Historical and Future Climatological Drought Projections Over Quetta Valley, Balochistan, Pakistan

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Abstract. The historical climatological records provide eminent evidence that drought is a permanent natural disastrous phenomenon of Balochistan. The precipitation data from 1950 to 2010 characterized that 18 drought events flashed with an interval of 3.3 years when average precipitation deficiency ranges from 20 to >40%. The longest historical drought span over 1945 to 1955 and the most recent dry-spell extended from 1997 to 2003. During the last drought, the average precipitation values decreased from 0-21% in Balochistan, while in Quetta from 40-70%. The historical record depicts that drought study also identifies the future drought frequency and severity with return period over the time. Strong affiliation has been recognized between the soil-moisture and standardized precipitation index, which ultimately helps to identify the spatial behavior of droughts. The Representative Concentration Pathways RCP4.5 and RCP8.5 were downscale at 25 km and 50 km, have been used for future behavior of meteorological parameters. The both RCPs show a positive increasing trend for mean temperature and a negative trend for precipitation for the 21st century. A significant increase in temperature has observed 0.04 °C/y and 0.12 °C/y at RCP4.5 and 8.5 over Quetta Valley respectively. The precipitation values represent no significant change in trend observed at 95% confidence level for the century. A marginally declining trend is identified by the statistical tests in precipitation. The precipitation and mean temperature data have been downscaled for midcentury 2040-2069 and far future 2071-2100 using different Regional Climate Models, namely ERA-40, ECHAM5 and fvGCM to identify association with the observational data of Quetta Valley. The observational data of mean temperature and precipitation shows a strong correlation to the downscaled data of ERA-40 as $R^2 = 0.97$ and $R^2 = 0.47$ respectively. The ERA-40 exhibits somewhat underestimate the mean temperature and overestimate the precipitation data. The observational data used to calibrate the downscaled data. The variability in temperature and precipitation has an enormous social and economic impact on the residents of Quetta Valley. The climatological variability devastated the ecosystem, depleted the groundwater resources and exhausted environment. The study outcome assists different stakeholders to predict and device immediate, short and long-term strategies to combat droughts. The Water Resource Managers and Planners may develop preeminent future “Drought Mitigation Policy” in the light of climate change over the Quetta Valley.

Keywords: Drought, Climatological Projections, Standardized Precipitation Index, Regional Climate Models, Quetta.

1. Introduction
The Quetta Sub-basin is a part of Pishin River Basin, which is one of eighteen river basins of Balochistan. The sub-basin extends from Latitude 29° 40’ to 30° 25’ N and longitude 66° 50’ to 67° 20’ E and covers an area of 1,860 km². Quetta itself is one of the 34 districts and the provincial capital of Balochistan, Pakistan. The city is situated at about 30° 10’ N and 67° 01’ E, it has an elevation of 1,680 m above mean sea level. The valley located in arid zone where groundwater is the major source for domestic, agriculture, commercial and industrial utilization. The aquifers developed in the valley are the only source for urban and rural water supply schemes. A continental
and semi-arid climate with great variations from summer to winter temperatures endures in the valley. The recorded highest temperature was 42 °C on 10 July 1998. The lowest temperature -18.3 °C recorded on 8 January 1970. The summer season continues from May-September with an average temperature 24-26 °C. The autumn spans from September-November with temperatures from 12-18 °C. The winter from October-March, temperatures varies 4-5 °C. Spring from April-May with average temperatures 15 °C. Quetta Valley does not have a monsoon season of sustained rainfall. The highest 24-hour rainfall 113 mm recorded on 17 December 2000. The highest monthly rainfall 232.4 mm documented in March 1982. The highest annual rainfall is 949.8 mm recorded in 1982. The snow falls in December-February, very rarely in March.

The imbalance in the precipitation and temperature is an important factor, the evaporation is higher than precipitation and the sustainability of groundwater table cannot be maintained. The climate change also impacts the variability in precipitation, fewer snowfall events and water availability are extremely high during dry years that worsen the conditions. The rural economy and livelihood of communities dependent on groundwater resources which are reliant on precipitation. The groundwater resources severely affected by repetition of droughts of diverse intensities and durations. The seasonal droughts cause severe damages to crop, the livestock and orchards are also vulnerable to persistent droughts. The valley has faced several droughts since 1955 to 2008 due to enormous gaps in regular rainfall patterns and an increase in temperature. A balance in climatic factors is required for sustainability of groundwater resources. The naturally developed gaps due to change in climate rigorously affected the natural restoration process of aquifers and resulted in heavy depletion of the groundwater table in the valley. The valley is surrounded by hills on three sides, it has limitations in terms of expansion. The population density is very high in urban and rural areas with vast urbanization. The periodic droughts, aridity, depleted groundwater resources, degraded rangelands, and rugged terrain is the foremost challenges communities are facing. The location map is presented in figure-1.

