Acta Geophysica
https://doi.org/10.1007/s11600-024-01464-7

REVIEW ARTICLE - ATMOSPHERIC & SPACE SCIENCES

Assessing the impact of climate change by using Mann–Kendall, Pettitt and statistical downscaling model (case study: Tabriz station)

Saeed Imani[1] · Yagob Dinpashoh[1] · Esmaeil Asadi[1] · Ahmad Fakheri-Fard [1]

Received: 6 April 2024 / Accepted: 7 October 2024

Abstract

Climate change is one of the most important phenomena in large cities. This phenomenon causes various disasters such as floods, drought, water insecurity, water war and summer heat waves in cities. In this research, different methods, including the statistical downscaling method, Mann–Kendall, Pettitt, a precipitation index (PI), a temperature index, a weighted precipitation index (WPI), a weighted temperature index (WTI) and frequency analysis, have been used for assessment of precipitation and temperature time series in Tabriz city, located in the northwest of Iran. Here, data from the base time period (i.e., 1951–2022) and future time period (2022–2100) were considered to analyze. Three distinct scenarios were used in the study, namely RCP 2.6, RCP 4.5 and RCP 8.5. Results indicated that in the base period, the monthly and annual precipitation time series showed insignificant statistical trends. In the base period, the mean of the annual precipitation time series decreased suddenly such that its mean value declined from 316.32 mm (in the first sub period, i.e., 1951–1982) to 261.51 mm (in the subsequent sub period, i.e., 1982–2022). Also, the average temperature time series on monthly and annual scales showed statistically significant upward trends. A significant change in the average annual temperature was detected in 1994, in which its mean value jumped from 11.76 to 13.32 °C. Future annual precipitation (2022–2100) time series showed a statistically significant upward trend using RCP 2.6. However, using the RCP 4.5 and RCP 8.5 scenarios, trends in this parameter will not be significant in the future period. In addition, in the future period, the average annual air temperature in Tabriz has been shown to be increased from 12.35 to 12.75 °C using the three used RCPs. The values of three indices, namely TI, WTI, PI and WPI, indicated that in the future, the number of dry and warm periods will be more than the wet and cold periods. Also, the frequency analysis showed that the intensity, duration and precipitation pattern in the future period will be somewhat different from that of the base period. In Tabriz, the average annual temperature in most of the future years will be between 12 and 13 °C. Therefore, it can be concluded that climate change has affected Tabriz's climate since the end of the nineteenth century and is anticipated to continue in the following years.

Keywords Climate change · Downscaling · Precipitation · SDSM · Tabriz city · Temperature

Introduction

Nowadays, climate change is triggering many extensive changes around the world. The effects of this phenomenon are greater in arid and semi-arid areas rather than in other regions (Allison et al. 2001; Barry and Carleton 2013; Aung et al. 2016; Zhang et al. 2016; Bathiany et al. 2018; Mansouri Daneshvar et al. 2019; Duan et al. 2020; Spinoni et al. 2021). Climate changes are caused by various factors, including internal factors (i.e., changes in atmospheric parameters), external forces and human-induced effects (IPCC 2023). Most researchers emphasize that climate change disasters have been exacerbated by greenhouse gases, construction of dams, indiscriminate use of underground and surface water resources, unprincipled agriculture, deforestation, indiscriminate development of urbanization, increase in population, etc. (Barry and Carleton 2013; Jianping et al. 2016; Liu et al. 2020; Lizarralde et al. 2021; Kashif et al. 2022). Cities are one of the places that have been affected by climate change and have caused mutually influencing

Edited by Dr. Ahmad Sharafati (ASSOCIATE EDITOR) / Prof. Theodore Karacostas (CO-EDITOR-IN-CHIEF).

✉ Saeed Imani
Saeedimani566@yahoo.com

[1] Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

Published online: 03 November 2024

alterations in the climate. In recent decades, the industrialization of cities, population growth, physical development, extensive changes in land use planning, and lack of preventive measures have increased (Adachi et al. 2012; Junk et al. 2014; Chapman et al. 2019; Miyamoto 2024). So, many researchers are interested in this topic and tried to analyze its effects. Bastin et al. (2019) studied the effects of climate change in 520 cities around the world. They used Global Climate Models (GCMs) with the downscaling method. Also, they assessed different parameters such as the average annual temperature, temperature of the hottest month, temperature of the coldest month, precipitation of the wettest month and annual precipitation in the analysis. They showed that the climate of 77% of the cities in 2050 will be different from the current climate conditions in the studied cities, and only 22% of the cities showed the same climate in 2050 similar to the current conditions. Especially, it has been anticipated that Madrid's climate in 2050 will be like Marrakech's present climate, Stockholm will be like Budapest, London to Barcelona, Tokyo to Changsha, Moscow to Sofia, and Seattle to San Francisco. Mansouri Daneshvar et al. (2019) studied the effects of climate change in the Middle East region, and especially in Iran. Their findings, which are based on statistical comparisons and IPCC reports, indicated mean temperatures will rise 2.6 °C and precipitation will decrease 35% in the next years in Iran.

Shakeri et al. (2020) investigated the climate change using the seven climatic variables and GCMs, SDSM, and fuzzy downscaling model (FDSM) in Tehran, Iran. They compared the mean of climatic variables in annual and monthly periods in Tehran between the base period (1989–2018) and the future period (2021–2040). Abbasnia and Toros (2016) assessed changes in maximum temperatures in seven stations namely Tehran, Tabriz, Esfahan, Ahvaz, Zahedan, Mashhad, and B-Abbas using the SDSM in the 2021–2100 period. Their results indicated that the maximum temperature will rise between 0.3 and 3.5 °C in the studied areas. Goodarzi et al. (2021) studied the mean monthly temperature and precipitation in the Kermanshah station using the SDSM. The results showed that the mean temperature will increase from 2041 to 2069 in all months compared with the 1961–1990 period. But, in the 2041 to 2069 period, the mean precipitation will increase in some months and decrease in others.

Global climate models are large-scale and grid-based predictive models having a scale of 250 to 600 km. Therefore, to evaluate climate change on a local, and regional scale, there is a need to select an appropriate spatial resolution. Also, for determining the relationships between local climate variables and predictions taken by global climate models, downscaling is needed (Bardossy 1997; Kilsby et al. 1998; Goodness and Palutikof 1998; Von Storch 1999; Harpham and Wilby 2005; Wilby et al. 2002). However, due to the low cost and achieving suitable results in predicting climate variables such as precipitation and temperature, most researchers have been using statistical downscaling methods for studying different regions of the world (Wilby and Dowson 2007; Aung et al. 2016; Ouhamdouch and Bahir 2017; Nazarenko et al. 2015; Melki and Abida 2018; Shukla et al. 2023; El Ouali et al. 2023).

In this study, some important climatic parameters including precipitation and temperature were predicted in Tabriz city with a statistical downscaling method, using the SDSM software (https://www.sdsm.org.uk/software.html) in the future time period. To have an accurate and clear vision on climatic changes in the city, trends in the time series and homogeneity analysis were carried out. In this regard, two nan-parametric methods namely MK (Mann 1945; Kendall 1975; Gilbert 1987) and Pettitt (1979) tests were used. Many researchers used the mentioned methods for different climate data series. Tabari et al. (2011) have used the Mann–Whitney and MK tests for trend analysis of climatic variables including the annual minimum, maximum, and average air temperatures, and precipitation time series in Iran in the 1966 to 2005 period. On average, the magnitudes of the significant positive trends in annual average temperature, maximum temperature, and minimum temperature are equal to (+)0.412, (+)0.452 and (+)0.493 °C, respectively. In addition, the precipitation data series doesn't have a uniform trend in the studied area. García-Cueto et al. (2019) studied climate change using the non-parametric MK test in some cities of Mexico employing the 14 climate variables. Their findings indicated that climate variables in most of the cities have changed in the studied period, i.e., 1980 to 2010. Also, they showed that the average of the annual maximum temperature, and minimum temperature time series showed significant upward trends. In addition, they indicated the number of wet days, and the number of very heavy rainfall days (i.e., with precipitation of more than 25 mm) will increase in the studied cities. Jaiswal et al. (2015) applied Pettitt's test for trend analysis in Raipur city, which is located in the state of Chhattisgarh in India, for the 1990 to 2000 periods. Results showed that the annual data of sunshine hours, wind speed, and minimum temperature time series had significant change points. However, the maximum temperature series showed to be homogeneous in the city. However, assessing the previous studies indicated the MK and Pettitt tests have been used in the analysis of time series in the past.

As can be deduced from the literature review the trends of climatic variables in either the base period or the future period are not comprehensively studied in large cities of Iran, especially in Tabriz. Moreover, in the previous studies investigators focused mainly on the trends in climatic variables time series in the historical period data and no pay attention to the trends of the generated time series for future period. Therefore, the main aim of this research is to investigate the climatic changes (mainly precipitation and air temperature) in Tabriz city during the historical and future periods. Therefore, to achieve these goals the following five stages are considered.

(a) Prediction of future temperature and precipitation time series by defining the RCP's scenario and downscaling method by using SDSM software and Global climate models (GCMs) in the future period (2022–2100),
(b) Detection of trends in precipitation and temperature time series by using the MK test for both past and future periods,
(c) Homogeneity analysis and identification of shifts in observations by using the non-parametric Pettitt test (Pettitt 1979),
(d) Identification of wet, dry, cold and warm years or periods by defining annual precipitation index (PI), weighted precipitation indices (WPI), average annual temperature index (TI), and weighted average annual temperature index (WTI), and
(e) Frequency analysis carried out on observed and predicted annual precipitation data.

