# ABSTRACT

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## 1. Introduction to the Problem

The increase in atmospheric $CO_2$ has been well documented since 1950 when accurate and consistent measurements began. This increase, along with increases in other radiatively active gases, is believed to be changing the earth's energy balance. There has been recent confirmation of anthropogenic changes in the earth's climate related to these increases, and further changes are anticipated (Haskett et al. 2000). Based on global circulation models, it has been suggested that a doubling of ambient $CO_2$ concentrations could increase the global mean air temperature by 1.4-5.8 °C from the pre-industrial level (Komatsua et al. 2007).

Recently, using a state-of-the art climate model to investigate the origin of the 20th century warming, Stott et al. (2000) showed that natural climate forcing alone cannot account for the increase in global temperature in recent decades. In spite of sufficient evidence on the role of anthropogenic activities in climate change there are still uncertainties involved in respect of nature and extent, cause and effect and reversibility of complicated processes that operate in a natural system. To tackle these uncertainties intense scientific efforts are being made by researchers so as to accurately predict the future trends. Globally, many studies have been carried out to identify the causes of climate change. These causes can be stated as:

i) Changes in atmospheric composition due to volcanic eruption and anthropogenic activities increase in the levels of GHGs,

ii) Modification of land surface characteristics due to land use change and

iii) The phenomena of urban heat island.

The above-mentioned causes may be applied to any region of the world. But for this it is important to first evaluate the trends in basic climatic elements. It is now recognized that instead of concentrating on larger regions, smaller regions should be taken up for the studies so as to understand the vulnerability of a region to climate change. Based on the findings strategies can be drawn to face future climate change. Therefore in the proposed study the southwestern part of Iran is taken up for assessing climatic trends.

With regard to this research, identification of long-term temperature,

precipitation and snow cover trends will be of significant importance to the Iranian government, as it will enable the government to make policy decisions in areas such as agriculture, water supply and industry. In Iran, surveys of long-term temperature, precipitation and snow cover variations, trends and projections of data continue to go unnoticed despite the fact that the region is suffering from serious environmental, agricultural and water resource issues.

This study focused on investigation of trends in TM, TMAX and TMIN, precipitation and snow cover series over time and space in southwest Iran. Secondly, the study attempted to project mean temperature, precipitation and snow cover over the southwestern part of Iran, using CNRM, ECHAM, MIROCH and UKMOC models under B1 and A1B emission scenarios.

## 2. Study Area

The study area covers southwestern part of Iran, particularly the provinces of, Isfahan, Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, Lorestan and Khuzestan. The region spreads over 231547 sq km which is about 14% of the country's area. According to the last formal census (2003), the population of the region was 12,000,000 which is about 17% of the country's total population. From geological point of view, this region can be divided into eastern plains, western plains, south western plains and the Zagros Mountain range. Geologically Zagros Mountains have originated from alpine mountain-producing activity. As per the theory of plate tectonics, the Arabia plate was thrust below the Iranian plate. The well-know mountain peaks of this area are Dena (4430m), Zard Koohe Bakhtiary (4221m) and Kino (3996m). Zagros region is Iran's second rainiest region. Rainfall usually occurs between October and April months. Most of the rain is in the form of snow because of coincidence with cold season. 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 Koohe Bakhyiary it exceeds 12m (Alijani, 1995). Thus, in this region, snow cover is one of the important and valuable sources of water. There are big rivers like Karoon, Dez, Zaiande Rood, Jarahi, Zohre, etc. There are also big dams like Shahid Abbaspoor, Dez, Zaiande Rood, Karkhe and Maroon. With the help of canals water from this area is taken to central parts of Iran, which are arid in nature. Therefore, snow cover is the most important source of water to the central parts of Iran also. That is why, along with studying climatic trends, investigations in snow cover changes are also being carried out in the proposed research.

**3. Aims and Objectives:**

The main aim of the proposed research was to evaluate climatic trends in the study area and to understand the effect of climate change on snow cover. To fulfill this aim following research questions were 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?

**4. Methodology and Data Available**

This study focused on trend analysis and projections in temperature, precipitation and snow cover series over southwestern part of Iran during snow cover observed period, seasonal and annual scales. Observed monthly temperature and precipitation series for period from 1950-2007 from 50 precipitation stations and 39 temperature stations, obtained from Iranian Meteorological Organization and Iranian Water Resources Management Company were considered for analysis. Monthly data are computed to obtain seasonal and annual averages for each station. Seasons were defined as follows: winter (January, February, March), spring (April, May, June), summer (July, August, September) and autumn (October, November, December).

To understand the tendencies in temperature and precipitation and effect on snow cover we analysed temperature and precipitation trends in the snow cover observed period of the year. This snow cover observed period includes the month of December, January, February, March and April.

