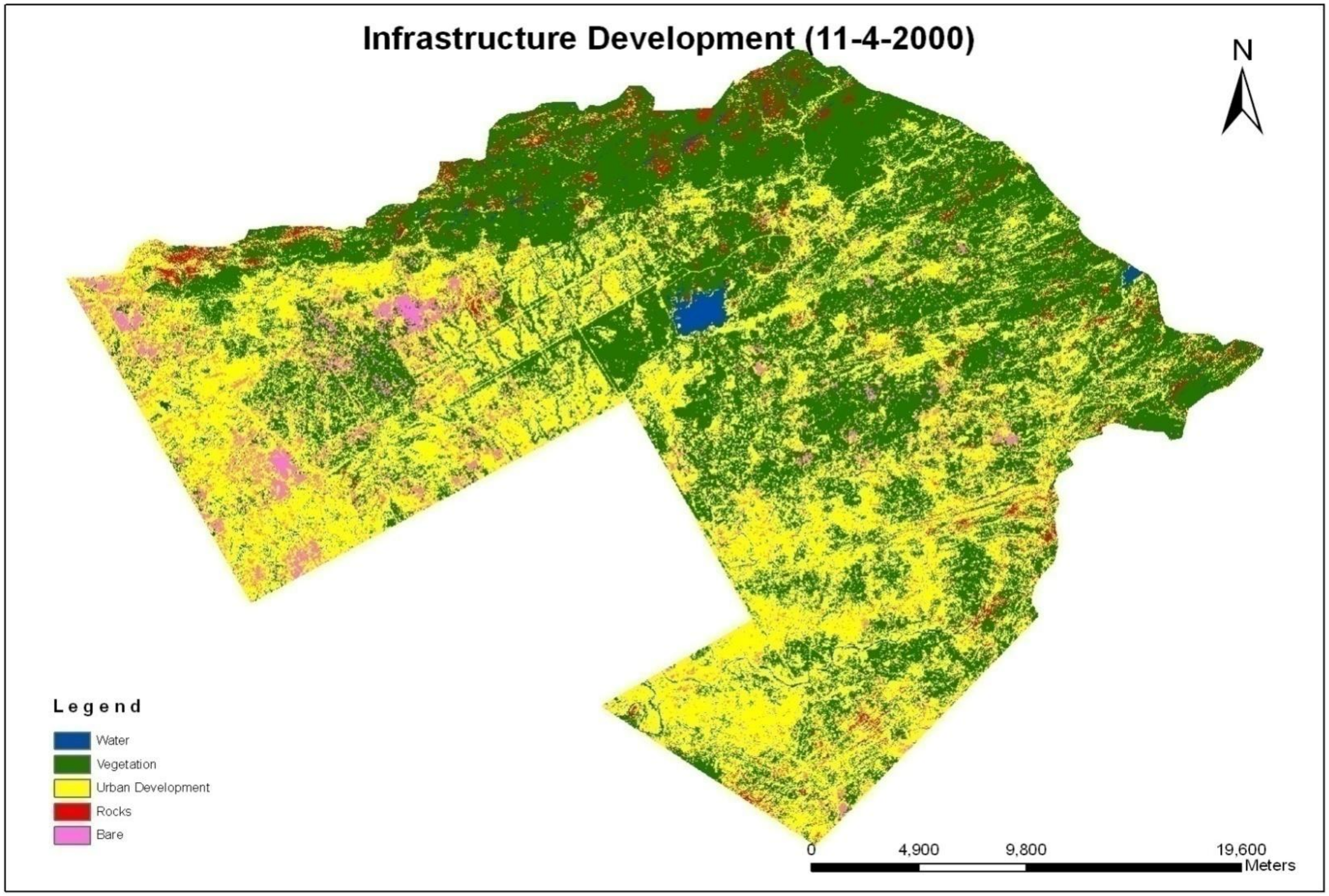

Figure 4.10: Supervised Classification of Satellite Image of Islamabad (2000)

CHAPTER 5

Discussion and Recommendations

5. Discussion

Climate change being a historical phenomenon cannot be mitigated completely; this would probably change the natural heating and cooling system of the Earth. The only way to manage climate change is by controlling the rate of climate change by careful land use planning, balance of infrastructure development, implementation of current policies with more spirit and behavioral changes in the community.

In Pakistan, the Heat Index has shown a significant rise especially in the summer season from 1961-2007. This change in Heat Index is associated with two factors, day time temperatures and relative humidity. Climate change is not only causing a rise in average temperatures but also causing shifts in weather patterns. (Zahid & Rasul, January 2010)

In this study, it was observed that Islamabad has extended since its inception in the 1960s. Covering a total area of 906.5sq.Km, Islamabad has turned into a metropolitan city. Residential areas have expanded rapidly in the outskirts of Islamabad (D-12, Bahria Town, PWD society, Soan Gardens etc) to cater the housing requirements of increasing population of the city. Although the city has expanded, the system of development has been somewhat systematic and coordinated with the master plan of Islamabad. Where there have been developments in areas such as Blue area, Faizabad fly over, H-8 and Korang area. Dense forests have decreased visibly and have been replaced by metaled roads, however, tree plantations on the road sides and around agricultural areas (in NARC) has increased. The biggest drawback for the city was the abrupt replacement of the green belts in the heart of the city for 7th and 9th Avenues. However, plantations around them have somewhat decreased.

Islamabad is at a big advantage due to the position of the Margalla Hills which have been keeping the climate of Islamabad very stable. Had they not been there, Islamabad would have faced many environmental problems. The dense forests of Margalla Hills not only provide aesthetic beauty but also a large area of carbon sinks giving Islamabad its signature cool climate. However, these hills are at a serious threat of encroachment. Originally it was declared that there will be no construction near the Margalla Hills, but now sectors such as E 10, E11 and D 12 have been developed. The impact of these sectors on the climate of Islamabad is going to be drastic, in order to protect the future we have to start thinking and working now.

According to the study the urbanization has increased from 15% to 45%. The temperature analysis of the city shows increasing trend and 2001 was the warmest year when annual maximum temperature rise to $30.2C^0$ and the annual rainfall graph shows an increasing trend and an overall decrease in annual rainfall stability. A vehicle in Pakistan on an average emits 25 times more carbonmonoxide (CO), 20 times more particulate matter, and 5 times more NO than a vehicle in a developed country like Japan and US. According to the Intergovernmental Panel for Climate Change (IPCC) over the last three decades, greenhouse gases emissions have increased by an average of 1.6% per year with carbon dioxide (CO_2) emissions from the use of fossil fuels growing at a rate of 1.9% per year. (Kamran, 2006)

The concentration of air pollutants in Islamabad are also under the control values set by the World Health Organization (WHO) according to the records of Environment Protection Agency (EPA).