Materials and methods

Study area

A 245 km^2 area of Tabriz city located in northwest of Iran, selected for this study (Fig. 1). Its coordinate at synoptic station of Tabriz is 38°4′ N and 46°18′ E. It is the fifth largest city of Iran, having specific industrial, economic, social and political importances for Iran. Nearly 1.8 million people are live in this city. It has a semi-arid cold climate and its average elevation is 1321 m above mean sea level (Saemian et al. 2020; Feizizadeh et al. 2021). To supply drinking water of Tabriz city, two river sources including Zarrieneh Rood and Nahand River, many wells and Qantas were used (WWC-EAP 2020). Since early 2020, urban water demand of Tabriz city increased for many reasons; especially because of population growth and fast urban development (Behboudi et al. 2018). Based on the WWC-EAP (2021), surface and underground water resources in Tabriz plain have been decreased compared to the past decades, and this worrying condition has caused city managers to face many problems with supplying water in Tabriz city in future decades. However, it is expected this city will be faced with additional water supplying problems due to climate change, especially with changing precipitation and temperature patterns (Soudi et al.

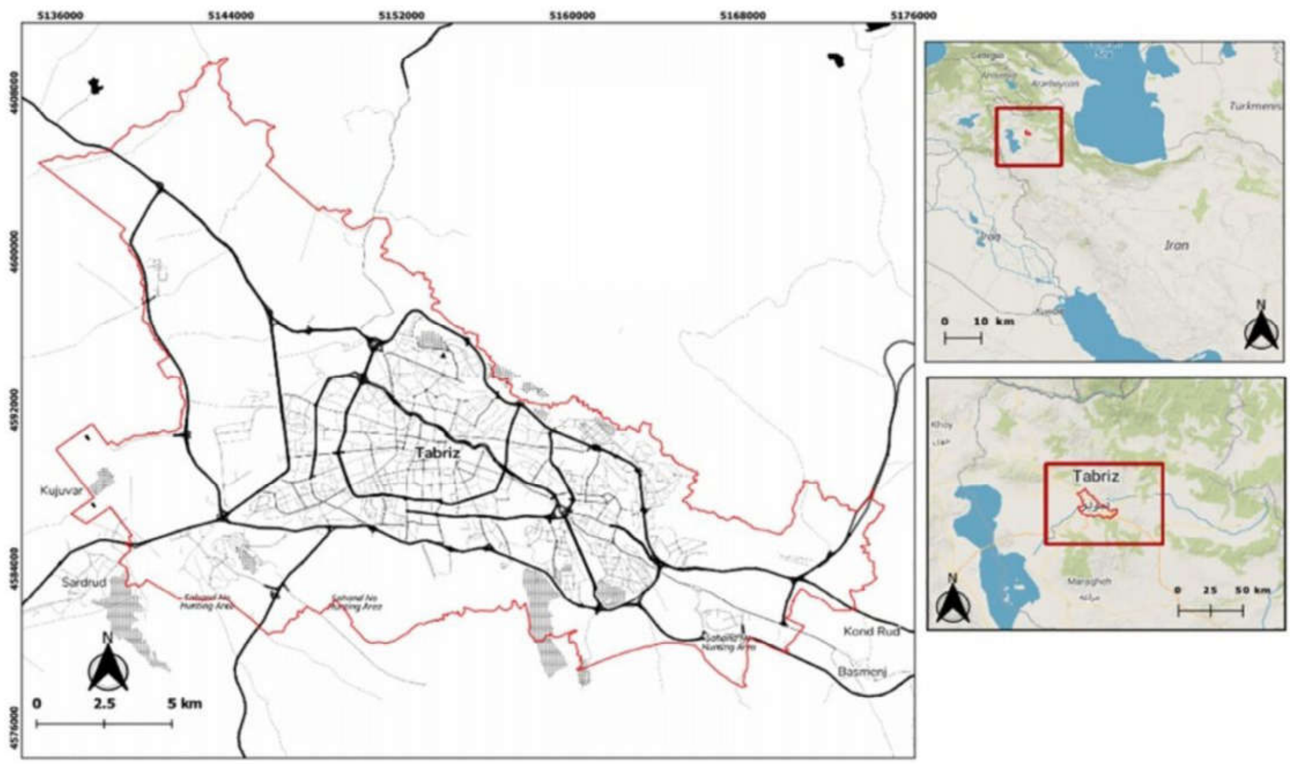


Fig. 1 Location of the Tabriz city in East Azerbaijan Province, Iran

2018). So, for better perception of climate change's impact on this city, Tabriz meteorology station data was used in this study. Tabriz meteorological station was established in 1951 and is located at 38° 05' N and 46° 17′. The elevation of this station is 1364 m above mean sea level.

Data

To investigate climate changes in Tabriz city, precipitation, average temperature, minimum and maximum temperature, actual sunshine hours, relative humidity and mean wind speed data series on the daily scale of Tabriz synoptic station obtained from the Iran Meteorological Organization (https://www.irimo.ir/) in the period 01/01/1951 to 05/03/2022. Data checked exactly for outliers. No missing data was in the observations. Given that in this manuscript, a second-generation Earth System Model (CanESM2) (https://climate-scenarios.canada.ca/?page=pred-canesm2) was applied for predicting meteorological variables at Tabriz station. This model is the 4th generation global climate change model that was developed by the Canadian global center for climate change analysis and assessment for the future 100 years. Also, using this model and analysis of observational data in the past period, can help to understand climate changes in different regions and provide scientific information about future climate events by generating three scenarios; RCP 2.6, RCP 4.5, and RCP 8.5. The resolution of this model is $2.79° \times 2.81°$ and has better results and lower uncertainty than other downscaling models such as HadCM3 (Waqed and Forgan 2020). In the CanESM2 model, the historical information accessible for prediction of meteorological variables is between 01/01/1961 and 31/12/2005. So, for the downscaling process, the observed data in the mentioned period has been used as the basis for analysis. But, all the observed data from 01/01/1951 to 05/03/2022 were used in trend analysis using the MK and non-parametric Pettitt tests.

Methods

In this research, firstly, future temperature and precipitation variables have been predicted by downscaling technique and using SDSM software in the period 2022–2100. In the second stage, the non-parametric MK test for trend analysis was used for precipitation and temperature variables in the past and future periods. In the third stage, the non-parametric Pettitt test (Pettitt 1979) was used to assess homogeneity of the climate variables time series. The homogeneity and trends in time series were tested using XLSTAT (Statistical software for Excel) in 95% confidence level. In the fourth stage, wet and dry years or periods, by defining the annual precipitation index (PI) and weighted precipitation index (WPI) have been determined. Also, warm and cold years or periods were identified by defining the average annual temperature index (TI) and weighted average annual temperature index (WTI). Finally, frequency analysis for predicted and observed annual precipitation data was carried out to understand the past, present and future conditions of Tabriz city climate.

Downscaling method

By promoting new technology, future global climate models with high resolution have been developed. But there will remain the need to use downscaling methods to predict the effects of climate change in a specific place or site (Conway et al.1996). Downscaling is defined as any action to derive high-resolution information based on low-resolution data (Kim et al. 1984; Wilby et al. 2001, 2003; Hessami et al. 2004).

In the SDSM, due to "low-tech" advantages and reduction of costs in statistical downscaling compared to dynamical downscaling, a hybrid conditional method weather generator technique is selected as a basis of the decision system. This software has seven steps, each of which is explained below.

1. Controlling the quality of data and their transformation

In order to control the quality of the input data, the daily precipitation and the daily average temperature of the Tabriz station from 01/01/1961 to 31/12/2005 were prepared in Notepad software in two separate files and saved them as "P.dat" and "tem.dat", respectively. There is no any missing data and the whole numbers of the daily precipitation and average temperature data were 16,437. These files are then used as input files in the SDSM software as a basis. In the data transformation phase, to achieve the best calibration for input data, the daily precipitation has been transformed. But, for the daily average temperature data, we didn't use transformation functions, because there was good accordance between the observed and modeled average temperature data.

2. Selection of the predictor variables

For downscaling of meteorological variables, it is needed to determine different predictor variables that are appropriate for the complexity of the model that will result in the prediction of the different climatic variables. Therefore, the meteorological predictor variables from the National institute for Environmental Prediction (NCEP)/National institute for Atmospheric Research (NCAR) downloaded from (https://climate-scenarios.canada.ca/?page=pred-canesm2) were applied. Table 1 represents the 26 different predictor factors and their descriptions.

