Chapter One

INTRODUCTION
Chapter One

INTRODUCTION

Climate changes have had a large impact on ecosystems, the environment, agriculture and water resources. This is the primary reason why climate change investigations have attracted attention from the global scientific community. Increasing temperature, retreating snow cover and changing patterns of precipitation are among the many consequences which are attributed to global warming. Trend detection is an active area of interest for climatology in order to investigate climate change and enhance climate impact research. Therefore, trend detection in climatic parameters is crucial for planning and designing regional water resource management (Karpouzos et al. 2010).

Trend detection in climatology has garnered greater attention over the last fifty years. By the end of this century, climate change will impact the world in numerous ways, specifically with respect to water resources and agriculture. Simulations of crop production under different climatic scenarios have shown decreasing wheat and maize yields in Iran by the end of this century (Iran Department of Environment 2009). In the last one and a half century, human beings have enhanced the natural greenhouse effect of the atmosphere by increasing the quantities of key greenhouse gases. Carbon dioxide has increased 32% because of the burning of fossil fuels and deforestation, while methane has increased by 151% because of agriculture. In Iran 89% of the energy sector depends on fossil fuel (oil and gas). The energy sector is the main source of greenhouse emissions followed by the agricultural sector and industrial emissions of CO₂, chiefly by oil industries. The main source of methane is waste, resulting from anaerobic bacterial decomposition of organic matter in landfills and open dumps (Iran Department of Environment 2009).

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global mean surface temperatures have risen by 0.74 ± 0.18 °C over the last 100 years (1905-2005). The rate of warming over the last 50 years (0.13 ± 0.03 °C /10 year) is nearly twice of that, over the last 100 years (0.07 ± 0.02 °C / 10 year). By the end of the 21st century, global temperature is expected to rise by 1.8 °C to 4.0°C under various SRES (Special
Water is one of the most important natural resource and vital for all life. Precipitation is the meteorological variable of most importance since it conditions the availability of water on the surface. It has played an important role in the past and in the future, and will play a central role in the well-being and development of our society. Changes in precipitation are important for water management in the coming century.

Snow cover is another significant parameter in the hydrological cycle. Any change in snow cover area is critical for water resources, especially in drier regions such as southwestern Iran. Hence, monitoring of snow cover is important for management of runoff prediction, electric power production, irrigation practices, flood control etc. Snow cover could be a useful indicator of climate change because of its sensitivity to temperature.

In Iran, there is a paucity of research with respect to trend analysis of snow cover, change point detection and projections of temperature, precipitation and snow cover. The southwestern part of Iran is the most important region from the point of view of surface water storage and any significant trend in temperature, precipitation and snow cover is very important for policy makers in water resource management and agriculture in Iran.

1.1 Review of Literature
1.1.1 International Scenario

The trend detection and projection of temperature, precipitation and snow cover on global as well as regional scales has acquired special importance in the last few decades, due to the clear indications of global warming in the post-industrial area.

On global scale, the results of trend analysis indicate that there has been a substantial increase in the global surface air temperature since the beginning of the 20th century. During this period the surface air temperature has shown an increase of about 0.5 °C to 1.1 °C (Karoly 1989; Folland and parker 1990; Wallace et al. 1996; Zhen-Shan and Xian 2007; Bhutiyani et al. 2007). The IPCC
has clearly identified temperature trends on global scale, detecting an average surface temperature increase of about 0.74 °C during the period 1900-2005. It was shown that pronounced warming occurred over two periods, i.e. 1910-1945 and 1976-2000. The 1990s were the warmest decade experienced and 1998 was the warmest individual year during the instrumental record. According to IPCC (2007) climate change computations for Asia showed an increasing trend of approximately 0.65°C over most of the continents during the 20th century and climate change scenarios indicate future warming ranging from 1.70 °C (B1 scenario) to more than 4.80 °C (A1B scenario).

From 1900 to 2005, precipitation increased significantly in eastern parts of north and south America, northern Europe and northern and central Asia but declined in the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has increased since the 1970s (IPCC 2007).

Observed decreases in snow cover and ice extent are also consistent with warming. Satellite data since 1978 shows that annual average Arctic sea ice extent has shrunk by 2.7 % per decade, with larger decreases in summer of 7.4 % per decade. Mountain glaciers and snow cover on average have declined in both hemispheres (IPCC 2007).