Population is directly proportional to the built-up area. As the population increases the demand for residential and commercial areas also increases. According to the statistics provided by the statistics division and a simple mathematical formula, the population of Islamabad has grown by 60% in the last 12 years (1998-2010). This will mean a similar percentage increase in built-up area for the growing population. Already the urban development has increased by 2 % in between years 1992 to 2000.

This growing population will promote many environmental issues in the coming years for Islamabad. Increased pressure on agriculture, exhaustion of natural resources and conversion of cultivable land to commercial and residential areas all will pose a threat to the environment of Islamabad. Deforestation and overgrazing will increase the rate of environmental degradation and put a stress on the climate. Without carbon sinks, the greenhouse gases will persist in the atmosphere and cause a positive urban heat island forcing. This will in return produce global warming and change the weather patterns. Already, Pakistan is facing extreme climates. As depicted by the annual rainfall graph, it can be noted that a year with less precipitation always is followed by a year of extreme rainfall. The stability of the climate is varying. Moreover, the annual rainfall is also decreasing along with these extremes. The highs and lows in the graph have a greater gap in the last ten years.

There is a peak in total rainfall between June and late August 2006-2009. According to the IPCC forcast, an increase in temperature in arid regions, decreasing trend in cooler parts, increasing rainfall in humid areas is expected to occur. As depicted by the precipitation analysis Islamabad is already experiencing these changes. The amount of rainfall in 2009 has increased by 1100 mm compared to the rainfall recorded in 2006. The stability in the rain patterns has decreased causing unpredictable weather. According to a study, climate change is causing increasing rainfall in tropical areas. Over the last three decades, the rainfall patterns around the world have hardly changed except for the tropics, where nearly rainfalls have increased by 5%.(NASA)

The changes in temperature are also taking place due to urbanization. The increase in population, vehicles and greenhouse gas emissions due to anthropogenic activities in and around the city are influencing the minimum, maximum and average temperatures. The greenhouse gases, namely carbon dioxide, methane and ozone trap the infra red rays coming from the sun underneath the layers of the atmosphere thus warming the atmosphere. They do not let the infra red rays exit the atmosphere as they slow down their velocity and hold them between their bonds. Urbanization has caused the concentration of these greenhouse gases to increase and they are the principal causes for global warming and climate change.

Although climate change is a well debated topic, the fact that it is actually occurring cannot be ignored due to the evidence of abrupt changes in our climate patterns. This does not refer to the weather of a certain region but the analysis of the climate over the years.

Climate change is making the precipitation and temperature patterns unpredictable, therefore people may not be able to adapt themselves to it at the right time, especially farmers who depend on the prediction of the climate and the same patterns that it had been following for planting and harvesting their crops. The decreasing precipitation will lead to an alarming issue of food security in the near future. It is predicted that extreme weather conditions will prevail in the future with more flooding and droughts.

The conclusions reached through this study are:-

1. Temperature variability, increase in minimum (15^{o}C), maximum (32^{o}C) and average temperature of Islamabad
2. Increase in average rainfall variation from 1954-2004 (figure 15)
3. Decreasing trend in summer and winter rainfall, with abrupt peaks showing decrease in rainfall stability.
4. The year 2009 bought about the most rainfall as compared to years 2006, 2007 and 2008 (figure 17) in the month of July-August which is the monsoon season showing an increase in rainfall on monthly basis.
5. Increase in urban development by 2 %
6. Decrease in vegetation by 3 %
7. Increase in population by almost 40% between the years 1998 to 2010. Compared to rural population, the rate of urban population in Islamabad has increased faster.
8. Changes in landuse changes, new plantations are focused on the outskirts of Islamabad rather than the centre as visible by the satellite images. Urban development has increased near the Margalla Hills more than the centre of the city. Infrastructure development has spread rampantly on the outskirts of Islamabad, comprising of housing societies (Bahria Society, PWD, Soan Gardens) and new sector developments (E10, E11, D 12)

5.1 Recommendations

In order to promote sustainable development in line with urbanization the solutions to environmental degradation are very simple. This includes not only a change in the use and utilization of resources but also a change in the attitude and behavior of the locals. The purpose of this study was to illustrate the changes in the climate of Islamabad, a city considered more “green” and environmental friendly than most of the cities in Pakistan. We need to look upon the changes at a smaller scale to protect our future. Some of the recommendations proposed are:-

1. Promotion of a balanced growth between urbanization and infrastructure development, including new plantations and protection of natural existing ecosystems i.e. natural parks, wetlands and forests.
2. Urban planning before the construction of roads and buildings along with Environment Impact Assessment of every new project before its commencement.
3. Urbanization should be discouraged in cultivable areas, such as around crop areas so that the natural ecosystems can be maintained for crop growth. However, maximum trees should be planted around crop lands to keep the soil fertile and intact.
4. Management of urban planning and careful consideration of long term and short term effects land use changes.
5. Upgrade infrastructure of old and new buildings by investing in thicker insulation and other cost effective, temperature regulating steps that can save money in the long run. Investing in new infrastructure or upgrading

existing highways and transmission lines, would help cut greenhouse gas emissions and drive economic growth in developing countries.

6. Energy-efficient buildings and using alternative fuels to fire up the kiln and factories could reduce greenhouse gas emissions.
7. Identification of gaps in environmental policies and transparent compliance with international environmental laws signatory to Pakistan.
8. Government authorities should work in close association with non governmental organizations to protect natural ecosystems.
9. Government should develop rural areas so that urban sprawl can be reduced as rural-urban migration mainly takes place due to economic constraints.
10. Annual reporting of changes in greenhouse gas concentrations, temperature and precipitation patterns to predict the steps needed to secure the future.
11. Educating the masses about the basic parameters in protecting the environment.
12. Introduce ways to conserve rainwater through rainwater harvesting.
13. Control the emission of greenhouse gases by vehicular emission regulations and by making vehicles and factories (especially brick kilns) more energy efficient.
14. Integration of GIS and use of high resolution images to make results more accurate for determining changes in development and land use/ land cover.
15. Involvement of young graduates and fresh minds in the research and development departments of public and private enterprises responsible for urban planning and management as well as environmental protection so that new ideas and up to date knowledge can be applied.