![Location Map](image)

**Figure 1.** Location Map; Study area shown in shaded box, Quetta Valley, Balochistan, Pakistan

2. Drought Climatology

The drought is an inception of a slow disaster and its impact differs from region to region. The meteorological, agricultural, hydrological and socioeconomic are the four major types of droughts. At a time either one or the other type of droughts may observe simultaneously with varying intensities in different regions of Balochistan. The present study based on the analysis of meteorological and hydrological droughts. The impacts are consistent with the environment, weather and soil conditions. The percentage of normal precipitation is used to define drought severity. The precipitation deficiency also utilized to describe drought, which permits a realistic regional evaluation. The results of problems require different definitions of drought, since both the
relative and absolute magnitudes of the precipitation deficiency may have obtained from analytical procedures. A single definition of drought is not applicable to the various drought problems encountered in meteorology and hydrology. The selected method should be adaptable for hydrologic application during periods of extended droughts. The irregularities in precipitation are a climate phenomenon that disturbs the hydrologic cycle and causes droughts. The climatology of precipitation, temperature, and atmospheric moisture content helps to assess the precipitation frequency. The correlation between precipitation, temperature, and atmospheric moisture help to assess the severity of droughts.

The atmospheric pattern of Quetta Valley demonstrates that droughts are recurring in rotational patterns that produce sporadically less than average precipitation. The atmospheric pattern during a drought may attain by drought circulation patterns like monthly and yearly averages, air dryness, and variation in temperature gradients. The causes of atmospheric droughts in Quetta Valley may go far beyond to provincial level. The regional nature of atmospheric circulations is the reason that produces sustained periods of less than normal precipitation. The drought physiognomies in Quetta Valley premeditated to ascertain the spatial and temporal distribution of droughts. The drought severity associated with climatological conditions and to ascertain the relationship of precipitation deficiency to depletion of the groundwater table in Quetta Valley. Stress has been placed upon hydrologic application in the approach to the problem and in the presentation of results. The study, based primarily upon monthly precipitation data from the Quetta Meteorological Station for the 60-year sampling period, 1950-2010. The baseline period was taken in the thirty-year period from 1960-1990 for data validation. For the future predictions midcentury from 2040-2069, and late-century from 2071-2100 have been designated.

3. Historical Droughts in Quetta Valley
The standardized precipitation index (SPI) is a standard means for defining and monitoring droughts. The index helps to delineate the rarity of drought at a given time scale for any rainfall station with historic data. The SPI provides the amount of rainfall, indicate the amount in relation to the normal and define whether a climatical station or region is experiencing drought. The drought frequency and historical drought years analyzed by SPI at different timescales of 3, 6, 9, 12 and 24 months [1]. The comparison between soil-moisture and precipitation with 12-SPI was conducted for sixty years during 1950-2010 over Quetta Valley.

The historical drought years along with their intensity were identified over Quetta Valley by using the SPI at time scales of 3, 6, 9, 12 and 24 months. The observational data of precipitation used for historical drought years, frequency, category, and types were identified. The SPI is calculated by using the observational data of precipitation to determine drought frequency, category, intensity, and types. Four different intensity classes, i.e. mild, moderate, severe and extreme is used. Similarly, four different types of drought are calculated as; 3-months SPI depicts the dry period, 6-months SPI meteorological, 9-months SPI agriculture, 12 and 24-months SPI, hydrological and extreme hydrological drought respectively.