For selection of 26 meteorological variables, a correlation analysis has been done to calculate correlation coefficients

Table 1 Predictors of NCEP and NCAR used for prediction of climatic variables in Tabriz

Row	Predictor	Description	Row	Predictor	Description
1	Ncepp850gl.dat	8500 hPa Geopotential	14	Ncepp5_ugl.dat	500 hPa Zonal velocity
2	Ncepprcpgl.dat	Accumulated precipitation	15	Ncepp5_vgl.dat	500 hPa Meridional velocity
3	Nceps500gl.dat	500 hPa Specific humidity	16	Ncepp5_zgl.dat	850 hPa wind speed
4	Nceps850gl.dat	850 hPa Specific humidity	17	Ncepp5thgl.dat	500 hPa wind speed
5	Ncepshumgl.dat	1000 hPa Specific humidity	18	Ncepp5zhgl.dat	500 hPa Divergence
6	Nceptempgl.dat	Screen air temperature(2 m)	19	Ncepp8_fgl.dat	850 hPa wind speed
7	Ncepp1_fgl.dat	1000 hPa Wind speed	20	Ncepp8_ugl.dat	850 hPa Zonal velocity
8	Ncepp1_ugl.dat	1000 hPa Zonal velocity	21	Ncepp8_vgl.dat	850 hPa Meridional velocity
9	Ncepp1_vgl.dat	1000 hPa Meridional velocity	22	Ncepp8_zgl.dat	850 hPa Vorticity
10	Ncepp1_zgl.dat	1000 hPa Vorticity	23	Ncepp8thgl.dat	850 hPa Wind direction
11	Ncepp1thgl.dat	1000 hPa Wind direction	24	Ncepp8zhgl.dat	850 hPa Divergence of true wind
12	Ncepp1zhgl.dat	Surface Divergence	25	Ncepp500gl.dat	500 hpa Geopotential
13	Ncepp5_fgl.dat	500 hPa wind speed	26	Ncepmslpgl.dat	Mean sea level pressure

between each of them and each of the four climatic factors. Also, in the selection of predictor variables, two statistical parameters, namely, the correlation coefficient (r) and the p values were assessed. The NCEP/NCAR predictors were selected to be applied in the development of the best calibrated model. After assessing the r and verifying the dependency of predictors and predictands via scatter plot, the total set of predictors was chosen. In this study, the selected predictor factors for precipitation are 850 hPa geopotential, 850 hPa divergence of true wind and accumulated precipitation.

In this study it was found that the predictors for Tabriz city in the case of maximum air temperature, are the 500 hPa, 850 hPa geopotential heights and screen air temperature (2 m). However, 500 hPa geopotential height, 850 hPa geopotential and 850 hPa Divergence of true were the selected predictors for minimum temperature. Also, mean sea level pressure, 500 hPa geopotential height and 850 hPa geopotential were selected for the mean temperature. Table 2 shows the predicted variables, the selected predictors variable, and both the correlation coefficients and p values for each of them. According to Table 2, all the r values were significant at 0.01 level.

3. Calibration of the model

In the third step, after the selection of a set of predictors and their statistical parameters in Tabriz station according to the previous step, i.e., (selection of the predictors variables step), the observed daily precipitation data series (P.dat file) and observed data series of average temperature (tem.dat file) have been calibrated. In this regard, the two mentioned files i.e., (P.dat & tem.dat) were used as input for the SDSM software, and the predictors that showed the high correlation coefficients were selected for the calibration in the SDSM software. Also, according to the SDSM Manual, for calibration "P.dat" file, a conditional model option, and

Table 2 The selected set of predictors and their statistical parameters in Tabriz

Predicted variables	Predictors	r	p value
Precipitation	ncepp850gl.dat (850 hPa Geopotential)	−0.248	<0.0001
	ncepp8zhgl.dat (850 hPa Divergence of true wind)	−0.279	<0.0001
	nceprcpgl.dat (Accumulated precipitation)	0.469	<0.0001
T_{max}	ncepp500gl.dat (500 hPa geo potential height)	0.882	<0.0001
	nceps850gl.dat (850 hPa Geopotential)	0.816	<0.0001
	nceptempgl.dat (Screen air temperature (2 m))	0.965	<0.0001
T_{min}	ncepp500gl.dat (500 hPa geo potential height)	0.838	<0.0001
	ncepp850gl.dat (850 hPa Geopotential)	0.828	<0.0001
	ncepp8zhgl.dat (850 hPa Divergence of true)	0.958	<0.0001
T_{mean}	ncepmslpgl.dat (Mean Sea level pressure)	−0.743	<0.0001
	ncepp500gl.dat (500 hPa geo potential height)	0.851	<0.0001
	ncepp850gl.dat (850 hPa Geopotential)	0.775	<0.0001

for calibration, «tem.dat» file, an unconditional model option was used (Wilby and Dawson 2007). In an unconditional model, it is assumed that there is a direct relation between predictand and predictors. In this manuscript, mean sea level pressure, 500 hPa geopotential height and 850 hPa geopotential are the predictors for average temperature in Tabriz (Table 2). These predictors have a direct link with the average monthly temperature. So, in calibrating the "tem.dat" file, an unconditional model has been selected. But, in the conditional model, the local climate and regional forces have an intermediate relationship (e.g., the amount of local precipitation is related to the wet periods. Also, the wet periods are related to predictors on a regional scale, such as pressure of the atmosphere and humidity. However, in this research, 850 hPa geopotential, 850 hPa divergence of true wind and accumulated precipitation predictors have been chosen for precipitation (refer to Table 2). However, these predictors have intermediate links with precipitation. Therefore, in calibrating the "P.dat" file, a conditional model has been selected. However, at the end of this step, the two calibrated files for average monthly temperature and the sum of monthly precipitation are obtained as output, i.e., (CLP1961-2005.PAR and CLTem1961-2005.PAR).

4. Weather generation using the observed predictors

In this phase, two calibrated files (CLP1961-2005.PAR and CLTem1961-2005.PAR) have been entered into SDSM software and the predictors that showed the maximum correlation coefficient were selected. Finally, a weather generated file for the average monthly temperature and a weather generated file for the sum of monthly precipitation are obtained as outputs, i.e., (WGP1961-2005.OUT and WGTem1961-2005.OUT).

5. Statistics analyzing

In this step, two obtained files from the previous section namely "WGP1961-2005.OUT" and "WGTem1961-2005.OUT" entered into the SDSM software as the input files and by selecting the «model» mode in the setting section, the two files are produced including "MONP-mod-1961-2005.txt" and "MON-obs-1961-2005.txt" for monthly precipitation. Also, for average temperature, two other files are generated including "MONTem-mod-1961-2005.txt" and "MONTem-obs-1961-2005.txt" in the SDSM software.

6. Model output and creating the graphs

To compare the modeled and observed time series namely monthly average temperature and monthly precipitation, the output files from the past phases (MONP-mod-1961-2005.txt, MON-obs-1961-2005.txt, MONTem-mod-1961-2005.txt, MONTem-obs-1961-2005.txt) were plotted. Their pattern compared graphically for Tabriz. At this stage, the accordance of the real model with the simulated model in SDSM software was checked for the monthly precipitation and average monthly temperature. For this purpose, the root-mean-square error percent (RMSE (%)) was calculated based on Eq. (1) (Hodson 2022):

$$\text{RMSE}\ (\%) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(X_{\text{obs}}-X_{\text{mod}})^2}{n}}}{\frac{1}{n}\sum_{i=1}^{n} X_{\text{obs}}} \times 100. \tag{1}$$

Results indicated that the amount of RMSE (%) between the observed monthly precipitation and the modeled one was equal to 4.33%. But, the amount of RMSE (%) between the observed average temperature and the modeled one was equal to 0.14%. Therefore, it can be concluded that the two predicted models in SDSM software are very close to the measured model and these models can be used in the next steps in SDSM software.

7. Using climate models predictors and generation of scenarios

To generate the climate scenarios, firstly, we go again to the calibration stage (the third step in the downscaling process) and the data date selected to be from 1/1/2020 to 30/12/2060 in the settings of SDSM software because the software cannot process data for more than 40 years. So, the observed data files namely "P.dat" and "Tem.dat" were selected as the input files and by selecting future climate predictors (RCP2.6, RCP4.5, RCP8.5) that showed the highest correlation coefficients, three files are created for precipitation (CLP-RCP 2.6-2020-2060, CLP-RCP4.5-2020-2060, CLP-RCP8.5-2020-2060), and three other files are obtained for average temperature (CLTem-RCP 2.6-2020-2060, CLTem-RCP4.5-2020-2060, CLTem-RCP8.5-2020-2060). Then, in the "settings" option, the data period of 1/1/2060 to 30/12/2100 was selected. Repeating the above steps, three files resulted for precipitation (CLP-RCP 2.6-2060-2100, CLP-RCP4.5-2060-2100, CLP-RCP8.5-2060-2100) and also three other files obtained for average temperature (CLTem-RCP 2.6-2060-2100, CLTem-RCP4.5-2060-2100, CLTem-RCP8.5-2060-2100). Similarly going back to the weather generator step, three weather generator files are created for the period 2020-2060 (WGP-RCP2.6-2020-2060, WGP-RCP4.5-2020-2060, WGP-RCP8.5-2020-2060). By the same way, three weather generator files for the future period of 2061-2100 created for precipitation (WGP-RCP 2.6-2061-2100, WGP-RCP 4.5-2061-2100-WGP-RCP 8.5-2061-2100. It was repeated for temperature data and six weather generator files (WGTem-RCP2.6 2020-2060, WGTem-RCP4.5-2020-2060, WGTem-RCP8.5-2020-2060, WGTem-RCP2.6-2061-2100, WGTem-RCP 4.5-2061-2100, WGTem-RCP 8.5-2061-2100) were created. Finally, in the scenario generator phase, six precipitation weather generator files entered to SDSM software as input files. The six output files (RCP2.6-2020-2060, RCP4.5-2020-2060, RCP8.5-2020-2060, RCP2.6-2061-2100, RCP4.5-2061-2100, RCP8.5-2061-2100) (RCPs scenarios for precipitation) were obtained. Then, six temperature weather generator files were used as input to SDSM. This led to production of six files (RCP2.6-2020-2060, RCP4.5-2020-2060, RCP8.5-2020-2060, RCP2.6-2061-2100, RCP4.5-2061-2100, RCP8.5-2061-2100) (RCPs scenarios for temperature).

In this research, all the explained procedures were carried out to generate RCP2.6, RCP4.5 and RCP 8.5 scenarios based on data of Tabriz synoptic station. The flowchart of the above-mentioned processes is shown in Fig. 2.