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Appendices

Monthly Precipitation (mm) 1954-2005

	Jan	Feb	Mar	Apri	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean/Average
1954	166.9	130.6	47.2	10.9	17	12.7	163.3	190	128	79.8	3	1.3	950.7
1956	34.8	74.9	86.6	14.2	0	118.1	284.7	329.9	76.5	18.3	0	6.9	1044.9
1957	138.7	34.5	94.2	102.1	60.5	48.5	33	240.8	27.2	95.3	53.6	82.6	1011
1958	9.1	6.6	95	14.2	3.6	10.4	257.3	188.2	132.1	6.6	13	115.3	851.4
1959	97	89.2	44.7	26.2	74.4	21.8	336.3	243.3	268.2	48	91.2	26.2	1366.5
1960	87.1	0	90.4	39.1	4.3	7.4	204	202.9	109.7	11.2	0	37.3	793.4
1961	145	43.4	21.1	124.7	12.7	25.7	246.6	154.7	279.1	39.1	43.7	8.6	1144.4
1962	13.7	51.3	68.6	25.9	23.9	52.3	201.2	421.6	78	5.1	26.7	82	1050.3
1963	0	42.9	73.9	57.4	51.6	8.9	220.5	336.3	92.5	0	47.2	44.2	975.4
1964	143.3	13.7	20.6	43.9	45.7	24.6	263.7	91.9	47	0	1.8	12.4	708.6
1965	38.6	92.7	90.9	210.1	115.3	20.6	111	119.1	13.5	10.9	25.7	10.7	859.1
1966	0	165.4	80.3	47.8	61	101.9	164.1	187.7	87.6	39.1	0	14	948.9
1967	0	66.5	134.9	38.9	23.1	18.5	261.6	342.4	56.9	19.8	3.6	152.4	1118.6
1968	69.3	81.5	64.5	36.6	49.8	14.2	249.4	401.3	20.8	36.8	45.7	44.5	1114.4
1969	2.8	62.7	54.4	35.3	55.9	15	84.6	274.3	50.3	95.8	6.3	0	737.4
1970	72.4	83.6	78.5	11.9	16.3	37.8	189	325.1	172	24.9	1	7.9	1020.4
1971	21.6	56.6	11.2	79	26.9	239	169.9	389.6	75.7	1.3	12.2	8.1	1091.1
1972	72.6	48.3	108.2	67.8	19	51.8	40.6	81.5	113.8	74.2	18.8	73.4	770
1973	62.7	80.3	75.7	24.6	52.1	111.3	370.1	403.4	93.5	14.2	3.6	19.3	1310.8
1974	32.8	53.8	35.8	15.9	27	99.8	477.9	210.1	56.8	0	0	32.7	1042.6
1975	39.2	59	63.6	42.7	33.1	18	235.7	391.3	153.6	0	0	5.8	1042
1976	115.9	208.4	117.3	65	3	33.3	366.9	442.5	202.5	40.1	0	1	1595.9
1977	72.2	15.2	12.9	54.6	61	142.9	618.1	254.4	38.3	19.3	23.3	20.7	1332.9
1978	50.4	32	100.1	23.3	14.3	139.8	258.9	496.9	171.7	69	70.2	4.1	1430.7
1979	78.2	102.3	171.5	14.1	40.7	28.8	118.5	231	97.6	17.3	36	22.6	958.6

1980	92.8	93.4	125.8	15.6	23.6	80	309.8	189.7	86.2	36.6	14.6	16	1084.1
1981	159.8	73.4	224	84.1	109.6	19.4	580.2	338.3	131.3	10	5	0	1735.1
1982	74.4	87.3	186.4	191	101.7	18.9	159.1	641.4	41.7	25.7	83	24.3	1634.9
1983	131.3	51.5	80.7	264.9	26.2	49.4	258.3	582.2	193	74	2.5	0	1714
1984	0	112.4	75.3	39.6	10	202.2	306.2	245.2	131.5	0	3.6	16.4	1142.4
1985	54	4.5	47	47.4	30.4	8.1	456.6	220.4	63.3	37.7	10.7	143.8	1123.9
1986	12.2	149.1	112.6	66.3	29.9	91.8	85.5	172.9	73	57.6	40.3	46.2	937.4
1987	0.5	133.8	72.7	51.9	99	27.1	63.4	264.5	1.3	74.4	0	7	795.6
1988	17.1	23.2	153.3	6.9	8.6	97.7	450.4	282.1	126.1	31.2	0	72.4	1269
1989	67.6	10.7	71.5	12.7	5.3	57	365.2	369.5	28.4	3.8	2	50.5	1044.2
1990	41.1	105.1	160.2	55.3	TRACE	29.4	327.4	436	168.3	21.1	7.9	177.9	1529.7
1991	9.2	106.8	103.9	116.6	16.8	88.6	251.8	264.2	211.5	3.3	3.8	17.1	1193.6
1992	99.2	91.3	119.1	30.5	36.8	14.5	256.7	305	257.9	9	34	7.9	1261.9
1993	36.4	30	140.6	22	44.7	77.8	152.7	211.2	93.5	6	15.4	TRACE	830.3
1994	36.1	51.4	36	69.3	36	54.8	596.7	637.7	56.2	29.8	1	93.2	1698.2
1995	31.5	99.8	104.3	107.4	17.2	20.5	743.3	331.8	39.8	64.6	20	35	1615.2
1996	80.5	135.9	143	36.3	43.4	138.3	199.9	411.7	118.3	57.8	3.4	7.6	1376.1
1997	39	20.3	84.3	172.2	46.1	64.7	194.8	496.4	158	95.8	22.4	19.8	1413.8
1998	36.7	248.8	75.8	110	29.6	27.3	306	428.4	138	11	0	TRACE	1411.6
1999	83.1	35.5	80.8	2	22.1	33	232.3	334	145	9.5	35	0	1012.3
2000	129	70.6	18	2.5	11	37	207	381	129	0	TRACE	14	999.1
2001	TRACE	4	40	24.2	16.5	153	647	207	44	33	7	2	1177.7
2002	7	38	32	6	12	155	109	350	157	38	TRACE	26.5	930.5
2003	42	173	110	19	15	63	266.5	260.5	217	6	21	54	1247
2004	146.8	48	TRACE	78	40	130	128.5	313	16	76	22	28	1026.3
2005	97	213	87	13	33	16	181	211	86	36	6	0	979