The 60 years historical analysis represent that 18 droughts of mild to extreme intensities at the time scale from 3 to 24-SPI occurred over Quetta Valley. The historical drought with intensity at different SPI timescale is presented in table-1. The results show that only four drought years were identified at three months SPI. Two extreme drought events recorded during 1971 and 2000 of 9-24 SPI. The two severe drought events of 24-SPI observed on 1972 and 2001. The maximum twelve drought events of different intensities were experienced in 9 and 24 month’s timescales. Quetta receives a somewhat reasonable amount of precipitation only in winter season under the influence of western weather patterns. Consequently, the 12-months timescale is a good indicator to monitor drought over the Quetta Valley. Similarly, the frequency of drought is very high in Quetta Valley as it receives drought after every three years of mild to moderate intensities. The drought severity monitored by correlating the soil-moisture departure and 12-SPI, soil-moisture departure and precipitation departure, precipitation departure and 12-SPI. The temporal comparison assessed
between 12-SPI, soil-moisture and precipitation from 1950-2010 over Quetta Valley. It was observed that the highest correlation exists between soil-moisture to 12-SPI with $R^2$ is 0.78, and 12-SPI to precipitation where $R^2$ is 0.76, and soil-moisture to precipitation $R^2$ is 0.67. The results show a good association among the parameters of soil-moisture and precipitation. The two extreme drought years 1971 and 2000 were identified for which the soil-moisture and precipitation departures were -76.7%, -79.0% and -86.5, -35.20 % respectively. The historical data represent a decreasing trend in seasonal as well as monsoon precipitation and a warmer trend in all seasons over Quetta Valley. A temporal comparison was conducted between 12-month SPI, percentage departure of soil-moisture and precipitation from 1950-2010 over Quetta Valley, shown in figure 2.

| Time Scale | Extreme | Severe | Moderate | Mild       |
|------------|---------|--------|----------|------------|
| 3-SPI      | -       | -      | 1971, 2000 | 1999, 2004 |
| 6-SPI      | -       | 1971, 2000 | 2004 | 1955, 1958, 1969, 1999, 2002, 2006, 2008 |
| 9-SPI      | 1971, 2000 | -    | 1955, 1999, 2002, 2004, 2006 | 1952, 1953, 1969, 1973, 2008 |
| 12-SPI     | 1971, 2000 | -    | 1955, 1999, 2002, 2006 | 1953, 1961, 1969, 1973, 2004 |
| 24-SPI     | 2000    | 1971, 1972, 2001 | 1970, 2002 | 1953, 1955, 1969, 1973, 2003, 2004 |

Figure 1. Table 1. The Historical Droughts with intensity at different SPI Timescale.

4. Representative Concentration Pathways
The Representative Concentration Pathways (RCPs) are four greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC), for the fifth assessment report (AR-5), [2], utilized for climate modeling. The four possible climate futures may assess depending on the quantities of greenhouse gas emission in future scenarios. The RCPs are fully integrated scenarios and are consistent sets of projections for components of radiative forcing that serve as input for climate modeling, pattern scaling, and atmospheric modeling. The RCP4.5 and 8.5 were downscale at 25 km and 50 km under the guideline of the IPCC, AR-5, 2014, to determine the future projection of temperature and precipitation for Quetta valley. Observational and Global Precipitation Climatological Centre (GPCC) data of precipitation are used for the period of 1950-2010, [3]. The same period’s soil moisture data accessed from the Climate Prediction Centre, Islamabad, 0.5° resolution was used to identify the drought behavior [4].
The future projection of temperature based on RCPs for 4.5 and 8.5 is downscaled for Quetta Valley at 25 km and 50 km spatial resolution. RCP4.5 for 25 km spatial resolution represents an increase in simulated temperature from 2010-2100 from 15-22 °C. A continuous increase in temperature of 0.08 °C simulated for ninety years and the R² is 0.885. The RCP8.5 for 25 km spatial resolution characterize an increase in temperature from 17-26 °C in the simulated ninety years from 2010 to 2100. The simulation results represent that temperature at the rate of 0.1 °C/y will increase in ninety years, the R² value is 0.55. The future projected model and emission scenarios show that the temperature has a significant increase of 0.04 °C/y and 0.12 °C/y for RCP4.5 and RCP8.5 respectively. The simulated average increase in temperature for the century is 0.08°C/y. The linear relationship of RCP4.5 and 8.5 for 25 km spatial resolution and the observed mean monthly temperature are shown in figure 3a.