On the regional scale also, trend analysis and projection of temperature, precipitation and snow cover have been attempted. Makokha (2010) used linear regression and MK-test to discern the annual temperature trends in Nairobi, Kenya. Results indicated that, the change of temperature over the thirty-four years study period is higher for TMIN than TMAX. The warming trends began earlier and are more significant at the urban stations than the sub-urban stations. Dhorde et al. (2009) employed linear regression and Mann Kendall test to find trends in annual and seasonal temperature series at four largest cities of India. Most of the trends showed positive changes in temperature with different rates in different seasons. In some cases, the trends showed asymmetry. Gadgil and Dhorde (2005) used MK-test and linear regression to evaluate temporal variation in temperature over Pune, India. The analysis reveals significant decrease in mean annual and mean maximum temperature. This decrease in temperature was
more pronounced during the winter season. Al Buhairi (2010), applied linear regression and Sequential Mann-Kendall test to evaluate variation in annual, seasonal and monthly temperature in Taiz, Yemen, during the period 1979-2006. The results of the analysis of the whole period reveal a statistically significant increasing trend in all the months and seasons. A tendency has also been observed towards warmer years, with significantly warmer summer and spring periods and slightly warmer autumn and winter, an increase of 1.79 °C and 1.18 °C has been observed in the mean summer and mean winter temperature, respectively. Positive trends of about 1.5 °C in the annual mean temperature were found for the whole period. Most of the break points in temperature series were around 1997 for most of stations.

Zhang et al. (2007) analyzed annual and seasonal precipitation from 1951 to 2003 in the Hanjiang basin in China using MK-test and linear regression methods. The results indicated, that precipitation in the Hanjiang basin had no trend, but the mean annual, spring, and winter runoff in the Danjiangkou reservoir basin had decreasing trends. Caloiero et al. (2011) applied MK-test and linear regression analysis to find any trend over one hundred and nine rainfall stations, with more than fifty years of data observed in a region of southern Italy. The result indicated a decreasing trend for annual and winter-autumn rainfall, and an increasing trend for summer precipitation. Fan and Wang (2010), employed Mann-Kendall test and Mann-Whitney test to find a trend from sixty-one stations across Shanxi, China from 1959-2008. The result indicated that annual precipitation had decreased by 99.20 mm during the past half century. The decrease was mainly caused by precipitation decline in rainy season (June-September), though precipitation in post-rainy season (October-November) also tended to decrease. An abrupt decrease in precipitation has occurred since late 1970s.

Acar and Şenocak (2008), investigated possible mean monthly snow cover depth trends at thirteen meteorological stations in east of Turkey. The Mann-Kendall test was used to demonstrate any existence of possible mean monthly snow cover depth trends. The results indicated that there are sixty-four series which did not indicate trend of mean monthly snow cover depth. However,
four stations showed a significant upward trend and one station a significant downward trend, while one station showed a significant both upward and downward trends for different months and all the others were without a significant trend. These changes could be associated with regional climate changes and global warming phenomena. Stephen et al. (2007), analyzed Northern Hemisphere snow cover extent (SCE) over the period 1972-2006 with NOAA images and the Mann-Kendall test reveals a significant decline in SCE during the spring over North America and Eurasia, with lesser declines during winter and some increases in the fall SCE. The weekly mean trend attains 1.28, 0.78, and 0.48 and 106 km² (35 years) over the Northern Hemisphere, North America, and Eurasia, respectively. The standardized SCE time series vary and trend coherently over Eurasia and North America, with evidence of a poleward amplification of decreasing SCE trends during the spring. Multiple linear regression analysis reveals a significant dependence of the retreat of the spring continental SCE on latitude and elevation.

Chen and Jiang (2011) employed AOGCMS model under A1B scenario over China for the middle and end of the twenty-first century. The result indicated that, surface air temperature is projected to increase significantly for both the middle and end of the twenty-first century under A1B scenario with larger winter for the period 2070-2099. There is a near 100% probability, across most of China for temperature to increase above 3°C. For a threshold of above 4°C northeast China, northwest China and Tibetan plateau exhibit high probabilities reaching 60% or higher. During summer high probabilities of precipitation increasing by 10%, mainly appear in southeast China and in the eastern part of northwest China. Jones et al. (2005) applied Had CM3 climate model between the 1950-1999 to 2000-2049 periods. Temperature regimes for the high-quality wine producing region are predicated to warm by an average of 1.24°C. Average predicted temperatures show increases within the 2000-2049 period which alone are 0.24 °C per decade and 2.04 °C overall, with warming rates for the Northern Hemisphere typically greater than the Southern Hemisphere wine regions. While, the observed warming of the late 20th century appears to have been mostly beneficial for high-quality wine production worldwide. Lu Liu et al. (2011)
employed the GCM under A2, A1B, and B1 scenarios over the six states of USA. The results of the study found that the average temperature over the study area is anticipated to increase by 1.7°C to 2.4°C in the twenty-first century based on the different emission scenarios with a rate of change that is more pronounced during the second half of the century. Summer and autumn seasons are projected to have more significant temperature increases, while the northwestern portions of the region are projected to experience more significant increases than the gulf coast region.