Table 6.1: Monthly Amount of Precipitation (mm) 1954-2005

Mean Monthly Maximum Temperatures (^0C) 1954-2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1954	14.7	17.2	23.7	31.1	37.8	39.8	36.4	34.8	33.1	28.6	24.2	20.3	28.5
1955	17.7	22.6	25.3	28.5	32.8	41.3	37.7	----	32.6	29.2	25.9	18.8	----
1956	17.3	21.8	22.1	30.7	40.3	38.1	32.1	31.2	34.7	28.8	24.8	19.5	28.4
1957	14.5	18.1	22.7	25.8	31.7	37.4	38.6	34.2	34.7	29.6	22.4	17.3	27.3
1958	----	20.5	24.3	33	35.2	40.3	35	33.3	33.1	30.5	25.1	18.2	----
1959	16.2	16.3	25.2	30	34.4	40.3	33.2	33.3	32.2	30.3	21.9	18.6	27.7
1960	16.4	23.8	21.5	28.1	36.4	40.7	35.4	33.7	34.2	31.9	25	20.9	29
1961	16.9	16.2	24.4	27.8	35.8	39.2	34.7	34.2	32.4	29.4	21.7	17.4	27.5
1962	17.1	19.3	23.7	30.4	35.2	39.1	36.3	33.2	31.6	29.8	23.4	19.3	28.2
1963	18.7	22.4	22.5	28.2	32.5	40.1	37.4	33.4	32.4	32.1	23.7	20.3	28.6
1964	13.6	18.7	26.1	30.1	34.7	38	34.4	34.2	32.7	31.8	25.6	18.9	28.2
1965	18.7	17.2	23.7	25.7	32.2	38.3	35.7	33.8	34.4	31.5	25.6	19.8	28.1
1966	20.8	20.9	23.4	27.6	35.7	38.2	34.9	33.7	31.6	29.7	25.6	19.9	28.5
1967	18.4	21.3	23.5	28.5	34.2	39.9	35.1	32.4	33.4	29.6	23.7	17.7	28.1
1968	15	17.4	24.6	30.9	32.7	39.7	35.3	32.7	35.8	29.8	24.8	18.2	28.1
1969	17.2	18.8	27.9	29.4	33.2	40.3	36.5	34.2	34.1	30.8	25.7	22.6	29.2
1970	18.1	21	23.6	33.6	38	38.8	36.1	32.8	32.2	31.6	25.7	21.4	29.4
1971	17.8	20.6	26.6	31.9	35.2	35.8	33.6	32.8	33.2	31.9	25.8	---- 18	----
1972	18.3	16.7	24.6	29.1	35.2	39.6	37.8	34.8	32.3	29.9	25.3	18	28.5
1973	15.9	19.7	22.9	31.8	36	38	33.6	32.2	32.8	30.2	25.4	19.1	28.1
1974	16.8	17.2	26.7	32.7	35.4	37.4	35.1	34.1	33.9	31.4	26	16.4	28.6
1975	17.1	17.5	23.1	30.5	35.5	38.1	34.2	33.1	32.3	32.7	25.3	20.3	28.3
1976	17.6	17.3	22	28.8	36	38.1	34.6	30.7	32.7	30.6	26.7	20.2	27.9
1977	16	21.4	29.1	30.1	33.3	36.7	32.4	33.1	33.8	31	26.7	20.4	28.7
1978	16.4	18.9	21.6	31.3	39.8	39.4	32	32.1	33.1	30.8	23.2	21.5	28.3
1979	18.5	19	21.5	31.5	33.3	39.3	34.6	33.5	33.2	31.7	26.1	20.3	28.5
1980	16.9	18.9	21.3	32.6	38.4	38.5	34.2	34.3	33.9	31.9	26.1	21.2	29

1981	16.8	19.3	22.5	31.3	36.5	39.3	34.8	34.7	34.4	31	25.5	21.6	29
1982	18.2	16.6	20.1	29	32	38.4	37.5	33.1	35	31.6	25	18.7	27.9
1983	17.7	19.2	22.2	25.4	33.4	36.9	35.2	33.3	34	30	27.3	20.5	27.9
1984	18.9	17.7	27.3	30.3	39.9	39.8	32.7	33.3	32.4	32.1	25.5	19.7	29.1
1985	17.6	23	28.4	31.7	37.3	40.7	34.5	34.2	34.6	30	25.7	19.1	29.7
1986	18.6	18.7	22	29.9	34	36.6	34.6	33.2	33.9	30.6	25.8	18.8	28.1
1987	20.4	20.7	23.1	31.2	31	38.3	39	35.9	36.1	30.9	27.9	22.1	29.7
1988	19.6	21.5	23.2	33.2	38.6	38.6	33	33.9	34.1	31	27	20.4	29.5
1989	17.1	18.7	23.3	29.3	36.5	38.9	35.7	33.4	34.9	32.4	25.5	19.5	28.8
1990	18.8	18.3	22.3	28.7	37.5	39.5	35	32.8	33	29.8	26.1	18.5	28.4
1991	16.8	18.3	22.9	26.4	33.3	37.9	36.8	33.4	31.7	29.6	25	19.3	27.6
1992	16.4	18.1	22.2	28.1	32.9	38.4	34.6	33.3	32.2	30.3	25	20.3	27.6
1993	15.9	22.4	21.5	30.8	37.1	38.1	34.4	35.4	32.5	31.7	27.1	22.4	29.1
1994	18.2	17.7	26	28.7	35.8	40.1	33.3	32.4	32.9	29.8	25.8	18.2	28.2
1995	17.5	19.3	23	26.5	36.2	40.7	33.1	33	34.1	31.1	25.9	18.5	28.2
1996	17.8	20.9	24.5	31.2	34.3	36	35.9	32.5	33.5	29.9	26.4	22.1	28.8
1997	18.3	20.7	23.8	26.7	31.6	36.3	35	32.7	33.1	26.9	23.4	17	27.1
1998	17	18.7	22.4	30.9	35.8	38.7	35.3	33.6	33.8	31.3	27.9	21.9	28.9
1999	16.6	20.6	24.6	34.1	37.9	39.1	36.1	34.2	34.5	31.9	25.2	22.6	29.8
2000	17.6	18.6	25	33.7	39.7	39.9	34.8	34	33	32.9	26.5	22	29.8
2001	19.1	23.2	28.4	31.8	39.4	36.3	33.7	34.8	34.9	32.3	27	21.9	30.2
2002	19.8	20.4	27.4	33.1	39	39	39	33.6	31.6	31	26.3	20.6	30.1
2003	19.6	19.2	24.2	31.5	35.6	39.4	34.9	34	32.7	30.5	24.2	19.4	28.8
2004	17.2	21.5	30.1	33.2	36.4	36.7	36.7	33.6	35.2	27.9	25.4	19.7	29.5
2005	15.8	15.9	23.7	30	33.6	39.9	34.4	34.4	34.5	31.2	25.5	21	28.3