The RCP4.5 and 8.5 for 50 km spatial resolution simulated for average yearly temperature from 2010-2100. The simulation represents a constant increase in temperature ranges from 16.5-23.5 °C in ninety years from 2010-2100. The increase in temperature is almost 0.08 °C/y and the R² is 0.89. The RCP8.5 for 50 km spatial resolution illustrate the temperature increase from 16-23.5 °C in the simulated ninety years from 2010 to 2100. The simulation results represent that temperatures will increase at 0.08 °C/y in ninety years, the R² is 0.55. The linear relationship of RCP4.5 and 8.5 for 50 km spatial resolution and the observed mean monthly temperature are shown in figure 3b. The results show that the mean annual temperature is increasing for both RCP4.5 and 8.5 for 25 and 50 km spatial resolution. The increase is slightly sharp for 50 km resolution. The temperature shows more variation in mid-century from 2041-2070 whereas a sharp increase in the late century from 2071-2100. The future projected model and emission scenarios show that the temperature has a significant increase of 0.04 °C/y and 0.12 °C/y for RCP4.5 and RCP8.5 respectively. The simulated average increase in temperature for the century is 0.08 °C/y.

Figure 3. Comparison of Mean Temperature in RCP45 and RCP85.
The future projection of cumulative yearly precipitation established by RCP4.5 and 8.5 downscaled for Quetta Valley at 25 km and 50 km spatial resolution. The RCP4.5 for 25 km spatial resolution characterize simulated yearly precipitation 2-29 mm with exceptional few peaks of the high precipitation range from 30-55mm during 2010-2100. A somewhat same trend in precipitation is simulated for ninety years, represented $R^2$ as 0.001. The RCP8.5 for 25 km spatial resolution characterize the cumulative yearly precipitation from 1-27 mm/y. A few peaks of high precipitations of 30-81 mm/y simulated for ninety years from 2010 to 2100. The simulation results represent an equitably similar trend of precipitation, the $R^2$ value is 0.0003. The linear relationship of RCP4.5 and 8.5 for 25 km spatial resolution and the observed yearly precipitation are shown in figure 4a.

The future projection of cumulative yearly precipitation established by RCP4.5 and 8.5 downscaled for Quetta Valley at 50 km spatial resolution. The RCP4.5 for 50 km spatial resolution characterize simulated precipitation 1-30 mm with a few peaks of high precipitation ranges from 32-74 mm during 2010-2100. The simulation represents no prominent change in the precipitation pattern and trend, the $R^2$ is $7E-05$. The RCP8.5 for 50 km spatial resolution characterize the cumulative yearly precipitation from 1-30 mm/y. A few peaks of high precipitations of 35-117 mm/y simulated for ninety years. The simulation results represent a similar trend of precipitation, the $R^2$ value is 0.0008. The future projection of precipitation based on RCPs for 4.5 and 8.5 is downscaled for Quetta Valley at 50 km spatial resolution are presented in figure 4b.

The RCP4.5 and 8.5 for 25 and 50 km spatial resolution results show that the cumulative yearly precipitation patterns are comparable to observed precipitation values. The outcomes display that the mean annual precipitation shows no change for both RCPs for 4.5 and 8.5. The future projected model and emission scenarios show that the rainfall has no significant increase, a slight decrease in annual precipitation was observed for RCP4.5. The precipitation shows more variation in the late century from 2071-2100.

Figure 4. Comparison of annual precipitation in RCP45 and RCP85.
5. **Mann-Kendal and Sen’s Slope Estimator**

The Mann Kendall and Sen’s slope estimator are used to determine the significance of the trend and its magnitude, [5], [6]. Mann-Kendal test is a nonparametric procedure for finding future drought trends in time series. This test compares the relative magnitudes of data rather than data values themselves. The test is useful because the data need not authorize any particular dissemination. In this test, the data values of time series are compared with all subsequent values. The Mann-Kendall statistics at the start of the test is assumed as zero. If the data value in succeeding time periods is higher than a data value in the previous time-period, it is incremented by one and Vice-versa. The linear trend of precipitation and temperature are calculated using Mann Kendall test, which has been broadly used to analyze the long-term climatological and hydrological time series.

The test statics S, the value of Z is approximately normally distributed and positive value of Z greater than 1.96 represents the significant increasing trend. Whereas, the negative value which is lower than -1.96 donates a significant decreasing trend at 95% significance level with two-tailed tests. Similarly, if the values of Z greater than 1.65 and less than -1.65 shows a significant level with one-tailed test. The result of all increments and decrements provides the final value of Mann-Kendall statistics. A linear trend if present in a time series, the true slope in changes per unit time can be estimated by a nonparametric procedure developed by Sen, [7]. The method assumes a linear trend in the time series. In this method, first the slopes T is calculated. The median of N values of T gives the Sen’s estimator of slope Q. A positive value of Q indicates an upward trend and a negative value indicates a downward trend in the time series.