All precipitation and temperature stations data were carefully analyzed for homogeneity and for missing data. These missing values were obtained for temperatures by subtraction method and for precipitation by applying the ratios method. Stations with more than 10% missing data were not used. Three tests for homogeneity data were used. The SNHT, Pettitt's test and the standard normal homogeneity test by Alexandersson and Moberg.

For spatial and temporal computations of temperature, precipitation and snow cover trend linear regression analysis; Sequential Mann-Kendall test and MK-test were applied. The presence of a monotonic increasing or decreasing trend was analyzed by the MK-test, a non-parametric test. Linear regression was used to find trends and rate of change in temperature over time. These trends were then tested for statistical significance by employing t-test. The Sequential Mann-Kendall test is used for determining the approximate year of the beginning of a significant trend.

For calculation of snow cover area we used remote sensing images from NOAA satellite image with AVHRR sensor. The data was for the period 1987-2007 for snow cover observed period including, December, January, February, March and April.

For future projection of temperature, precipitation and snow cover we used CNRM, ECHAM, MIROCH and UKMOC models under B1 and A1B emissions scenarios were used.

## 5. Results and Discussion

### 5.1 Homogeneity Tests

The result for precipitation series indicated that from the annual and seasonal precipitation series only 3 out of 50 stations belonged to class 2 or doubtful and other stations belonged to the class 1 or useful.

In annual temperature it was found that 6 stations out of 39 stations belonged to class 2 or doubtful and other stations were in the class 1 or useful. The homogeneity of autumn temperature series indicated that 4 stations belonged to class 2 (doubtful) and other stations belonged to class 1 (useful). The spring temperature series of 6 stations out of 39 qualified for class 2 (doubtful) and other stations for class 1 (useful). In summer series, 4 stations were found to be falling under class 2 (doubtful) and other stations under class 1 (useful). The analysis of winter temperature series depicted that the series of 4 stations was found to be doubtful (class 2) and other stations as useful (class 1). In the precipitation and temperature data series we did not find any Class 3 or suspect stations. The study showed that all the three tests are very sensitive to non-homogeneity in the series and can be effectively used for temperature as well as precipitation data. The three-way approach is therefore, in a way a robust approach to test and confirm homogeneity in data series.

### 5.2 Serial Correlation Effect

The result indicated that most of the stations had positive lag-1 serial correlation coefficient in temperature and precipitation series. The significant correlations were found at about 37 %, 32 %, 44% and 4% of the stations in the TM, TMAX, TMIN and precipitation respectively. In summer temperature series, most of the stations showed significant lag-1 serial correlation coefficients.

### 5.3 Trends and Projections: Temperature

The results of statistical analysis over southwestern Iran indicated that most of the stations had positive significant trends during summer and spring and winter was more stable than other seasons. These results are true for projection of temperature patterns as well. TMAX was found to be more stable than TM and TMIN in seasonal and snow cover observed period. The result of snow cover observed period showed that December was more stable than other months and more significant temperature trends were found in February and April. Most of the stations had negative insignificant trends in December series. In summer TMIN and March TMAX series, some stations indicated an increase of more than 1 $^{\circ}$C per decade.

Sequential Mann-Kendall test showed that, most of the positive significant mutation points occurred after 1990. Vast urbanization and industrialization during the past decade can be considered as a reason for positive trend in air temperature. The urbanization process in study area started after the war between Iran and Iraq (1988) stopped and when the government started to construct cities and develop the oil industry and agriculture. The government's decision to promote industrial development and establishment of factories and industries around big cities led to an influx of population thereby increasing the construction of high-rise buildings and large housing estates in the 1990s.

Temperature projections indicate that major changes may occur in summer and spring seasons. The result of temperature projection in snow cover observed period shows that temperature will increase more in December, March and April in both scenarios, with more warming occurring in April. February temperatures are projected to remain relatively stable. Taking into consideration different forecasted periods, and different seasons and years for the scenarios, the highest temperature average is forecasted for MIROCH and ECHAM, models. The model projections by MIROCH model for snow covered observed period indicate that during most of the months, in 2081-2100, there will sudden rise in temperature. CNRM model shows less change in temperature than the other models.

Temperature increment will be higher in coastal regions of the Persian Gulf, east of Khuzestan and south and southeast regions of Isfahan in comparison to other area in Zagros Mountains.