Table 6.2: Mean Monthly Maximum Temperatures (^{0}C) 1954-2005

Year	Jan	Feb	Mar	Apri	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean/Average
1954	2.7	7.1	9.6	14.7	20.6	24.8	24.8	23.7	22.4	12.5	7.1	1.3	14.3
1955	1.4	2.5	11.6	12.7	17.8	24.4	24.8	----	21.2	13.5	5.8	4	----
1956	2.1	4.2	11.1	15.8	23	24.4	23.9	22.5	22.8	14.4	5.9	2.8	14.4
1957	3.1	3.9	9.6	13.3	18.2	23.1	26.1	23.6	19.7	14.1	8.8	4.9	14
1958	----	4.1	10.1	17.4	20.1	23.9	25.2	23.1	22.3	14.9	7.6	5.7	----
1959	3.4	5	10.3	15.1	21.2	25.4	24.1	24.6	23.3	16.6	7.6	3.4	15
1960	2.3	7.2	9.7	13.2	20.2	24.8	25.4	25.2	20.9	14.6	9.6	1.8	14.6
1961	3.1	3.7	9.6	14.6	20.6	25.6	24.8	24.3	22.8	13.8	6.6	1.7	14.3
1962	1.6	5.2	10.3	15.4	19.7	24.1	25.6	23.4	20.6	13.4	7.1	3.1	14.1
1963	0.7	6.4	10	14.6	18.6	26.1	26.1	23.4	20.1	16	9.7	3.6	14.6
1964	1.8	4.8	10.3	15.4	17.8	22.9	23.5	24.8	21.1	13.4	6	3.7	13.8
1965	4.2	5.6	9.8	13.6	17.4	22.3	24.1	22.4	19.7	15.2	9.3	0.4	13.7
1966	1.3	7.9	9.7	13.6	18.6	23.8	23.6	23.3	19.4	13.6	5.1	0.1	13.3
1967	0	1.6	3.7	13.1	18	24.3	25.3	23.4	21.5	13	8.1	4.6	13.1
1968	3.7	4.2	10	14.9	19	24.2	24.7	22.2	20.4	13.2	6.6	3.1	13.8
1969	1.9	5.5	10.8	14.1	18.8	23.9	25.7	23.9	20.1	14.8	7.8	1.6	14.1
1970	2.1	5.1	9.8	15.9	20.9	25.1	24.2	24.1	21.2	15.4	5.8	2.2	14.3
1971	0.9	5.2	10.3	16.2	21.1	24.3	22.5	23.4	17.9	12.4	7	----	----
1972	2.8	2.8	9.8	13	18.7	22.6	24.9	24.1	20.1	13.7	8.7	5.7	13.9
1973	3.1	6.8	10.3	16.3	22.4	25.3	25.1	23.9	21.8	13.2	7.5	2.7	14.9
1974	2	4.2	15	17.7	20.8	23.1	24.2	24.1	20.9	11.9	6.7	3.7	14.5
1975	3.6	5	8.9	15.6	20.3	23.2	23.6	23.9	21	14.5	5.6	3.5	14.1
1976	4.1	6.3	9.7	14.7	20	23.1	25.1	22.5	20.7	14.1	6.8	2.5	14.1
1977	3.1	4	10.8	16.5	19.2	23.4	23.6	23.5	21	15.6	9.2	4.5	14.5
1978	2.3	5.7	9.3	16.1	22.3	25.1	24.1	23.4	21.1	14.7	8.7	3.3	14.7
1979	2.9	5.5	8.7	16.9	18	22.9	25.3	22.8	19.1	14.8	8.8	4.6	14.2

1980	3.2	6	9.6	16.1	21.2	23.7	23.8	23.1	19.7	14.4	7.7	3.8	14.4
1981	3.9	6.2	10	15.3	19.8	22.2	23.7	22.4	18.8	12.3	6.5	1.6	13.6
1982	3	4.6	8.7	14.5	18.1	21.3	23.9	23.1	19.2	14.3	7.9	4.4	13.6
1983	2.3	4.6	8.3	13.3	18.8	21.9	23	24.3	22.4	13	6.6	2.7	13.4
1984	0.6	3.3	11.5	14.7	20.9	25.6	23.5	24.1	19.1	11.5	7	2.3	13.7
1985	2.8	4.8	11.1	16	20.1	24	24.3	23.5	20.9	12.9	7	5.8	14.4
1986	1.4	5	9.3	14.1	17.9	21.7	24.3	23.4	19.7	14.6	9.1	4.2	13.7
1987	2.9	5.9	11.1	14.6	17.6	21.5	24.2	24.3	21.9	15	7.5	4	14.2
1988	4.7	6.6	10.6	16.7	21.2	23.8	24.4	23.2	21	13.8	8.4	4.6	14.9
1989	2.5	3.9	10.2	13.5	19.5	23.7	24	23	21.1	14.3	8.9	5.4	14.2
1990	5.4	6.5	9.4	14.4	22.6	25.1	24.2	23.5	22.4	14	8.4	4.9	15.1
1991	2.9	6.1	10.2	13.9	19.3	22.5	24.7	23.6	21.4	12.7	7.5	5.7	14.2
1992	5.2	5.5	9.9	14.6	18.9	23.4	24	24.2	20.5	14.5	8.5	5.5	14.6
1993	3	7.4	8.8	15.9	21.5	22.8	24	23.7	20.5	13.1	8.5	3.7	14.4
1994	4.4	5.4	11.5	14	20.8	24.7	24.5	24.2	19.5	13.6	8.7	5	14.7
1995	2.4	5.9	9.5	14.2	19.7	23.5	24.3	24	20.9	15.2	7.5	3.7	14.2
1996	1.9	6.1	11.1	17.8	17.6	22.8	24.1	22.9	21.2	13	6.1	1.2	13.8
1997	2.1	4.7	10.2	14.3	17.7	23	25.5	23.6	22.1	15.1	8.3	5.2	14.3
1998	3.4	6.2	9.8	16.4	20.9	23.4	24.5	23.8	21.9	15.9	8.1	3.2	14.8
1999	4.8	7.8	10.5	16.4	21.3	24.7	24.8	24	22.8	15.2	9.7	3.6	15.5
2000	4	5	10.3	17.2	24.6	25.6	24.7	23.3	21	15.9	9.7	4.4	15.5
2001	2.1	5.9	11.3	17.4	23.9	24.9	24.2	24.8	21	16	8.5	5.1	15.4
2002	3	5.7	11.7	18	23.1	25.2	25.6	24.8	19.8	15	9.3	5.3	15.5
2003	1.8	6.5	11.3	16.8	20	24.5	24.4	23.8	22	14.1	8	5.3	14.9
2004	5.1	6.2	12.8	18.3	20.7	23.6	25	23	22.1	14.2	8.8	5.4	15.4
2005	2.9	6.2	11.7	14.6	19.2	24.9	24.7	23.5	22.1	15.2	7.7	2	14.6

Table 6.3 : Mean Monthly Minimum Temperatures (^{0}C) 1954-2005

Months	**2006**	**2007**	**2008**	**2009**
January	92.8	0.6	123.8	73.5
February	29.2	127.1	47.5	75.5
March	42.2	188	18.2	63.4
April	30.7	17.2	114	126.2
May	63.4	39.6	15.6	27.6
June	90.5	82.5	232	17.9
July	579.2	326.8	531	40.4
August	417.8	317.4	227	120.7
September	36.8	232.4	35	63.6
October	29.7	0	17.2	0
November	11.5	13	15.1	15.2
December	160.5	14	86.6	0
Total rainfall (mm)	1584.3	1358.6	1463	624
Mean rainfall (mm)	4.3	3.72	3.99	1.70