Analysis of temperature and precipitation trends using Mann-Kendall Test and the Sen’s Slope Estimator for Quetta Valley were conducted for the 21st Century. The table 2, represents the calculated Z and Q values for temperature and precipitation, 25-50 km resolution for RCP4.5-8.5 from 2010 to 2100. The temperature values showing significance at 95% confidence level for a Z statistic range from 7.69 to 11.19. Similarly, the significance at the 95% confidence level the Q values range from 0.044 to 0.116. The Quetta meteorological station demonstrated a significant trend, the trend is in increasing direction. The increasing trend in temperature might be due to environmental change, fast urbanization heat effect on temperatures and steadily increasing population in Quetta Valley. Studies indicate and reported that temperature increasing trends are dominant nationwide as well as province-wide. The statistical analysis of precipitation obtained by the Mann-Kendall test and the Sen’s slope estimator are given in table 2.

The statistical results of precipitation display significance at 95% confidence level under RCP4.5 and RCP8.5 of Quetta Valley for 21st Century. The analysis represents the calculated Z and Q values for precipitation, 25-50km resolution for RCP4.5-8.5 from 2010 to 2100. The precipitation values showing significance at 95% confidence level for Z values range from -0.50 to -1.54. The significance at the 95% confidence level the statistical values of Q vary from -0.025 to -0.91. The precipitation values represent no significant change in trend observed at 95% confidence level for the century by the Mann-Kendall test and the Sen’s slope estimator. However, a slightly declining trend is identified by the statistical tests in precipitation.

The difference between parametric or linear regression and non-parametric or Mann-Kendall test and the Sen’s Slope estimator methods on the precipitation is small. The temporal pattern of precipitation trend analysis is important for planning and management of water resources. The significance test of the Mann Kendal method represents no significant increase in precipitation. However, a significant increase in temperature has observed 0.04 °C/y and 0.12 °C/y at 95% significance level under RCP4.5 and RCP8.5 over Quetta Valley respectively.
Table 2. Statistical results of temperature and precipitation showing significance at 95% confidence level under RCP4.5 and RCP8.5 of Quetta Valley for the Century.

| Parameters | Resolution (km) | Scenarios | Duration | Mann Kendal (Z) values | Sen's Slope (Q) values |
|------------|-----------------|-----------|----------|------------------------|-----------------------|
| Temperature (°C) | 25 | RCP4.5 | 2010-2100 | 7.7 | 0.044* |
| | 50 | RCP8.5 | 2010-2100 | 11.04 | 0.114 |
| | 25 | RCP4.5 | 2010-2100 | 7.69 | 0.044 |
| | 50 | RCP8.5 | 2010-2100 | 11.19 | 0.116 |
| Precipitation (mm) | 25 | RCP4.5 | 2010-2100 | -0.61 | -0.021 |
| | 50 | RCP8.5 | 2010-2100 | -0.5 | -0.025 |
| | 25 | RCP4.5 | 2010-2100 | -1.54 | -0.062 |
| | 50 | RCP8.5 | 2010-2100 | -1.54 | -0.091 |

*Bold values represent significance at 95% confidence level.

6. Regional Climate Modelling

Regional Climate Model (RegCM) is a professional modeling technique for climate-related studies. The Earth Systems Physics, a group of the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, has prepared Regional Climate Model version 3 (RegCM3), [8]. The RegCM3 interactions on the topic of climate and associated impacts research and modeling. The Regional climate model has the ability to provide more accurate and detailed information after resolving the atmosphere and surface boundary problems. Therefore, the climate change projection based on the Regional Climate model is important in the valley to identify the future vulnerability. The future data is accessed for temperature and precipitation to identify the positive or negative trends. The precipitation data from 1950 to 2010 was used to identify the drought events over the Quetta Valley. The RegCM3 simulations applied to determine the future projection of temperature and precipitation over the valley. The model was run at Global Change Impact Study Centre, Islamabad and the temperature and precipitation data were accessed.