Mann–Kendall (MK) test

The MK test is based on a Kendall rank statistic which presented by Kendall (1938) and Mann (1945). This test is widely used to detect monotonic trends in hydrology and climatology data series such as water quantity, river discharge, precipitation (Dinpashoh et al. 2014), temperature (Jhajharia et al. 2014), evaporation and evapotranspiration (Dinpashoh et al. 2011) and so on. The non-parametric MK test statistics calculated by following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right), \tag{2}$$

where X_i and X_j are the ith and jth observations and n is the number of data. The sign function is given by following equation:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}. \tag{3}$$

A positive (negative) value of S indicates an upward (downward) trend. For $n > 8$, the statistic S is nearly Gaussian-distributed with $E(S) = 0$ and its variance evaluated from the following equation (Mann 1945; Kendall 1975):

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(i-1)(2i+5)}{18}. \tag{4}$$

In which, n is the number of data, P is the number of tied groups, and t_i is the number of same data in the ith group. Ultimately, the MK Z value is obtained:

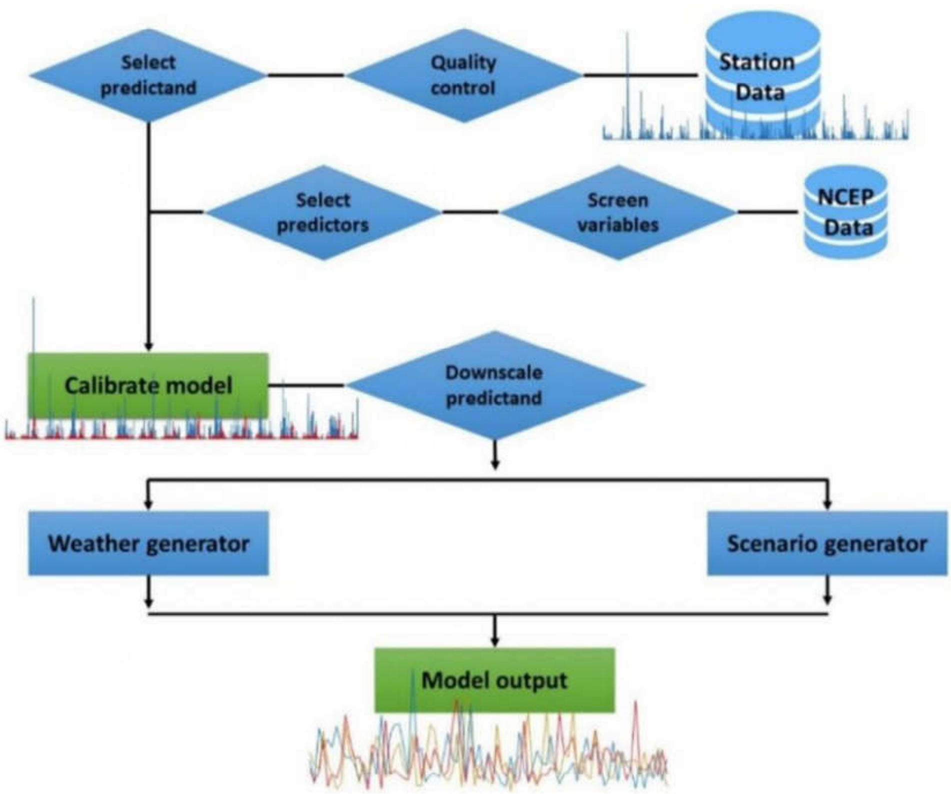


Fig. 2 Flowchart of conceptual methodology (Wilby and Dawson 2007; El Hafyani et al. 2023)

$$z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0; \\ 0 & \text{if } S = 0; \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0; \end{cases} . \quad (5)$$

Which follows the standard Gaussian distribution with a mean of zero and a variance equal to one. The calculated z compared with the Z extracted from the normal standard table corresponds to non-exceedance probability of $1-\alpha$. If the absolute value of calculated z is greater than the corresponding z of normal table, then trend considered to be significant at α level. Positive z means trend direction is upward and negative z means trend direction is downward.

The exact p value of the MK test can be estimated using the Gaussian cumulative distribution function (CDF) from the following equation (Li et al. 2014):

$$P = 2\left(1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{|z|} e^{\frac{-t^2}{2}} \, \mathrm{d}t\right). \quad (6)$$

If the p value is small enough, the trend is quite unlikely to be caused by random sampling. At the significance level of 0.05, if $p < 0.05$, then the existing trend is considered to be statistically significant. The slope of a trend line is calculated using the Theil–Sen approach (TSA) (Theil 1950; Sen 1968), and it is calculated as follows:

$$b = \mathrm{median}\left(\frac{x_j - x_k}{j-k}\right); \quad \forall k < j, \quad (7)$$

where b is the trend line slope. x_k and x_j are the kth and jth observations. The slope (b) determined by the TSA is a robust estimate of the magnitude of a trend. Since the appearance of the paper of Hirsch et al. (1982), the TSA has been popularly employed for calculating the slope of trends in hydrologic time series (Jhajharia et al. 2014; Li et al. 2014).

Pettitt test

Pettitt (1979) introduced a rank-based non-parametric statistical test to detect change points in a data series. Suppose a sequence of data series $X_1, X_2, \ldots, X_T$ with change point at time τ, which is separated in two groups with distinct distributions function: $F_1(X_t)$, $t = 1, 2, \ldots, \tau$, and $F_2(X_t)$, $t = \tau + 1, \ldots, T$.

Therefore, the tested hypotheses are:

$$\begin{cases} H_0 : F_1(X) = F_2(X) \text{ (no change point)} \\ H_1 : F_1(X) \neq F_2(X) \text{ (change point)} \end{cases} . \quad (8)$$

To disclose the break point, this test uses the statistic $U_{t.T}$, similar to the Mann–Whitney test statistic (Mann and Whitney 1945) for two groups, stated by (Pettitt 1979):

$$U_{t.T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \mathrm{sgn}(X_i - X_j) . 1 \leq t < T, \quad (9)$$

where:

$$\mathrm{sgn}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} . \quad (10)$$

The point τ will likely be a change point when it satisfies the following equation:

$$K_\tau = U_{t.T} = \max \left| U_{t.T} \right|. \quad 1 \leq t < T. \quad (11)$$

According to the above discussions about the test statistics, Pettitt (1979) introduces Eq. (12) for calculating the p value of the test approximately:

$$P \approx 2\exp\left(\frac{-6k_\tau^2}{T^3 + T^2}\right). \quad (12)$$

Therefore, with a supposed significance level α, if $p < \alpha$, the null hypothesis, $H_\circ$, that the two distributions are similar, is rejected (Pettitt 1979).

precipitation and weighted precipitation indexes

The annual precipitation index (PI) determines the deviation from the average result of the observation station's data for a long period. This index is obtained using the precipitation in the year, the mean and the standard deviation of the series (El Hafyani et al. 2023):

$$\mathrm{PI} = \frac{X_i - X_m}{\sigma}, \quad (13)$$

where X_i is precipitation depth in the ith year, X_m is the mean of series, and σ is the standard deviation of the precipitation series.

To determine inter-annual fluctuations of precipitation, seasonal factors are deleted by using a weighting and moving average method to the annual precipitation time series through the following equations (El Hafyani et al. 2023):

$$X_t = 0.06X_{(t-2)} + 0.25X_{(t-1)} + 0.38X_t + 0.25X_{t+1} + 0.06X_{t+2}, \quad (14)$$

where $3 \leq t \leq (n-2)$, X_t is the weighted precipitation value at time t. $\left(X_{t-2}\right)$ and $X_{(t-1)}$ are the observed precipitation directly before the time t, $X_{(t+2)}$ and $X_{(t+1)}$ are the precipitation totals of two times directly after the time t. The weighted precipitation totals for the first two ($X_{(1)}$ and $X_{(2)}$) and the last two $\left(X_{n-1} - X_n\right)$ times in the data were analyzed as follows:

$$X_{(1)} = 0.54X_{(1)} + 0.46X_{(2)}, \quad (15)$$

$$X_{(2)} = 0.25X_{(1)} + 0.5X_{(2)} + 0.25X_3, \quad (16)$$

$$X_{(n-1)} = 0.25X_{(n-2)} + 0.5X_{(n-1)} + 0.25X_n, \quad (17)$$

$$X_{(n)} = 0.54X_{(n)} + 0.46X_{(n-1)}. \quad (18)$$

Also, the annual weighted precipitation index (WPI) is calculated from the following equation:

$$\mathrm{WPI} = \frac{X_{iw} - X_{mw}}{\sigma_w}, \quad (19)$$

where X_{iw} is the weighted precipitation in the ith year, X_{mw} is the mean of the weighted precipitation data, and σ is the standard deviation of the weighted precipitation series (El Hafyani et al. 2023). Also, the above-mentioned method was used to calculate annual average temperature, the annual average temperature index (TI) and the weighted annual average temperature index (WTI) which is explained in section "Temperature analysis".

Frequency analysis

Frequency analysis is a useful method for analyzing data and predicting the occurrence of an event at a certain or specific period of time. Also, it can be used to check the reliability of predictions. Frequency analysis has many usages in flood prediction, design of hydraulic and drainage structures, and so on. In this research, firstly, the time series of precipitation and temperature (observed and predicted) is prepared in annual scale in Excel spreadsheet using the XLSTAT software in the past (1951–2022) and future (2023–2100) periods. Then, the Bin range of time series is identified based on the minimum and maximum value of the data. Finally, by using the software, cumulative percentage and frequency output charts have been obtained.