Table 6.4: Total Rainfall (mm) 2006-2009

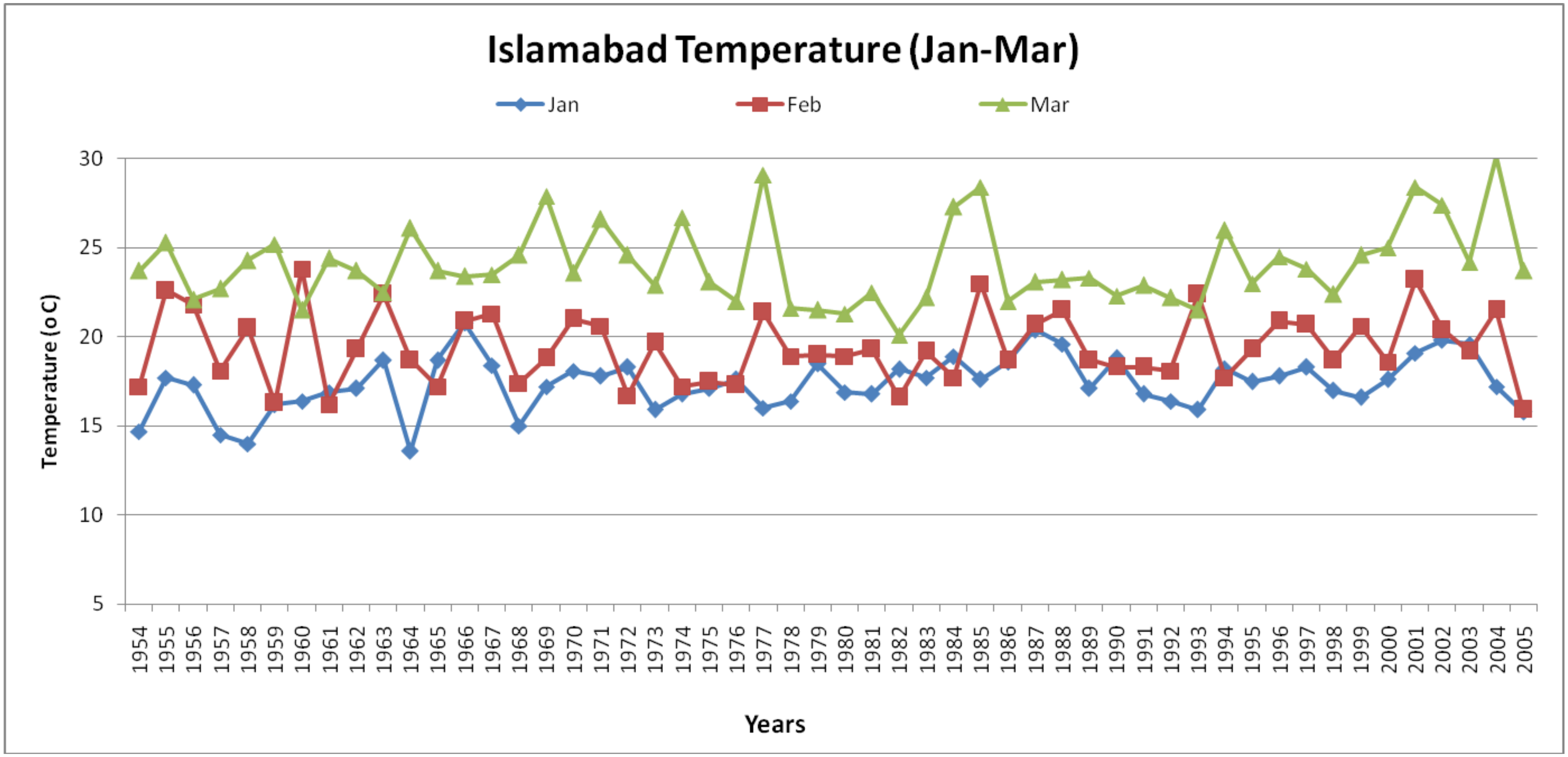

Figure 6.1: - Mean Yearly Temperature Variation in Islamabad (January-March)

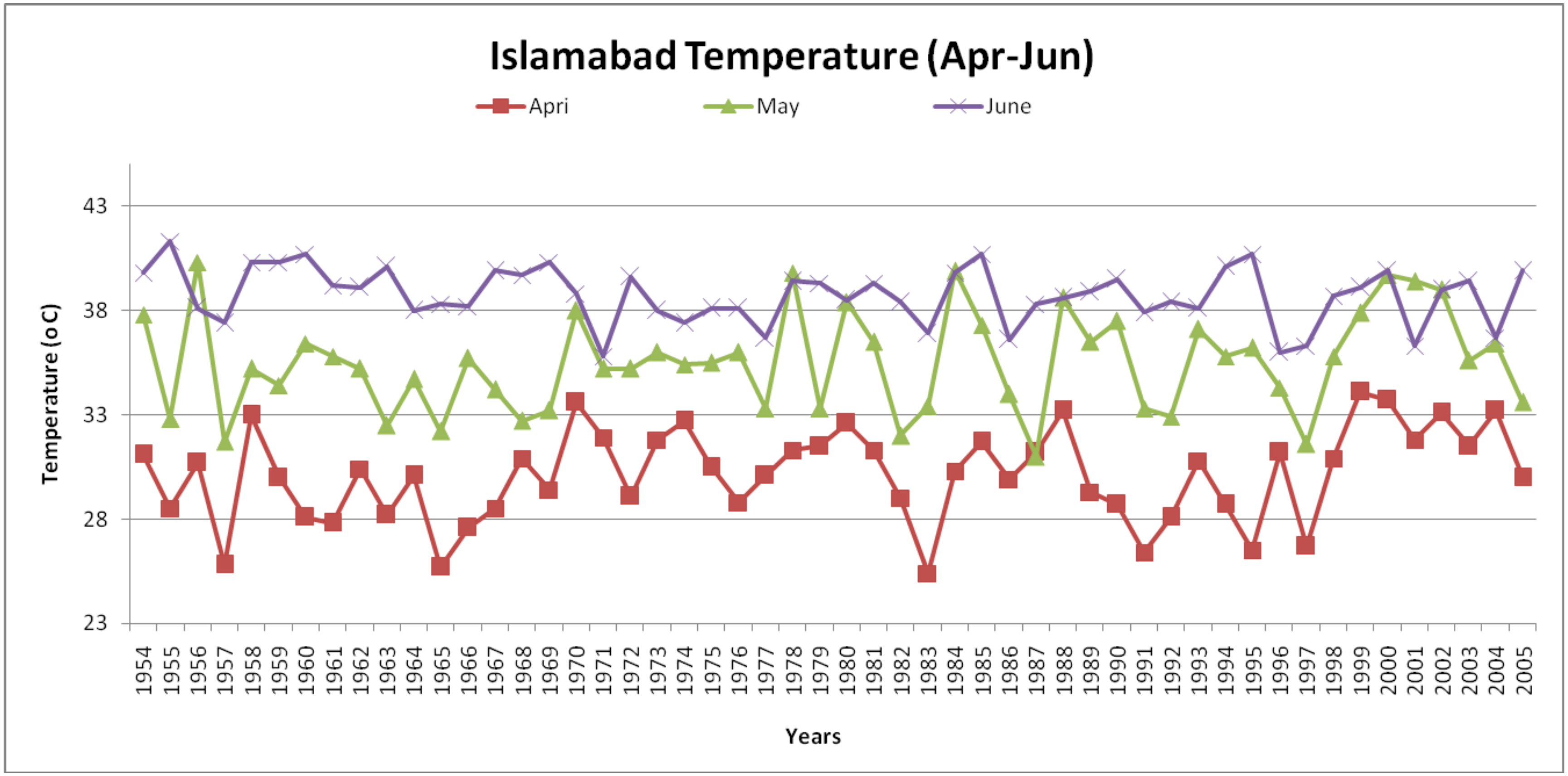

Figure 6.2: - Mean Yearly Temperature Variation (April – June)