Hilario et al. (2008) applied HadCM3Q model, based on A1B scenario for projections of rainfall over the Philippines. The result indicated that in June, July, August, September, October and November seasonal rainfall in 2020s and 2050s will exhibit increasing trends with major peaks in June, July and August under the A1B scenario. Projection of seasonal temporal rainfall variation is largest (-35 % to 45%) during the seasons of June, July, August, and March, April and May. Meanwhile, projection of seasonal temporal rainfall variation is lesser (-0.5 % to 25%) during the seasons of December, January and February, and September, October, November. The drier seasons of December-February and March-May will become drier still, while the wetter seasons of June-August and September-November become wetter. Roy et al. (2009) used an ensemble of 15 GCM outputs by using MAGICC/SCENGEN version 5.3 under A1B scenario in the South-Western Bangladesh. The result indicated that, winter rainfall is likely to increase by 3.8% and 10.4% by the year 2030 and 2075. The pre-monsoon rain is likely to be less varying over the projected years, though post-monsoon rainfall shows a huge increase of 6.2 and 17 percent by the year 2030 and 2075 respectively. Nazrul Islam (2009), applied climate model named Providing Regional Climates for Impact Studies (PRECIS) adapted in generating rainfall scenarios for Bangladesh for 2010-2020. In 2009, the monsoon rainfall is projected with a surplus of 0.29 mm/decade (2.03%) and it will be surplus by 0.44 mm/decade (14.02%) in Postmonsoon. It will be deficit by 0.11 mm/decade (2.08%) and 0.01 mm/decade (1.44%) in pre-monsoon and dry season respectively. During 2009-2020, the change of rainfall is projected between +5.3% (in 2018) to -1% (in 2013) approx.
Scherler et al. (2011) used coup model to simulate the evolution of two high alpine permafrost sites in Switzerland under A1, B1, and A1B scenarios. The result indicated that the projected snow cover (> 10cm) at the two sites shows a general decrease in duration of about 50 to 80 days per year during the 21st century. The onset of the snow cover is delayed and the time that the sites become snow-free is earlier than observed in the recent years. For the Schilthorn site, three scenarios indicated that the active layer varies between 5m and 12m until around 2020s. After that period, the thaw layer does not freeze up anymore and a talik develops. Two scenarios show no stable permafrost conditions after 2020s. One scenario predicts stable permafrost until 2050s. For the Murtel site three scenarios show an increase of active layer depth from 2.5m to around 7m in 2090s. One scenario shows no change until 2050s.

1.1.2 Climatic Change: Iranian Scenario

Many scientists have studied the trend detection of temperature and precipitation in Iran.

Alijani (1997) investigated mean annual and seasonal temperature records using the MK-test at Tabriz, Tehran, Isfahan, and Bushehr stations from 1951 to 1993. His results did not show any dominant and widespread climate change, but a climatic fluctuation was observed at the stations. Besides, winter temperature series was relatively stable and showed a trace of cooling trend, while the other seasonal series indicated a noticeable change and the second half of the study period became warmer. Kousari et al. (2011) surveyed trends in the precipitation, temperature, and relative humidity series in Iran using the MK-test. They reported an increased trend for air temperature and a decreased trend for precipitation and relative humidity at the majority of the selected stations. Tabari and Hosseinzadeh Talaee (2011a) applied Mann-Kendall test and Mann-Whitney test for twenty-nine synoptic stations in Iran for a period of forty years (1966-2005). The influences of significant lag-1 serial correlation were eliminated from data by the trend-free pre-whitening method prior to the trend analyzed. The magnitude of the temperature trends was derived from the Theil-Sen’s slope estimator. It was found that, the annual mean air temperature increased at twenty-
five out of the twenty-nine stations, of which, seventeen stations showed significant monotonic trends. The magnitude of the annual mean air temperature trends was 0.22 °C per decade. Most of the stations with the significant positive monotonic trends had a significant upward shift. The analysis indicated that the change point year of the significant upward shift changes was 1972. Shirgholami and Ghahraman (2009) investigated a long-term trend of annual mean temperature in thirty-four synoptic stations in Iran by applying the minimum square-error and Man-Kendall methods. The results confirmed a positive trend in 59% of stations, while 41% of the stations were negative for the whole time-horizon of the data. Considering the significance level, three zones of positive, negative, and no trends for annual mean temperature were detected in Iran.