### 5.4 Trends and Projections: Precipitation

Results of statistical analysis for annual, seasonal and snow cover observed period precipitation data are approximately similar and indicate both positive and negative trends by all the tests. However, only some negative trends and positive trends were significant. One of the reasons for so many insignificant trends could be non-availability of century scale data for the selected stations. The highest numbers of stations with significant trends occurred in winter while no significant trends were detected by statistical tests in summer precipitation. No decreasing significant trends were detected by statistical tests in annual and seasonal precipitation series. Annual and winter series show more positive significant trends. In January and December most of the stations had positive trend and were distributed in all parts of study area. The results also indicated negative correlation of precipitation with the surface temperature of Persian Gulf. In February and March series some stations showed downward trend.

The result of CV showed that all stations in Zagros Mountains show less CV as compared to other stations in eastern and western part of the study area. Largest CV values also could be seen in eastern part where the rainfall amount is low. At seasonal level winter shows less CV compared to other seasons and summer shows the largest CV.

The result of precipitation projection shows that precipitation may decrease according to most models under both scenarios. Autumn precipitation will increase with higher rates than other seasons. The simulated precipitation using the CNRM, MIROCH and UKMOC models under A1B and B1 scenarios in study area does not indicate substantial future changes. ECHAM model showed more changes as compared to other models. The result of modeling showed that in winter and spring rainfall may decrease and in autumn rainfall may increase until 2100. Results of modeling indicated precipitation will increase in coastal regions of the Persian Gulf and east of Khuzestan and decrease in Zagros Mountains.

### 5.5 Trends and Projections: Snow Cover

Results of trend analysis for snow cover observed period are approximately similar and indicate no significant trends. January, February and December showed positive insignificant trends and in March and April showed decreasing insignificant trends according to linear regression analysis, MK-test and sequential Mann-Kendall test. The results of correlation between sea surface temperature Persian Gulf and Mediterranean Sea and snow cover area indicated significant correlation at 95% confidence level in March (both were negative) and April (Mediterranean Sea was positive and Persian Gulf was negative).

The result of correlation between climatology signal and snow cover area indicated that most of the months had a positive insignificant coefficient correlation with snow cover in all periods. Most of the significant correlation coefficient with snow cover happened in January.

The result of snow cover projection showed that snow cover may be decreasing in all the models under both scenarios by the end of 21st century. The result of snow cover projection showed that MIROCH indicted more changes as compared with other models and the UKMOC model indicated less change as compared with other models.

**6. Conclusion**

In this study, trend analysis and projection of temperature, precipitation and snow cover series were examined. Precipitation and TM, TMAX and TMIN series for the period 1950-2007 have been analyzed for 50 precipitation stations and 39 temperature stations located in southwest Iran. Snow cover change was investigated for the period 1987-2007.

Observed temperature tendencies indicated a positive change in temperature, particularly in summer and spring over most of the stations. Moreover, temperature increment in winter is less in comparison to other seasons. Increasing tendencies in TMIN were more than TMAX in all the seasons. Therefore, the increase in annual and seasonal TM can be attributed to higher increase in TMIN. The results showed that most of the positive significant mutation points began in 1990s in the study area. Temperature projections were carried out and they also indicate that increase in temperature may occur in the summer and spring seasons for both scenarios, with more warming occurring in summer.

Taking into consideration different projected periods, different seasons and years for the scenarios, the highest average temperatures were projected by the MIROCH and ECHAM models. The CNRM model showed less change in temperature than the ECHAM, MIROCH and UKMOC models.

The results of precipitation series indicated that most of the stations showed an insignificant trend in annual and seasonal series. The highest number of stations with significant trends in precipitation occurred in winter while no significant trends were detected in summer precipitation. No decreasing significant trends were detected by statistical tests in annual and seasonal precipitation series. Precipitation variability over the Persian Gulf coast is significantly influenced by the sea surface temperature. The result of precipitation projection shows that precipitation will decrease as per most models under both scenarios. Autumn precipitation will increase with higher rates than other seasons.

Results of statistical analysis by linear trend, MK-test and Sequential Mann-Kendall test for snow cover are approximately similar and indicate no significant trends. Result of January, February and December showed a positive insignificant trend and March and April shows a decreasing insignificant trend. However, some consistencies in temperature at snow cover area trends are observed during March and April with increasing trends in temperature and decreasing in snow cover area. The result of snow cover projection shows that snow cover may decrease in all the models under both scenarios by the end of $21^{st}$ century.

Overall the study revealed that temperatures are rising over the study area. Precipitation was more or less constant with some stations registering increase. Trend analysis of snow cover did not yield very significant results. But, in the future with increase in temperature the snow cover is likely to decrease. These will considerably affect contribution of melt water to stream and river discharge. This will in turn affect agricultural sector. Projected increase of temperature may increase losses through evapotranspiration. Therefore, the results of this research will be beneficial for future water resource planning.