The ECHAM5 is a general circulation model developed by the Max Planck Institute for Meteorology, Germany [9]. The model created by modifying global forecast models to use for climate research. The model configures and resolve climatic issues at different atmospheric settings. The finite-volume General Circulation Model (fvGCM) is a three-dimensional Navier-Stokes solver designed by NASA. The fvGCM is utilizing for quasi-operational weather forecasting. The model designed with innovative algorithms for global high resolution atmospheric modeling. The finite volume transport scheme conserves mass locally and monotonically to ensure proper correlations among the constituents. The velocity preserving horizontal dynamics enhances the simulation of atmospheric oscillations and vortices, which are characteristic of climate and weather phenomena. The atmospheric dynamics are based on the flux form semi Lagrangian advection [10, 11, 12]. The ECHAM5 and fvGCM are used as a driving data with support to the ERA-40 reanalysis data of 50 km resolution under A2 Scenario. The ERA-40 data of the European Center for Medium Range Weather Forecasting (ECMWF) were used in the model simulation. The baseline period was taken for thirty years from 1960-1990 on which data were validated. The future periods designated as midcentury from 2040-2070 and late-century from 2071-2100. The future periods; mid and late-century was calculated for ECHAM, and one period of the late-century for fvGCM.

The comparison of temperature data is conducted between RegCM3 and observational data of Quetta. The modeling results of surface air temperature and precipitation derived from model RegCM3-ERA-40, RegCM3-ECHAM5, RegCM3-fvGCM were analyzed to confirm the validity of numerical modeling. The baseline period is thirty years from 1960-1990 for time series analysis of monthly precipitation. The time series analysis was conducted among observational monthly precipitation data and the RegCM3 model. The simulations were conducted between precipitation
and RegCM3-ERA-40, RegCM3-ECHAM5 and RegCM3-fvGCM models. The time series analysis shows considerable variation in the prediction identified by the RegCM3 models during the designated baseline period. The relationship of observed precipitation and RegCM3 models are shown in figure 5.

The time series analysis of the thirty-year period from 1960-1990 and cumulative monthly precipitation with regional climate model ERA-40 were conducted. The time series analysis represents that ERA-40 slightly captured the observed data of precipitation during the baseline period. Throughout the year; based on the cooperation and temporal analysis ERA-40 is slightly coordinated to the observed data. The ERA-40 model’s annual mean precipitation is slightly underestimated in comparison to the observational data during all the months except June-September. The overestimation of annual precipitation by the ERA-40 model is the reason for overlaying temperature during July and August. The time series graphical representation of observed and simulated precipitation is given in figure 6.

![Figure 5](image1.png)

**Figure 5.** Time series of observed precipitation data and regional climate models of Quetta.

![Figure 6](image2.png)

**Figure 6.** Precipitation (mm) comparison of observed and regional climate model ERA-40 at Quetta
The modeling results of RegCM3-ERA-40, RegCM3-ECHAM5, and RegCM3-fvGCM were analyzed and correlated with observed temperature data. The time series analysis of entire three models is well overlaid the observed temperature data during the baseline period from 1960-1990. The observed mean temperature data versus RegCM3-ERA-40, RegCM3-ECHAM5 and RegCM3-fvGCM model results of Quetta are presented in figure 7. Based on the cooperation and temporal analysis ERA-40 is well coordinated to the observed data. The evaluations for ERA-40 temperature have been performed, the data reanalysis is a useful resource for depictions of seasonal variations. The ERA-40 model annual mean temperature is slightly overestimated in comparison to the observational data during all months except July and August. The annual mean temperature comparison of observed and regional climate model ERA-40 is shown in figure 8.

The time series comparisons of the monthly mean temperature of both regional climate models ECHAM5 and fvGCM are conducted for the current century of Quetta. The result of ECHAM5 shows a high annual variation from 3.4 °C on January 2041 to 33.3 °C on June 2069. Depicting the January and June as the coldest and hottest months during 2040-2069 respectively. The lowest temperature 5.78 °C is observed in January 2085 and highest 36.24 °C in June 2091, whereas the fvGCM identifies the lowest temperature for January 2096 as 5.22 °C and highest since June 2096 as 34.71 °C. These results depict that the temperature would rise almost 2°C in Quetta at the end of the century that will increase the evapotranspiration, crop water requirements, and put a pressure on water resources. The time series comparison of temperature ECHMA5 and fvGCM for the Century presented in figure 9.