Asadi and Heydari (2010) applied linear regression, Z Score, moving mean, independent and homogeneity tests, Beta test and Mann-Kendall test techniques to temperature and precipitation data during fifty-five years period between 1951 to 2005 in Shiraz, Iran. The annual precipitation average showed a decrease in the trend and the seasonal precipitation average was observed in all seasons except in winter. At this station, precipitation and temperature annual increasing trend followed an inverse trend, it means that, with increasing temperature, precipitation was decreasing. Ramazanipour and Roshani (2011) investigated the type and time of discharge changes in relation to precipitation in the Polroud basin in Iran by using MK-test and linear regression for the period 1968-2005. These results suggest that, data series had trend and an abrupt change. On the other hand, there was a good fitting between discharge and precipitation trend. There were also the same trends in autumn winter and spring, especially. These parameters had ascending and descending trends in autumn and spring, respectively. The precipitation had an ascending trend, whereas a descending trend of discharge was seen in summer. The discharge presents a descending trend in all of the seasons. Totally, the trends of parameters were similar and the changes of discharge are dependent on precipitation. Eslamian and Khordadi (2009), applied Mann-Kendall test, linear regression analysis, the cumulative deviation, to find the trend in rainfall and discharge data in Karkhe basin located in west of Iran during 1966 to 2002. The results indicated that, rainfall and
discharge data had no significant long-term trends. Raziei (2008) employed MK-test to find any trend in precipitation data at 79 climatological stations from 1965 to 2000 in arid and semi-arid regions of Iran. The result indicated that, there was no evidence of climate changes in the study area. Although many stations showed negative trends indicating a decrease in precipitation. This trend was not statistically significant at 95% confidence level. Ghahraman (2006) analysed annual precipitation data in Iran where mean annual rainfalls were collected from thirty synoptic stations with a reasonable geographic distribution and with data equal to or less than fifty years was used. Trend analysis was investigated using a linear regression slope method. The result indicates that, for the entire period, (at 95% confidence level), seven stations showed a negative trend, while a positive trend was found at six stations. The same data over the period of last forty years demonstrated that, four and eight stations had negative and positive trends, respectively. Decreasing the record length, up to the last thirty years resulted in fewer stations with any significant trend. Katiraie et al. (2007) investigated the daily precipitation data from thirty-eight stations in Iran for the period of 1960-2001 to evaluate the possible long term trend in annual and seasonal precipitation by using Mann-Kendall and least square method. The result indicate that, the annual precipitation had a decreasing trend at stations in the west, northwest and southeast and an increasing trend at most of the stations in the other parts of the country. The winter precipitation indicated a trend, very similar to that of the annual precipitation. Most of the stations had shown a reduced precipitation during spring and increased precipitation in autumn.

Fattahi (2009) used NOAA satellite image with AVHRR sensor for the period 1988-2005 covering northwest of Iran. The images of AVHRR sensor were processed by stage manner using the ERDAS software. In order to survey the variation of snow cover trend Mann-Kendall test was done. The results did not support significant trend for snow cover in the region. Fattahi (2010) investigated correlation with variations of large scale climatic signals such as SOI, NAO, and ENSO with snow cover area in southwestern Iran. In order to estimate the snow cover area variations, satellite data of NOAA-AVHRR were used for the selected days in the cold period of 1986 to 2007. The areas covered by snow were
detected by applying a threshold based method and using radiances in band one and three, and land surface temperature derived from brightness temperature. In the end, the snow cover area was predicted three to six months in advance by applying an artificial neural network approach. The results indicated that NAO, SOI, Nino4, and Nino1+2 signals were the most effective signals on variations of snow cover area.