Results and discussion

Precipitation analysis

The Mann–Kendall (MK) trend test for observed precipitation (past and present period)

Table 3 shows the results of the MK trend test for observed monthly and yearly precipitation time series in the period 1951–2022 for Tabriz station at 95% confidence level. Results showed that in the January, February, June, August, September and October the monthly precipitation values showed decreasing trends. However, these trends are not significant in the base time period, i.e., (1951–2022). In contrast, in the March, April, May, July, November and December the monthly precipitation series exhibited increasing trends. None of the trends were significant at 0.05 level. Annual precipitation series of Tabriz showed decreasing trend between 1951 and 2022 which was not significant at 0.05 level. Therefore, it can be concluded that the amount of annual precipitation decrease is not statistically significant. On a monthly scale, the precipitation changes are not statistically significant in different months (Table 3). As can be seen from Eq. (6), b is the slope of a trend line which is computed for both monthly and annual precipitation series of Tabriz. It changes between −0.445 to 1.490 for all the series of monthly precipitation in Tabriz. The steepest decrease in trend line slope is equal to −0.445 that belonged to the August and the steepest increase in the trend line slope belonged to the April. The trend line slope of annual precipitation in Tabriz is equal to − 1.01 mm per year (Table 3).

Table 3 Results of Mann–Kendall trend test for observed monthly and yearly precipitation (1951–2022) in Tabriz station

Month/annual	Z	b (mm per year)	Trend/ direction	SIG/NS
Jan	−0.024	0.230	↓	NS
Feb	−1.424	0.246	↓	NS
Mar	0.054	0.730	↑	NS
Apr	0.715	1.490	↑	NS
May	0.841	1.050	↑	NS
Jun	−1.745	−0.120	↓	NS
Jul	1.138	−0.337	↑	NS
Aug	−1.122	−0.445	↓	NS
Sep	−1.053	−0.320	↓	NS
Oct	−1.614	0.133	↓	NS
Nov	0.248	0.395	↑	NS
Dec	0.345	0.345	↓	NS
Annual	−0.452	− 1.013	↓	NS

SIG statistically significant, *NS* statistically insignificant

The Mann–Kendall (MK) trend test for predicted precipitation (present and future period)

Results of the MK trend test for monthly and yearly predicted precipitation in the future period of 2022–2100 for Tabriz station at 95% confidence level are shown in Tables 4, 5 and 6 for the three RCPs scenarios, namely RCP 2.6, 4.5, 8.5, respectively. Also, the obtained test results indicate increasing trend in January, February, March, April, May, September, October, November and December and decreasing trend in June, July and August

Table 4 Results of Mann–Kendall trend test for monthly and yearly predicted precipitation (2022–2100) in Tabriz station for the RCP 2.6 scenario

Month/annual	Z	b (mm per year)	Trend/direction	SIG/NS
Jan	1.492	0.095	↑	NS
Feb	2.339	0.167	↑	SIG
Mar	0.924	0.087	↑	NS
Apr	0.665	0.067	↑	NS
May	1.783	0.152	↑	NS
Jun	−0.004	0.025	↓	NS
Jul	−0.139	0.000	↓	NS
Aug	−0.328	0.000	↓	NS
Sep	0.370	0.000	↑	NS
Oct	2.470	0.167	↑	SIG
Nov	0.834	0.063	↑	NS
Dec	0.707	0.048	↑	NS
Annual	3.320	1.080	↑	SIG

SIG statistically significant, *NS* not statistically insignificant

Table 5 Results of Mann–Kendall trend test for monthly and yearly predicted precipitation (2022–2100) in Tabriz station for the RCP 4.5 scenario

Month/annual	Z	b (mm per year)	Trend/direction	SIG/NS
Jan	−0.415	−0.025	↓	NS
Feb	0.787	0.052	↑	NS
Mar	0.330	0.031	↑	NS
Apr	0.728	0.090	↑	NS
May	0.982	0.124	↑	NS
Jun	0.001	0.020	↑	NS
Jul	−0.110	0.000	↓	NS
Aug	−0.271	0.000	↓	NS
Sep	−1.299	−0.048	↓	NS
Oct	0.102	0.009	↑	NS
Nov	−0.872	−0.067	↓	NS
Dec	0.897	0.049	↑	NS
Annual	0.042	0.090	↑	NS

SIG statistically significant, *NS* not statistically significant

in RCP2.6 scenarios. Also, there is upward trend in February, March, April, May, June, October and December and downward trend in January, July, August, September and November in RCP4.5 scenarios. In RCP 8.5, There is upward trend in February, May, July and August and downward trend in January, March, April, June, September, October, November, December. Also, at 95% confidence level, annul precipitation in RCP 2.6 and 4.5 have increasing trend and has decreasing trend in RCP 8.5 scenario (Table 4, 5 and 6).

Table 6 Results of Mann–Kendall trend test for monthly and yearly predicted precipitation (2022–2100) in Tabriz station for the RCP 8.5 scenario

Month/annual	Z	b (mm per year)	Trend/direction	SIG/NS
Jan	−0.927	−0.064	↓	NS
Feb	2.290	0.128	↑	SIG
Mar	−1.910	−0.197	↓	NS
Apr	−1.215	−0.124	↓	NS
May	1.950	0.209	↑	NS
Jun	−0.495	−0.027	↓	NS
Jul	0.725	0.009	↑	NS
Aug	1.703	0.023	↑	NS
Sep	−0.279	−0.007	↓	NS
Oct	−1.122	−0.069	↓	NS
Nov	−2.041	−0.15	↓	SIG
Dec	−0.305	−0.021	↓	NS
Annual	−1.118	−0.309	↓	NS

SIG statistically significant, *NS* not statistically significant

Table 7 Results of Pettitt homogeneity test for monthly and annual observed precipitation (1951–2022) in Tabriz station

Month/annual	Chang point at year	p value (two-tailed)	Shift direction
Jan	No	–	No
Feb	1988	0.016	Downward
Mar	No	–	No
Apr	No	–	No
May	1984	0.025	Upward
Jun	No	–	No
Jul	No	–	No
Aug	No	–	No
Sep	No	–	No
Oct	No	–	No
Nov	1984	0.045	Downward
Dec	No	–	No
Annual	1982	0.011	Downward

Pettitt homogeneity test for observed precipitation (past and present period)

The Pettitt test for monthly and annual precipitation time series in the past period (1951–2022) has been done for Tabriz station. Results indicate change points in February (1988) and November (1984) with downward trends in 95% confidence level. Also, an upward change point was detected in May (1984). In addition, change points in other months were not detected. According to this test, the p value is lower than the significant level of alpha = 0.05 (Table 7). Also, Fig. 3 shows the output of Pettitt test for Tabriz annual

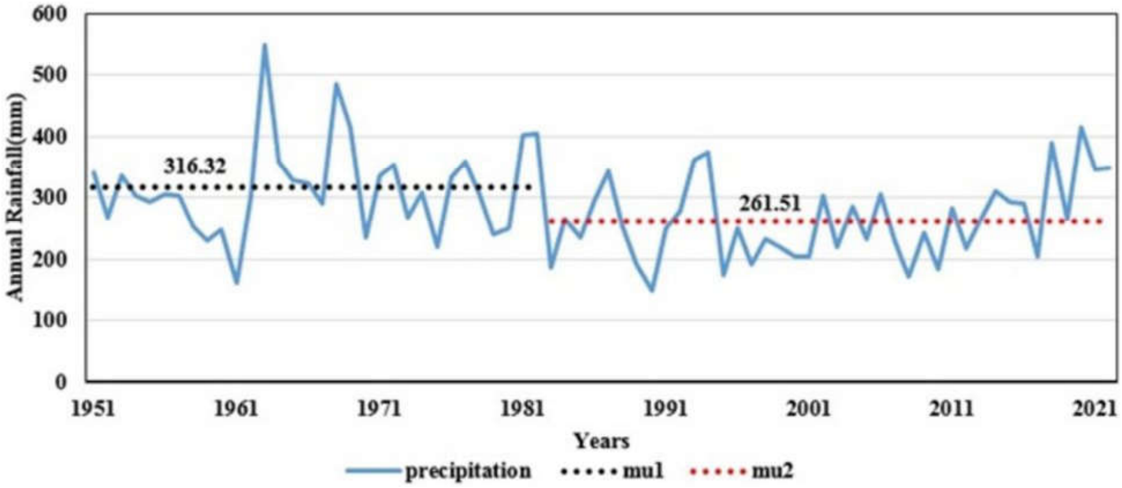


Fig. 3 Annual precipitation time series showing sudden change in 1981 in Tabriz station

precipitation. In this figure, a sudden change has been detected in the precipitation time series in 1981. However, the average annual precipitation before and after the break point is equal to 316.32 mm and 261.51 mm, respectively. However, the calculated change in average annual precipitation before and after the break point is about 55 mm and is equal to 17.33% of the total annual average precipitation between 1951 and 1981 (Fig. 3).

The Pettitt homogeneity test for predicted precipitation (present and future period)

Pettitt homogeneity tests (39 tests) using Statistical Software for Excel software (XLSTAT) software version 2022 have been done for predicted monthly and yearly precipitation for three different climate scenarios. Table 8 shows the results of the Pettitt test for annual and monthly precipitation in Tabriz station at RCP 2.6. In this table, the series which showed significant changes are listed. These tests have been done at a 5% significant level. Results showed that among all the series, there were three change points: in July in 2054, in October in 2061 and in the annual precipitation time series in 2061 for the RCP 2.6. Also, there is a change point in July in 2080 in RCP 4.5 (Table 9). Also, there isn't any sudden change point using the RCP8.5 (Table 10).