The time series comparisons of monthly precipitation of both regional climate models ECHMA5 and fvGCM are conducted for the 21st Century of Quetta. The result of ECHAM5 shows a high temporal variability in precipitation. The results depict precipitation remained zero in most of the months of May and November whereas the highest rainfall of 7.03 mm/day is observed on July 2063 at Quetta. Similarly, the highest precipitation is observed during March 2088 as 7.01 mm/day. Whereas, the fvGCM identifies the highest precipitation for March 2100 as 3.94 mm/day. Both models identified precipitation variation during different months. No major increase in precipitation is observed by the two models which are an alarming sign for socioeconomic sectors for the residents of Quetta Valley. The time series comparison of precipitation for both models ECHMA5 and fvGCM of the Century in Quetta is shown in figure 10.

![Figure 7. Time series for the mean monthly temperature of observed and regional climate models, Quetta Valley.](image-url)
Figure 8. Monthly mean temperature comparison of observed and RegCM3-ERA-40.

Figure 9. Time series comparison of temperature ECHMA5 and fvGCM for the 21st Century of Quetta.
The comparison of RegCM3 model with observed monthly temperature data ERA-40, ECHAM5 and fvGCM was conducted, shown in figure 11. The values of $R^2$ ranges from 0.896 to 0.972 represent that the entire three models show good correlation to observational data. The ERA-40 shows maximum $R^2$ is 0.972, signify a rational correlation between observed and simulated temperature values.

A comparison between annual observational precipitation data of Quetta and RegCM3 model was conducted. The modeling results of precipitation derived from model RegCM3-ERA-40, RegCM3-ECHAM5, RegCM3-fvGCM were analyzed to confirm the validity of simulation results. The RegCM3-ERA-40 model with observational monthly precipitation data represents a reasonable correlation as $R^2$ is 0.47.

The RegCM3-ECHAM5 and RegCM3-fvGCM models represent a rational, linear relationship with observed monthly precipitation. The value of $R^2$ ranges from 0.03-0.002 for RegCM3-ECHAM5 and RegCM3-fvGCM respectively. The ERA-40 shows somewhat good correlation $R^2 = 0.471$ to observational data in comparison to the rest of the two models i.e. ECHM5 and fvGCM.

The comparison of three modeling results with observed monthly precipitation data of Quetta is presented in figure 12.
Conclusions

The 60 years historical analysis represent 18 droughts of mild to extreme intensities from 3 to 24-SPI happened as an average after every three years over Quetta Valley. Five severe drought events were identified at six and 24-SPI. Four extreme drought events recorded during 1971 and 2000 at 9 to 12-SPI. Only one extreme drought event of 24-SPI observed in 2000.

The temperature projections indicate an increase of 0.04 °C/y and 0.12 °C/y for RCP4.5 and RCP8.5 respectively. The average increase in temperature approximately 0.08 °C/y for the next century. The increasing trend in temperature might be due to environmental change, fast urbanization, and steadily increasing population in Quetta Valley.

The future projection of precipitation based on RCPs, downscale at 25 and 50 km spatial resolution results shows that the cumulative yearly precipitation patterns are comparable to observed precipitation values. The future projected model and emission scenarios demonstrate that no significant increase in precipitation is forecasted.

The drought frequencies will be a major problem in the future for Quetta Valley. The stakeholders like Climate Change Experts, Hydrologists, Agronomist and Water Resource Managers should prepare a viable drought mitigation policy. As per drought severity immediate, the short, midterm and long-term measure should be a significant component of drought mitigation policy.
The severity of droughts directly related to the amount of precipitation. The planning, management, and conservation of surface and groundwater resources should be integrated with drought mitigation policy. An integrated weather and water resources data management for drought modeling, prediction and early warning system are imperative.

To mitigate drought impacts, the structural or physical measures embrace the selection of appropriate crop types and construction of water storage, delay action, and check dams. The community awareness, commitment and ownership, knowledge dissemination, capacity building and operational practices are among non-structural measures.

The sustainable development should be an integral part of the drought mitigation policy. The sustainable development may comprise water, food and environmental security, biodiversity, forests, rangelands, livestock, and watershed management. Implementation of policy with legal context will help sustainable development of groundwater resources for public supply, industry, and agriculture in Quetta Valley.

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