Roshan et al. (2011) analysed trend in minimum, maximum, and mean seasonal temperature from 1951-2005 in Iran. They applied MAGICC SCENGEN model under different climate change scenarios for forecasting. In the analysis of the country's current temperature trend and in the forecasting indicated that a significant temperature increase was observed during the summer months. Also, with regard to altitudinal levels, it was evident that, stations at higher altitudes show a more significant increase in daily and mean daily temperatures. Taking into account the output mean of the different climate change scenarios, the temperature simulations show a 4.41 °C increase in Iran mean temperature by 2100. Most of these temperature increases would occur in the southern and eastern parts of Bushehr, certain coastal regions of the Persian Gulf, eastern and western parts of Fars, Kohgilooeye, Boyerahmad, southern parts of Yazd, as well as southern and southeastern parts of Isfahan.

Roshan and Grab (2012) analyzed temperature and precipitation trend during 1960-2009 and projected future changes to up 2100 based on the MAGICC/SCENGEN 5.3 compound model. Result indicates that, winter precipitation has marginally increased across the country as a whole; a significant decline in mean spring precipitation was recorded between 1960 and 2009. However, considerable variability in trends is measured across various climatic regions of Iran. Mean annual temperature and rainfall changes in the various climate zones of Iran for the period 1960-2009 is as follow: +0.1°C per decade and +0.43 mm per decade in arid regions, -0.1 °C per decade and -1.7 mm per decade in semi-arid regions, +0.1 °C per decade and -1.33 mm per decade in Mediterranean - semi humid regions and -0.01 °C per decade and -0.04 mm per decade in humid-hyper humid regions. Temperature projections to up 2100 indicate an overall temperature rise of 4.25 °C relative to that for 1961-1990, with
increases projected for all climatic regions of Iran. Despite an overall projected mean precipitation increase of 36% for the year 2100, relative to that for 1961-1990, these are insufficient to compensate of temperature increases.

In trend analysis, most of the Iranian scientists have focused only on a single climatic parameter. In this research, more climate parameters have been considered and 3 statistical tests were used for trend and change point detection, in order to find out climate trends in the climate of the study area.

In connection with projection of precipitation and temperature, it is seen that the results of previous studies are generally based on only one model simulation. However, in this study, outputs of four leading international center models have been used. Such a study, combining trend analysis and projections with four models is attempted first time for any area in Iran.

1.2 Study Area

The area under consideration consists of southwestern part of Iran, particularly the states of Isfahan, Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, Lorestan and Khuzestan (Fig. 1.1). The region spreads over 231547 square kilometers which is about 14% of the country's area. According to last census (2003), population of region was 12,000,000 persons which is about 17% of the country's total population. This region is the most important petroleum, gas and petrochemical zone in Iran. According to land use map (Fig.1.2), the largest area was rangelands with 5-25% canopy cover with 6867998 hectares. All classes in the area have been represented in Table1.1.

1.2.1 Drainage

The southwestern part of Iran is the most important region with respect to surface water storage in Iran. There are big rivers like Karoon, Dez, Zaiande Rood, and Karkhe (Fig.1.3). There are also big dams like Shahid Abbaspoor, Dez, Zaiande Rood and Karkhe. With the help of canals, water from this area is taken to central parts of Iran, which are arid in nature. Therefore, snow cover and precipitation are the most important source of water to the central parts of Iran.
Fig. 1: Location of Iran and the study area.
<table>
<thead>
<tr>
<th>Class</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different types of sand dune</td>
<td>397004</td>
</tr>
<tr>
<td>Dry farming</td>
<td>1312439</td>
</tr>
<tr>
<td>Forest with 25-50 % canopy cover</td>
<td>1264333</td>
</tr>
<tr>
<td>Forest with 5-25 % canopy cover</td>
<td>1631196</td>
</tr>
<tr>
<td>Forest with more than 50% canopy cover</td>
<td>412697</td>
</tr>
<tr>
<td>Irrigated farming and orchards</td>
<td>2431560</td>
</tr>
<tr>
<td>Kavir (low desert lands without canopy cover)</td>
<td>217174</td>
</tr>
<tr>
<td>Lakes and water reservoirs</td>
<td>37750</td>
</tr>
<tr>
<td>Large river beds</td>
<td>114455</td>
</tr>
<tr>
<td>Marsh lands with high level surfaces water</td>
<td>316109</td>
</tr>
<tr>
<td>Plantation forests</td>
<td>399752</td>
</tr>
<tr>
<td>Rangelands with 25-50% canopy cover</td>
<td>2964534</td>
</tr>
<tr>
<td>Rangelands with 5-25% canopy cover</td>
<td>6867998</td>
</tr>
<tr>
<td>Rangelands with less than 5% canopy cover and out crop</td>
<td>2133530</td>
</tr>
<tr>
<td>Rangelands with more than 50% canopy cover</td>
<td>1244281</td>
</tr>
<tr>
<td>Reed bed in the water or swamp margines</td>
<td>83346</td>
</tr>
<tr>
<td>Salty lands</td>
<td>845881</td>
</tr>
<tr>
<td>Shrublands with more than 10% canopy cover</td>
<td>160867</td>
</tr>
<tr>
<td>Smooth clay surfaces in the margines of Kavir</td>
<td>54776</td>
</tr>
<tr>
<td>Smooth sand surfaces</td>
<td>29859</td>
</tr>
<tr>
<td>Urban and rural areas and installations (settlement)</td>
<td>205226</td>
</tr>
</tbody>
</table>
1.2.1.1 Karun River