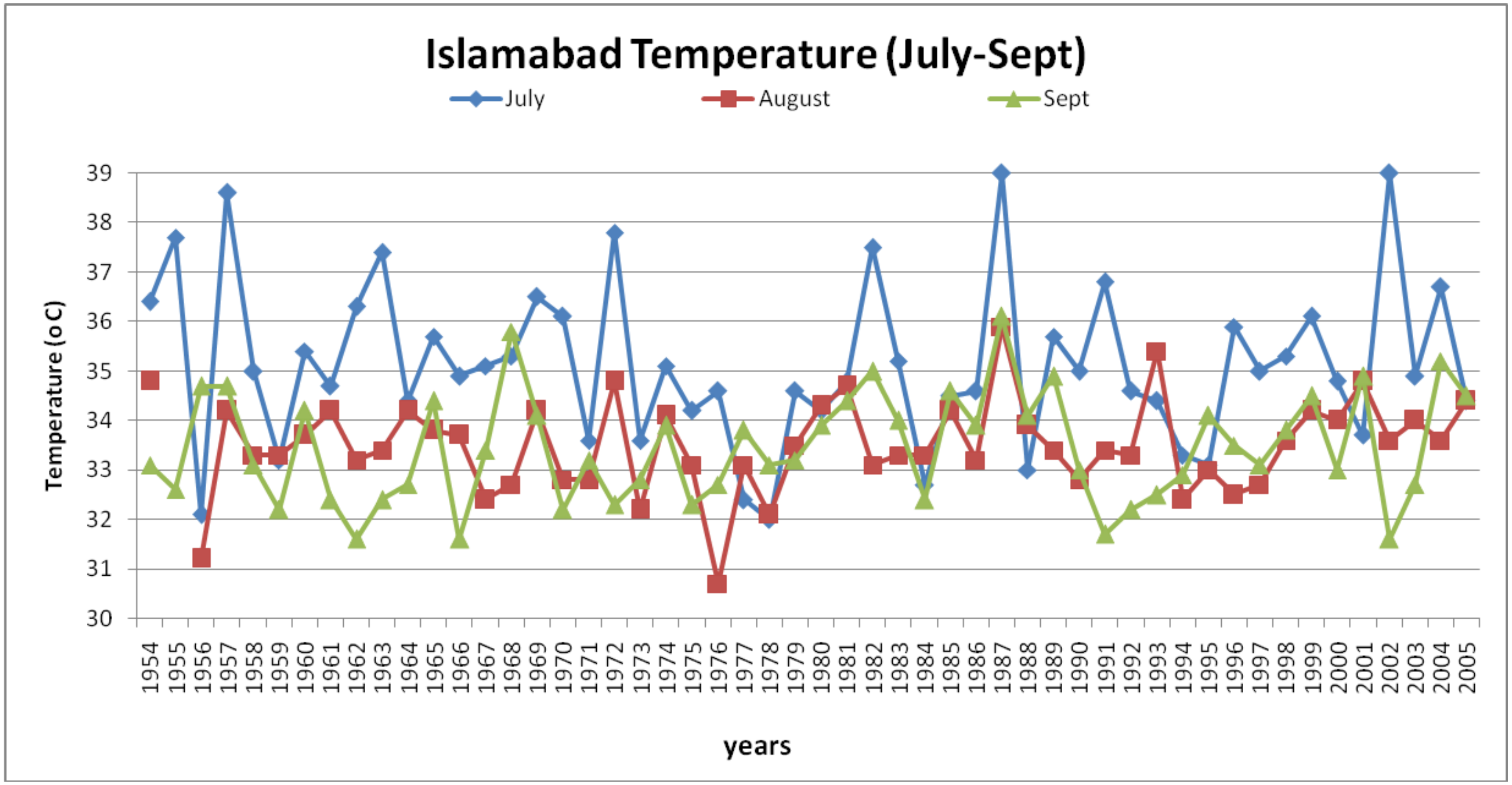

Figure 6.3- Mean yearly Temperature Variation in Islamabad (July-September

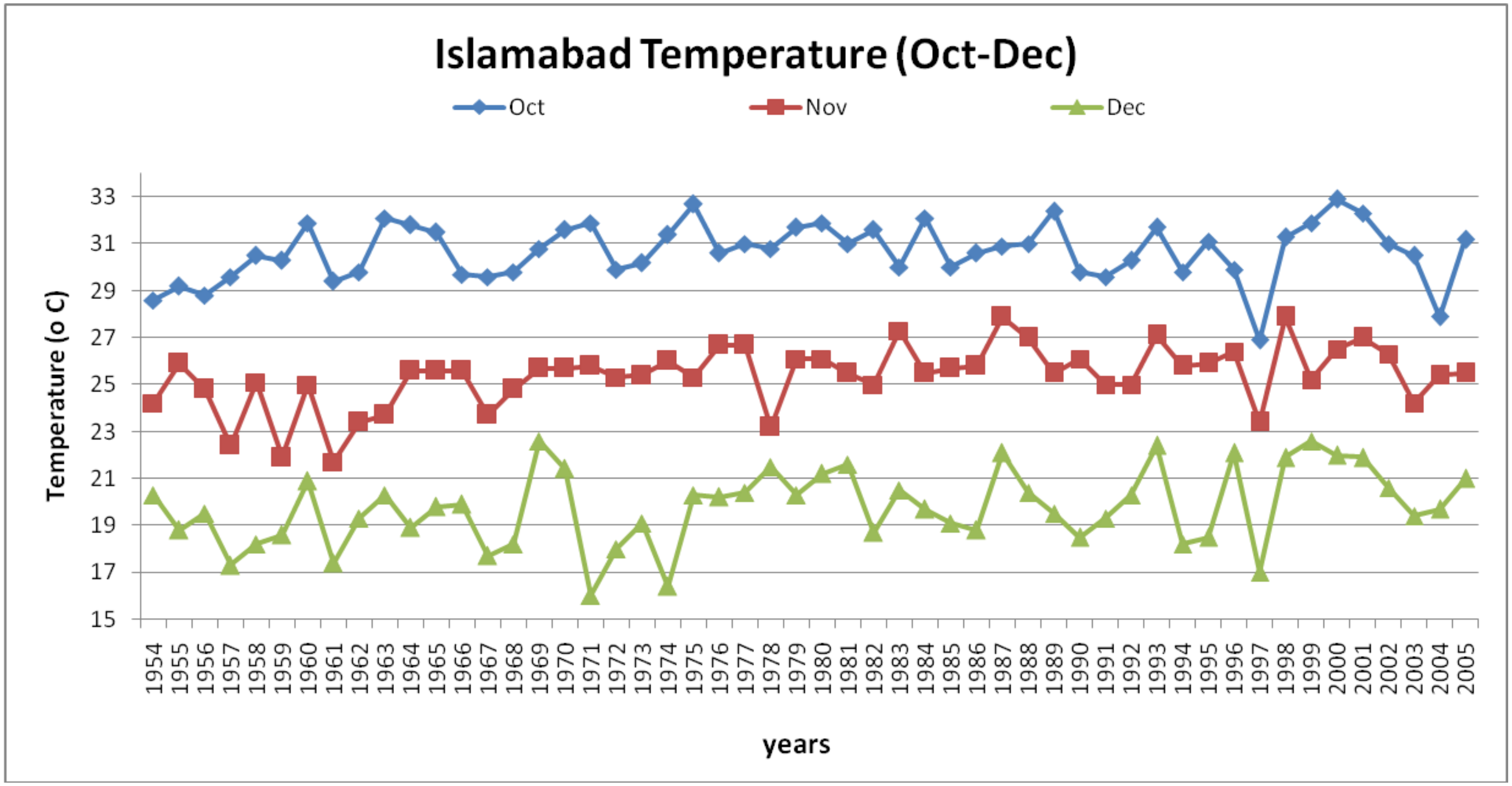

Figure 6.4: - Mean Yearly Temperature Variation (November- December)

Material	Density ρ/kg m^{-3}	Specific heat c/J kg^{-1} K^{-1}	Heat capacity cρ/J m^{-3} K^{-1}	Thermal conductivity λ/W m^{-1} K^{-1}	Thermal diffusivity a/m^2 s^{-1}	Thermal admittance b/J s$^{-0,5}$ m^{-2} K^{-1}
Asphalt	2,100	920	$2.0 \cdot 10^6$	0.75	$0.4 \cdot 10^6$	1,200