Table 8 Results of Pettitt homogeneity tests for monthly and yearly predicted future precipitation (2022–2100) in Tabriz station for the RCP 2.6

RCP 2.6			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	No	–	No
Apr	No	–	No
May	No	–	No
Jun	No	–	No
Jul	2054	< 0.0001	Downward
Aug	No	–	No
Sep	No	–	No
Oct	2061	0.042	Upward
Nov	No	–	No
Dec	No	–	No
Annual	2061	0.002	Upward

Precipitation index (PI) and weighted precipitation index (WPI) for observed period (past and present period)

Figures 4 and 5 show the PI and WPI time series in Tabriz, respectively. These indexes evaluated to distinguish between the humid periods from the dry periods. Results showed that the maximum dry spell in the whole time period lasted 7 years between 1995 and 2001 (Fig. 4). Also, as can be seen from Fig. 5, the humid period was viewed from 1951 until 1957 and a dry period occurred from 1958 until 1962. After 1962, a humid period has been observed from 1962 until 1974 and Tabriz city has been faced with unstable periods from 1975 until 1995. Also, a dry period which lasted 19 years from 1995 until 2014 occurred in the studied period. Also, from 2014 to 2017, unstable conditions have been repeated, and a humid period has been observed from 2017 to 2022 (Fig. 5).

Table 9 Results of Pettitt homogeneity tests for monthly and yearly predicted future precipitation (2022–2100) in Tabriz station for the RCP 4.5

RCP 4.5			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	No	–	No
Apr	No	–	No
May	No	–	No
Jun	No	–	No
Jul	2080	0.04	Upward
Aug	No	–	No
Sep	No	–	No
Oct	No	–	No
Nov	No	–	No
Dec	No	–	No
Annual	No	–	No

Table 10 Results of Pettitt homogeneity tests for monthly and yearly predicted future precipitation (2022–2100) in Tabriz station for the RCP 8.5

RCP 8.5			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	No	–	No
Apr	No	–	No
May	No	–	No
Jun	No	–	No
Jul	No	–	No
Aug	No	–	No
Sep	No	–	No
Oct	No	–	No
Nov	No	–	No
Dec	No	–	No
Annual	No	–	No

Precipitation index (PI) and weighted precipitation index (WPI) for future period

In this study, the precipitation index (PI) and the weighted precipitation index WPI were computed for the future period using the three RCPs scenarios for Tabriz (Figs. 6, 7). The positive amounts for both indicators show wet years, but the negative amounts show dry years. As seen from Figs. 6 and 7, no apparent discrepancies can be seen between the three used scenarios. In addition, results indicated that more arid spells will occur compared to the wet periods in the future period of 2020–2100 using the three scenarios, namely RCP 2.6, RCP 4.5 and RCP 8.5.

Also, the percent of positive and negative values of (PI) and WPI for both the base period and future period at Tabriz have been obtained in Fig. 8. In the past period (1951–1982), 78.13% of all years were humid years and 21% were dry years. From 1983 to 2022, 52% were humid years and 48% were dry years. Also, results indicate in the future period (2022–2050), 61% will be the humid year and 39% will be the dry years in the RCP2.6. In addition, in the RCP4.5, 54% will be humid years and 46% will be dry years in the period between 2022 and 2050. In RCP 8.5, approximately 57% will be humid years and 43% will be dry years in the future period (2022–2050).

In the future period (2051–2100), 38% will be humid years and 62% will be dry years in the RCP2.6 and RCP4.5 scenarios. In addition, in RCP 8.5, approximately 46% will be humid years and 54% will be dry years in the future period (2051–2100).

Analyzing observed precipitation

Monthly precipitation Figure 9 shows the average monthly precipitation of Tabriz city during the last statistical period, i.e., from 1951 to 2022. According to the results, the highest precipitation was in April, which was 51.99 mm, and the lowest precipitation was in August, which was 3.4 mm. Also, the analysis of Fig. 9 indicates that the pattern of precipitation in different months of year does not have the same trend and the amount of precipitation reaches less than 10 mm in the months of July, September and August. In addition, the average precipitation in 12 months of the year is equal to 23.7 mm and this value, compared to the average precipitation in humid and rainy regions, is very low.

Annual precipitation Assessing the annual precipitation at Tabriz station indicated that the pattern and amount of precipitation has been changed in both short and long periods. Figure 10 shows the annual precipitation values of Tabriz. Statistical calculations based on observed data (1951–2022) showed that the minimum, average and maximum value of annual precipitation at Tabriz station is equal to148.01, 285.87 mm and 547.61 mm, respectively. The precipitation amount was less than the mean value in 37 out of the 72 years in the period (1951–2022). The dispersion of the data is equal to 75.24 mm compared to the mean and the amount of change is approximately 26.32% (Fig. 10).

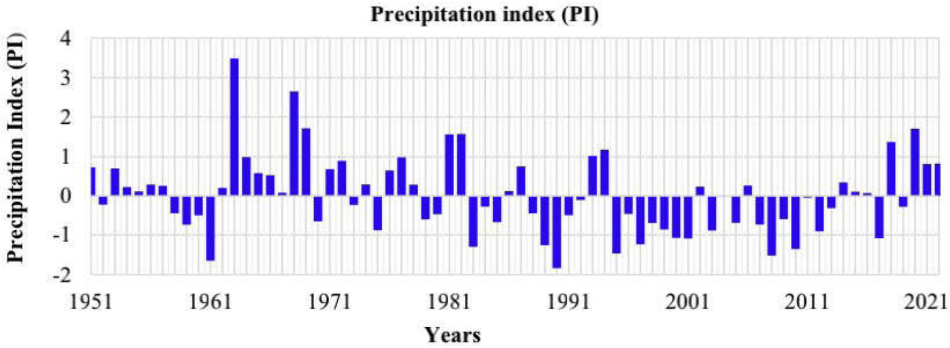


Fig. 4 Precipitation index (PI) for annual observed precipitation time series

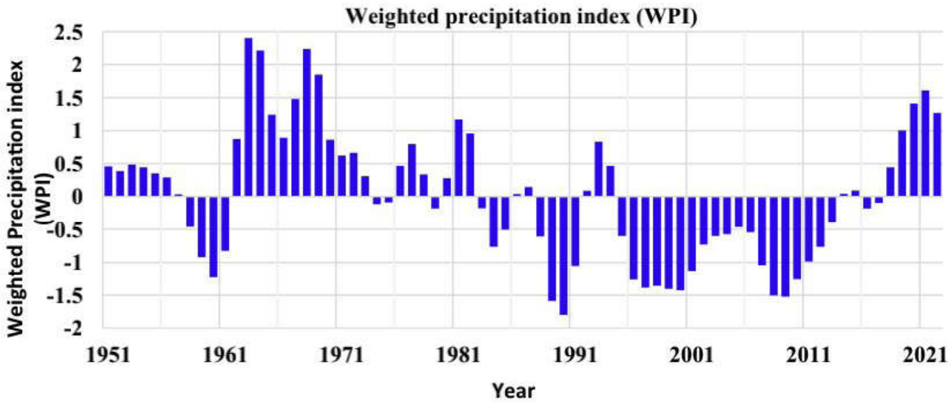


Fig. 5 Weighted precipitation index (WPI) for annual observed precipitation time series

Analyzing predicted precipitation

Monthly precipitation The monthly precipitation series of Tabriz in the past period compared with the predicted amounts that are obtained from the three different RCPs scenarios are reported in Fig. 11. In this figure, the pattern of observed and predicted monthly precipitation using three RCPs scenarios is shown. As can be seen from Fig. 11, in the RCP 2.6 scenario, the average monthly precipitation will rise in all the months (except February, April, May, July) in Tabriz city. Also, comparing the past and future periods using the RCP 4.5 scenario, the average monthly precipitation will increase in all the months (except July and November). In addition, in RCP 8.5, the average monthly precipitation will rise in all the months (except February, April, July and December) comparing the past and future periods.

Annual precipitation Figure 12 shows the predicted precipitation time series for the future period (2020–2100) resulted from the three RCPs scenarios. As it can be seen from it, the predicted annual precipitation in the all three RCPS scenarios (RCP 2.6, RCP 4.5 and RCP 8.5) have not a specific trend. Obtained results indicate the average annual precipitation for RCP 2.6, RCP 4.5 and RCP8.5 are 317.96, 318.85 and 313.76 mm, respectively. According to Fig. 12, annual precipitation fluctuates between 181 and 442 mm in the all three RCPs scenarios in the future periods. Also, in RCP 2.6, annual precipitation will be decrease to less than 200 mm in 2072. In addition, it reduces less than 200 mm in RCP8.5 in 2082. In contrast, the annual precipitation reaches up to 400 mm for RCP2.6 in the 2023, 2064, 2079, 2087, 2088 and 2097. Similarity, the annual precipitation will be increase in the 2025, 2049, 2087 and 2095 in the RCP 4.5 scenario. Figure 12 shows wet years in the 2029, 2040, 2066, 2087 and 2095 in the RCP 8.5.

Analysis of observed and predicted annual precipitation frequencies

Figure 13 shows the observed frequencies of annual precipitation of Tabriz city in the base period. As can be seen from Fig. 13, the frequency of annual precipitation in the bins of 300 and 350 mm is more than the other bins. So, in the 35 years of the base period, annual precipitation of Tabriz was between 250 and 300 mm. In the 52 years, the annual precipitation was between 250 and 350 mm. In the 10 years, annual precipitation was between 350 and 450 mm and only in the 2 years, the annual precipitation was between 450 and 550 mm (Fig. 13).