The Karun River with a drainage area of 58100 km² at Ahwaz is the largest river in Iran and drains into the Persian Gulf. The Karun River originates in the Zagros Mountains 75 km southwest of Isfahan and flows in a general westerly direction through a descending series of anticline ridges and synclinal valleys before emerging in Khuzestan. The river is around 950 km long and has an average discharge of 575 (m³/s). There are a number of dams on the Karun River, mainly built to generate hydroelectric power and provide flood control. Gotvand Dam, Masjed Soleyman Dam, Karun-1, Karun-3, and Karun-4, are the most important dams on Karun River.

1.2.1.2 Karkheh River

Karkheh River originates from the middle and south-west zones of Zagros Mountain range, located on the west and north-west regions of the country. After crossing a distance of about 900 km from north to west, the river reaches Huralazim Lagoon, on the border of Iran and Iraq. Karkheh is the third largest river in Iran, after Karun and Dez. The watershed of Karkheh consists of an area
of 42000 km$^2$. The average annual water yield of the river at Pay-e-Pol hydrometric station is 5916 mm, and the average annual long-term water yield at this station amounts to 188 m$^3$/s.

1.2.1.3 Dez River

The Dez River rises in the Zagros range and joins the Karun River at Bamdej. The catchment area of the Dez River at its confluence with the Karun is estimated to be 21720 km$^2$. The maximum altitude of the basin is 4124 m and the minimum (Bamdej) is 19 m. The catchment area of the Dez River above the dam site is 17372 km$^2$. The associated reservoir is about 60 km in length.

1.2.1.4 Zayandeh Rood River

The Zayandeh Rood rises in the Zagros Mountains and flows 400 km eastward before ending in the Gavkhouni swamp, a seasonal salt lake, southeast of Isfahan city. There are 2,700 square kilometers of irrigated land in the Zayandeh River basin, with water derived from the nine main hydraulic units of the Zayandeh River, wells, qanat and spring in lateral valleys. Zayandeh River water gives life to the people of central Iran mainly in Isfahan and Yazd provinces. Water diverted per person is 240 litres per day in villages. The flow of the river has been estimated at 38 m$^3$/s.
1.2.2 Physiography

Physiographically the region can be divided into eastern plains (Isfahan), western plains (Khuzestan), and Zagros Mountain range in the middle (Fig. 1.4).

1.2.2.1 Eastern Plains (Isfahan)

Based on tectono-sedimentary zones, Isfahan plains include parts of central Iran zone. Central Iran zone is triangular in shape is one of the largest & most complicated lithologic units. Early Precambrian rocks exceed 10,000 m in thickness, which are in turn the product of older rocks decomposition. They are intensely metamorphosed by Katangan orogeny, which made up Iranian plateau. It is covered with late Precambrian to Triassic continental to shallow marines, referred to as plateau covering, but movements along the faults often displaced them vertically that led into angular unconformity & facies charges.

1.2.2.2 Zagros Mountain Range

The Zagros Mountains are located in western and southwestern Iran at the eastern edge of the Persian Gulf and are a part of the Alpine-Himalayan mountain chain that stretches across much of southwest Asia and the Middle East. The Zagros are located on the boundary between the Arabian and Eurasian lithospheric plates, and are an orogenic response to a collision between Eurasia and advancing Arabia during the Cenozoic (Takin 1972; Agard et al. 2005).