Loamy soil (40 % pore space; dry)	1,600	900	$1.4 \cdot 10^6$	0.25	$0.2 \cdot 10^6$	600
Ratio Asphalt/ Loamy soil	1.3	1.02	1.4	3.0	2.0	2.0

Table 6.5: Thermal properties of typical "urban surfaces" (asphalt) and "natural bare surfaces" (natural loamy soil)(Kuttler, 2008)

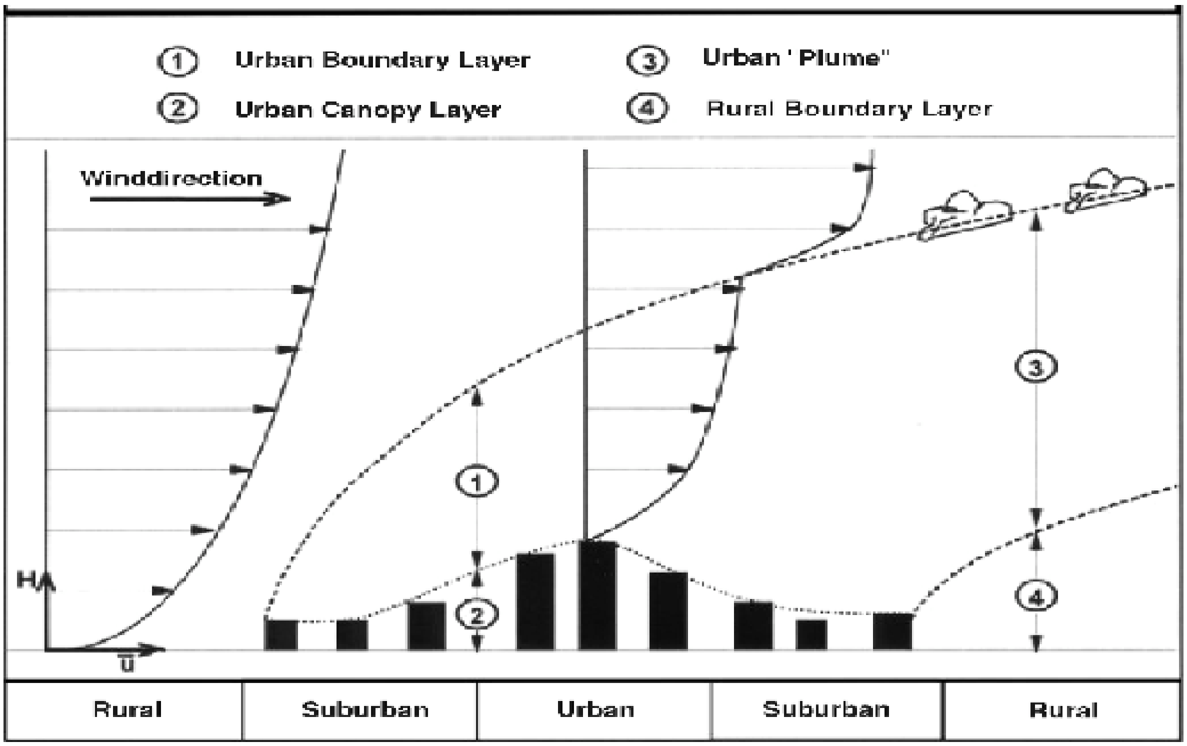

Figure 6.5:- Urban Atmospheric Layers (Kuttler, 2008)

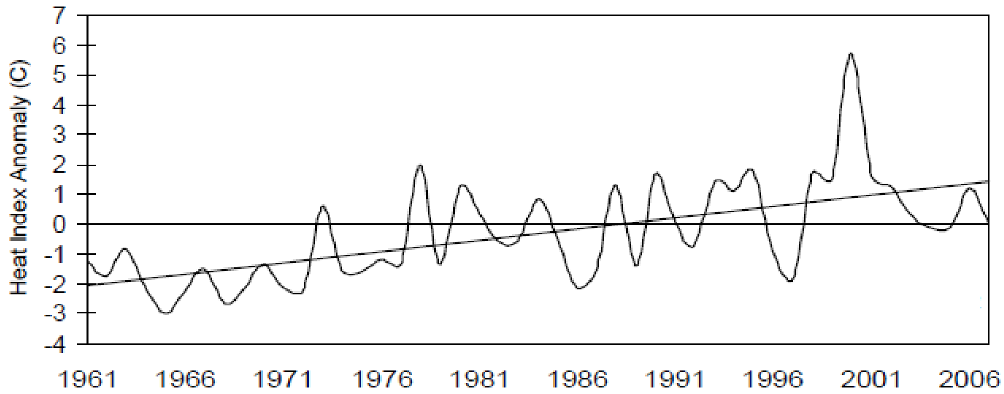

Figure 6.6: - Heat Index increment over the years in Punjab (Zahid & Rasul, January 2010)