Figure 14 shows the predicted frequency of Tabriz annual precipitations using the RCP 2.6 scenario. According to this figure, 43 out of the 82 years of annual precipitation will

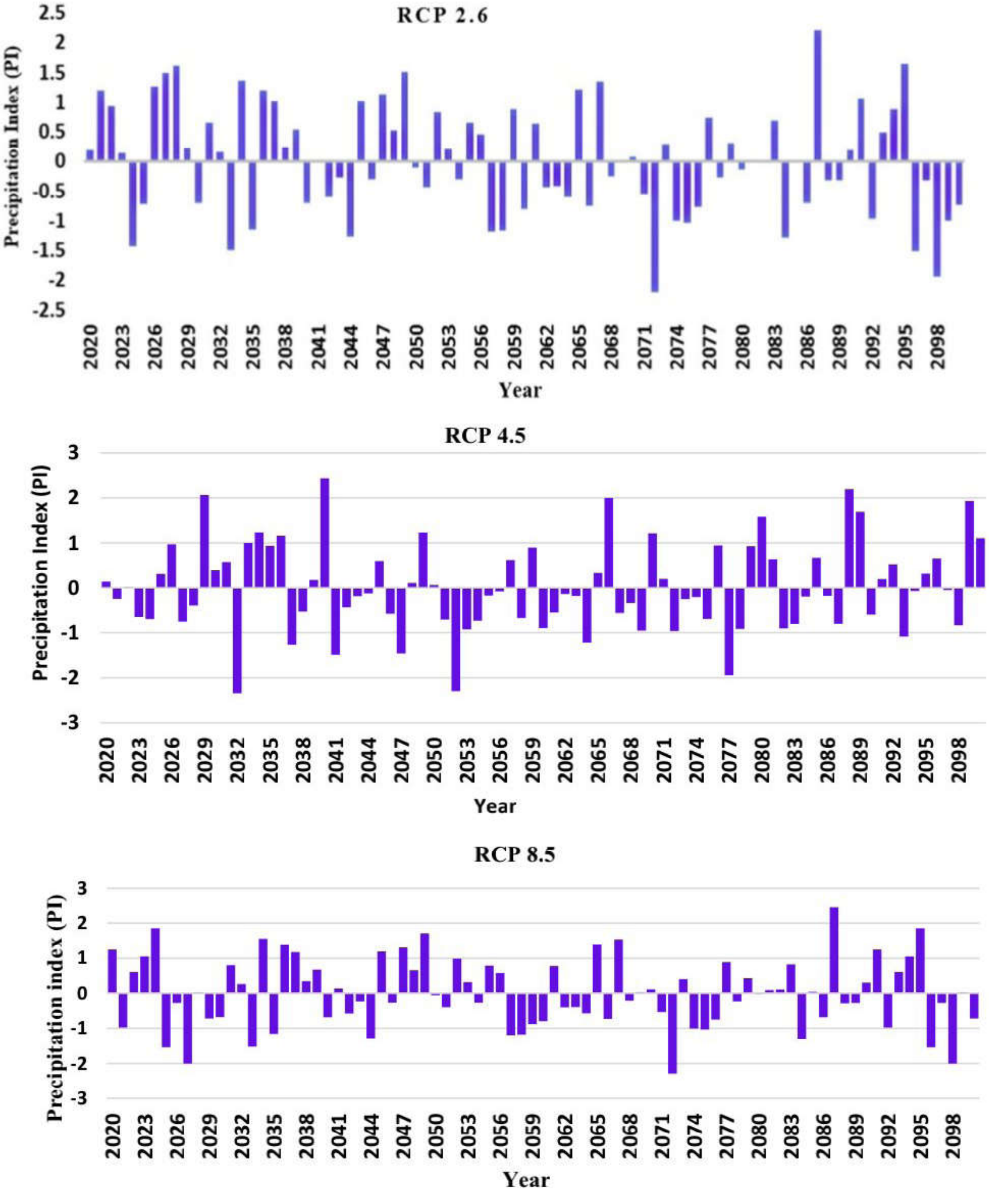


Fig. 6 Predicted precipitation index (PI) for future time period according to the three RCPs scenarios in Tabriz

be between 250 and 350 mm. In 7 years, annual precipitation will be between 400 and 450 mm. Also, only in the 2 years, the annual precipitation is between 150 and 200 mm (Fig. 14). In the future period Tabriz will not experience annual precipitation more than 450 mm.

Figure 15 shows the predicted frequency of annual precipitation using the RCP4 in Tabriz. According to this figure, 51 out of the 81 years of annual precipitation will be between 250 and 350 mm. In the next 6 years, annual precipitation will be between 400 and 450 mm. Also, in 5 years, precipitation will be less than 250 mm (Fig. 15).

The predicted frequency of annual precipitation in RCP 8.5 scenarios is shown in Fig. 16. As can be seen, in 28 out of the 82 years, annual precipitation will be between 250 and 350 mm. In the 19 years, the annual precipitation will be between 350 and 450 mm. Also, in 7 years,

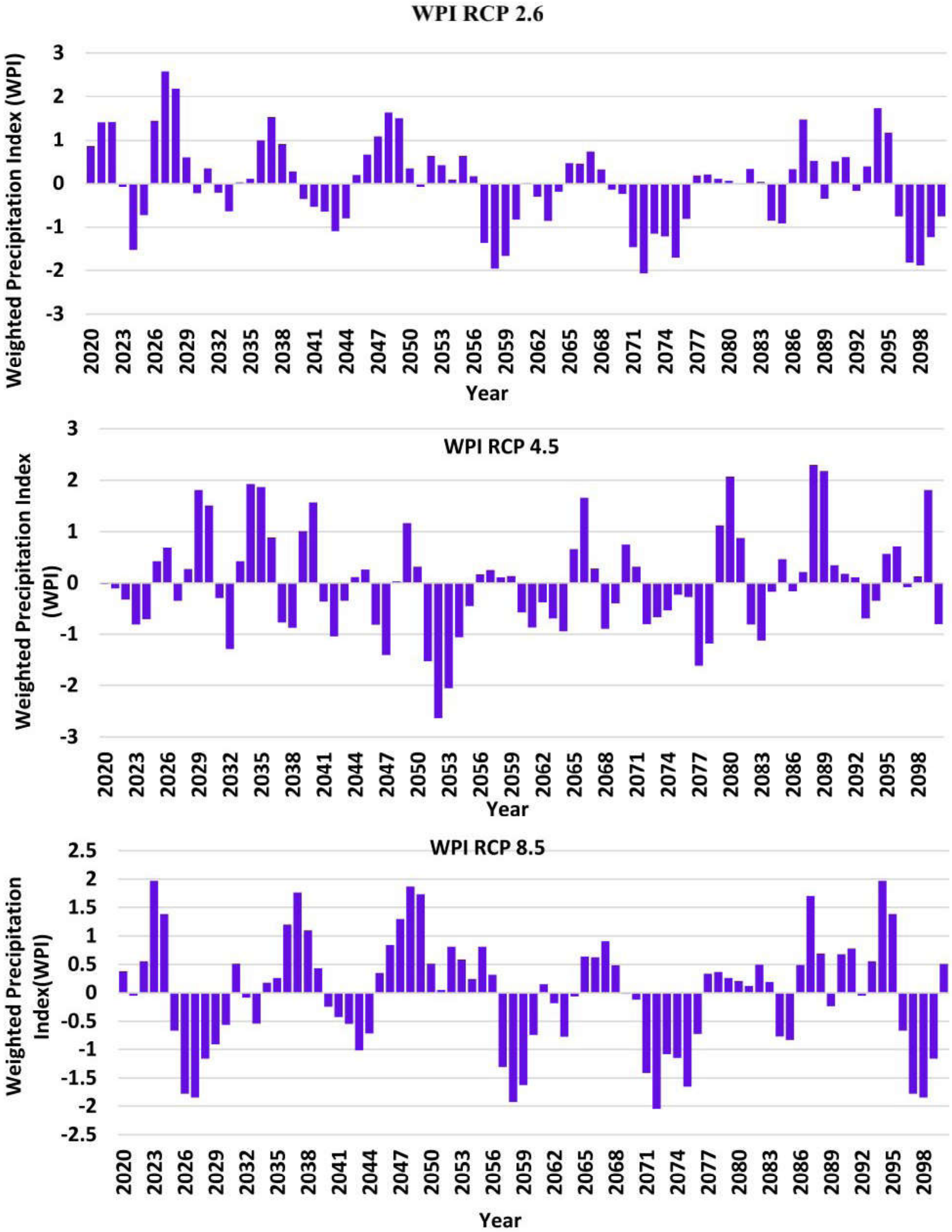


Fig. 7 Predicted weighted precipitation index (WPI) for future time period according to the three used RCPs scenarios in Tabriz

precipitation will be less than 250 mm. Also, it is predicted that the annual precipitation of Tabriz never exceeds 450 mm in a year (Fig. 16).