Geologically, Zagros Mountains have originated from alpine mountain-producing activity. As per the theory of plate tectonics, the Arabia plate has thrust below the Iranian plate. The result of this phenomenon, which still continues is creation of three distinct land-making regions called winkled region, up-driven region and broken up region of Zagros. Because the region is calcareous, there are various geomorphological features like calcareous caves and ditches. The well-know mountain peaks of this area are Dena (4430m), Zard Koohe Bakhtiary (4221m) and Kino (3996m).
1.2.2.3 Western Plains (Khuzestan)

From geomorphological viewpoint, three morphologic faces are dominant on Khuzestan. At first are the rocky units which are located in the north-east region of the plains. Second; hill units which have a coverage area located around Dezful, Ramhormoz & Ahwaz. Third, alluvial plains & flood plains that form the grounds located in south of Ahwaz to Persian Gulf beaches & are a kind of deposited geomorphologies. Structural position of Khuzestan plains is in tectonic- sedimentary & structural history is dominant on it. Mountainous part of Khuzestan is a sample from uniform folded mountainous masses that are named folded Zagros due to special lithologic & structural characteristics. In morphology, tectonic phenomena, lithologic composition of geological formations, amount of compaction & susceptibility of rocks to erosion & finally generative origin (erosion- deposit) have an important role.

1.2.3 Climate

Iran, with an area of 1,648,000 km$^2$, is located in the south west of Middle East. Climatically, in most parts of the country, usually there are four seasons, and in general, each year can be divided into two seasons, warm and cold. Iran has both geographical and topographical differences thus resulting in climatic differences from region to region. Iran is surrounded by two mountain ranges, namely Alborz in the north and Zagros in the west and the highest point of the country is located within the Alborz mountain range with an elevation of 5,628 m above the sea level. These mountains avoid Mediterranean moisture bearing systems crossing through this region to the east. The Zagros mountain range is responsible for the major portion of rain-producing air masses that enter the region from the west and north-west, with relatively high amounts of rainfall (Sadeghi et al. 2002). The directions of its mountains, its being adjacent to the hot and arid Saudi Arabian deserts, and its distance from the seas are the most important reasons behind Iran's diverse climatic conditions. One distinct climatic feature of Iran is the intense temperature gradients, which at certain instances exceed 40 degrees centigrade.
The warmest areas of the country are the coastal regions of the Persian Gulf and the Oman Sea as well as the pits in Loute and Sistan. The climate in this region is defined as subtropical with hot and dry weather in the summer. The main cause of annual rainfall variability in Iran is the changing position of synoptic systems and year to year variation in the number of cyclones passing through the region (Modarres and da Silva 2007).

Southwestern Iran is located in the mid-latitude belt of arid and semiarid regions of the Earth. The climate of the southwestern Iran is mainly arid or semi-arid, except the Zagros Mountains. Koohrang station, with an annual average rainfall of (1026 mm) which is the highest rainfall in the area. Distribution of precipitation in southwestern Iran is uneven. The average amount of precipitation is 252 mm/year, which is less than one-third of the world average (Alizadeh and
Keshavarz 2005). About 30% of the precipitation is in the form of snow, and the rest is rain and other forms of precipitation (Mousavi 2005). Average thickness of snow at 2000 to 2500 m altitude is 1.5 to 5 m. Beyond 2500m it varies between 5 and 10m and in Zard Kooh-e Bakhyiary it exceeds 12m (Alijani 1995). Precipitation in southwestern Iran has a high spatial and time variability. There are regions in the Zagros Mountains which receive up to 1200 mm of annual precipitation. Whereas in eastern parts of the study area get less than 100 mm and Khuzestan receives rain between 100 to 300 mm. Furthermore, most of the precipitation in southwestern Iran falls during the winter and autumn seasons, due to the prevalence of humid westerly winds of Mediterranean origin. However, mean average precipitation from 1970-2007 was 432.29 mm in annual, 261.5 mm in winter, 73.9 mm in spring, 1.24 mm in summer and 122.90 mm in autumn. The major part of precipitation occurs between October to April, and then the warm-dry season prevails. The Zagros mountain range is responsible for the major portion of the rain producing air masses that enter the region from the west and northwest, with relatively high rainfall amounts for those areas (Sadeghi et al. 2002).

Most parts of southwestern Iran, especially in the warm season, are affected by a subtropical high mass of the air. For this reason, summer is the warm-dry season. Temperature range (maximum and minimum) in most parts of the southwestern Iran is about 22-26 °C. Mean annual temperature is 16.71°C, mean winter temperature 6.24°C, mean spring temperature 20.18°C, mean summer temperature 27.15°C and mean autumn temperature 13.1 °C. Mean maximum annual temperature is 24.58 °C, mean maximum winter temperature 12.66 °C, mean maximum spring temperature 28.46°C, mean maximum summer temperature 36.26°C and mean maximum autumn temperature 20.46 °C. Mean minimum annual temperatures is 8.73°C, mean minimum winter temperature 0°C, mean minimum spring temperature 11.79°C, mean minimum summer temperature 17.6°C and mean minimum autumn temperature 5.5°C from 1970-2007 (Fig. 1.5; Fig 1.6).
Fig. 1.5: Annual temperature and rain fall zones.

Fig. 1.6: Monthly average precipitation and temperature from 1970 to 2007.
1.3 **Aims and Objectives:**

The main aim of the proposed research is to evaluate climatic trends in the region under consideration and to understand the effect of climate change on snow cover. To fulfill this aim following research questions have been framed.

I. What has been the trend of maximum, minimum and average temperature since 1960?

II. Whether the trends observed on annual and seasonal scales are similar?

III. Has rainfall/snowfall increased or decreased during the study period?

IV. In response to the above changes that have occurred, whether any change in the snow cover is evident?

V. Based on above investigations, can we project the status of snow coverage in the future?

VI. What are the projections for temperature and precipitation in the 21st century?

1.4 **Arrangement of Text**

The entire work has been organized in six chapters.

The first chapter deals with the introduction of subject of climate change and its significance for temperature, precipitation and snow cover changes and the recent observations that are made by different researchers. It also discusses the objectives, introduction to the study area. A review of literature on relevant research work is also highlighted in this chapter.

The methodology adopted for executing the present work has been explained at length in second chapter. This chapter describes the meteorological, remote sensing and modeling data obtained from different agencies and government publications. It also discusses the statistical techniques applied such as linear regression, t-test, MK-test and Sequential Mann-Kendall test, Pettitt’s test, SNHT, the standard normal homogeneity test by Alexandersson and Moberg test and description of remote sensing techniques and climatology modeling like CNRM, ECHAM, MIROCH and UKMOC models for projection of temperature, precipitation and snow cover.
Chapter three throws some light on, the regional variation in temperature during annual, seasonal and snow cover observed period scales. Since temperature is a major indicator of climate change, attempt is made to analyze the trends in different temperature series, that is, the maximum, minimum and mean temperature during annual, seasonal and snow cover observed period scales. Also to project the temperature over southwestern Iran under two B1 and A1B emission scenarios and four models CNRM, ECHAM, MIROCH and UKMOC from 1981-2100 during annual, seasonal and snow cover observed period.

The fourth chapter seeks to find out the precipitation trends during different annual, seasonal and snow cover observed period scales. The chapter also highlight projection of precipitation over southwestern Iran under two B1 (lowest) and A1B (medium) emission scenarios and four models CNRM, ECHAM, MIROCH and UKMOC from 1981-2100 during annual, seasonal and snow cover observed period.

The fifth chapter investigates the trend in snow cover using remote sensing data. For the analysis of trend in the snow cover, which was observed in the months of December, January, February, March and April the remote sensing image from NOAA website from first of every month was downloaded. This was followed by calculating the area and computing it in the trend analysis. Also projection of snow cover over southwestern Iran under B1 and A1B emission scenarios and four models viz. CNRM, ECHAM, MIROCH and UKMOC were studied for the period 1981-2100.

Based on the result obtained, the conclusion and major findings are discussed in the sixth chapters. It summarizes the overall trends in temperature and rainfall and snow cover and result of projection of temperature, precipitation and snow cover.

1.5 Significance of the Study

The complex physical conditions of Iran including topography, vegetation cover and landscape have created a diverse climate pattern (Alijani 1995). We know that, climate is a very important factor in the development and progress of the country and therefore, it has to be studied and understood particularly for
planning and policy decisions. To understand climate and to investigate changes in it, a region specific approach is required where, we take up smaller regions to comprehend the alterations in a better way. Climate controls our natural resources and in itself is a resource to the mankind. In the proposed study, an attempt will be made to evaluate changes in temperature, precipitation and snow cover in the southwestern part of Iran. This region also includes a part of Zagros Mountain ranges. These ranges are covered by snow for some part of the year and in other months the snow becomes a precious source of water for the ecosystems and the human population in this area. Any negative change in climate particularly temperature and rainfall would affect this precious source of water in the area. Thus, the proposed research would lead to understanding of tendencies in temperature and precipitation and their effect on snow cover during the last forty years. It will also attempt to predict change in temperature, precipitation and snow cover in the future.