Summary of results for observed and predicted precipitation in Tabriz

The obtained results of monthly and annual precipitation time series of Tabriz are summarized in Tables 11, 12, and

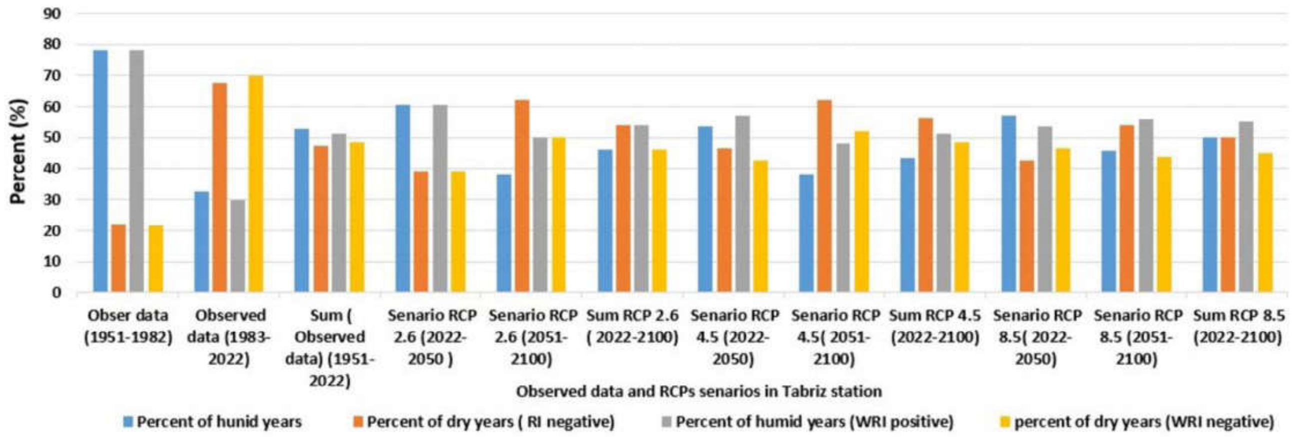


Fig. 8 The percent of years with positive and negative PI and WPI in the historical period (1951–2022) and the future period (2022–2100) at Tabriz station

Fig. 9 Average monthly observed precipitation between 1951 and 2022 in Tabriz

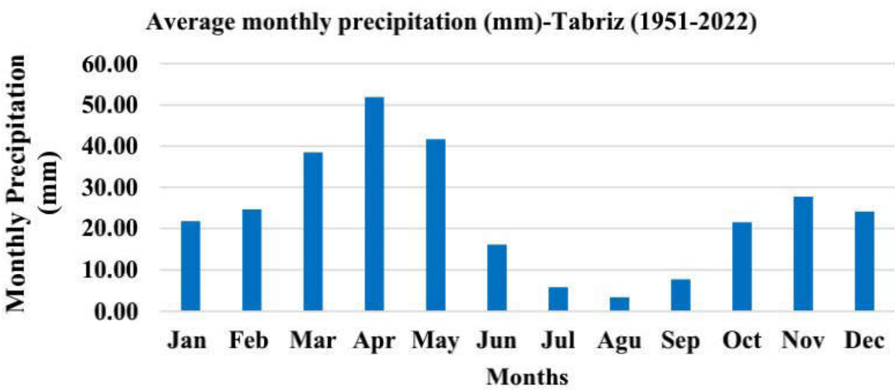
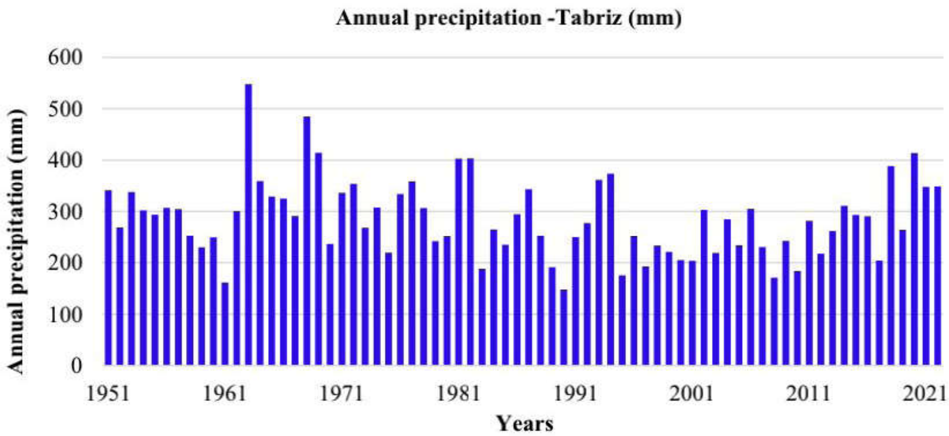


Fig. 10 Annual observed precipitation in the 1951–2022 in Tabriz



13. By using these tables, it is possible to have a clear vision of results and to compare the obtained results in the past (1951–2022) and future period (2022–2100). In Table 11, the observed monthly and annual precipitation time series with RCP 2.6 are obtained. In Table 12, the output results of monthly and annual precipitation time series with RCP 4.5, as well as the observed one In Table 13, the observed monthly and annual precipitation time series and the predicted one using the RCP 8.5 are presented.

Fig. 11 Observed and predicted monthly precipitation (mm) of Tabriz using three RCPs scenarios

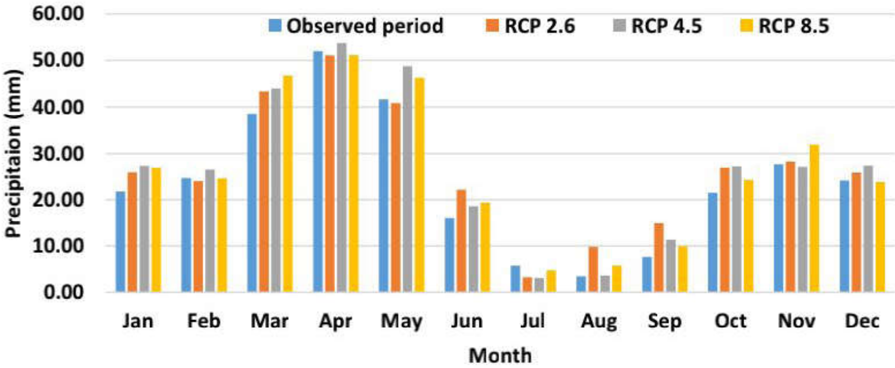


Fig. 12 Predicted annual precipitation time series using the three RCPs scenarios in Tabriz in the future time period (2022–2100)

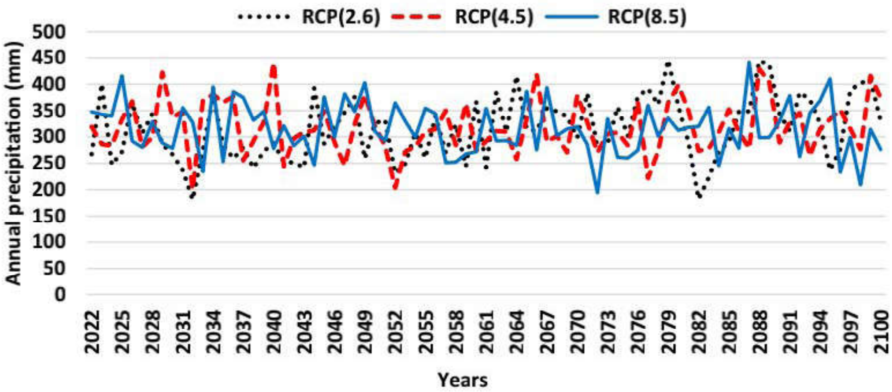
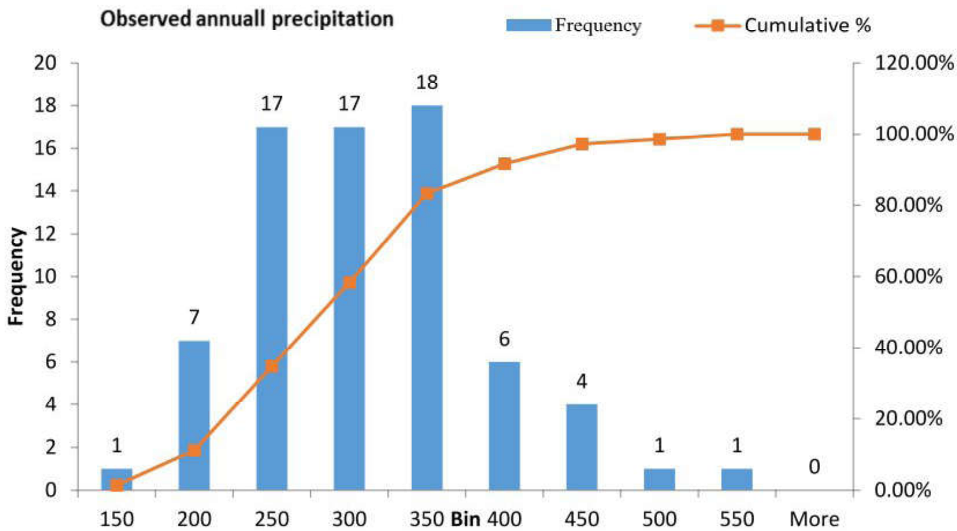


Fig. 13 Observed and cumulative annual precipitation frequency in Tabriz in the base period



Temperature analysis

The Mann–Kendall (MK) trend test for observed temperature (past and present period)

Results of the MK trend test for observed monthly and yearly temperature in the period of 1951–2022 for Tabriz station at 95% confidence level are indicated in Table 14.

As shown from Table 14, all months and annual temperature showed increasing trends. In addition, these trends are significant in all the months (except January and December). This increasing trend is obvious from Fig. 17. Also, the annual mean air temperature of Tabriz showed significant ($p < 0.05$) increasing trend (Table 14). As can be seen from Eq. (6), b is the slope of a trend line which is computed for the months and annual temperature. All the

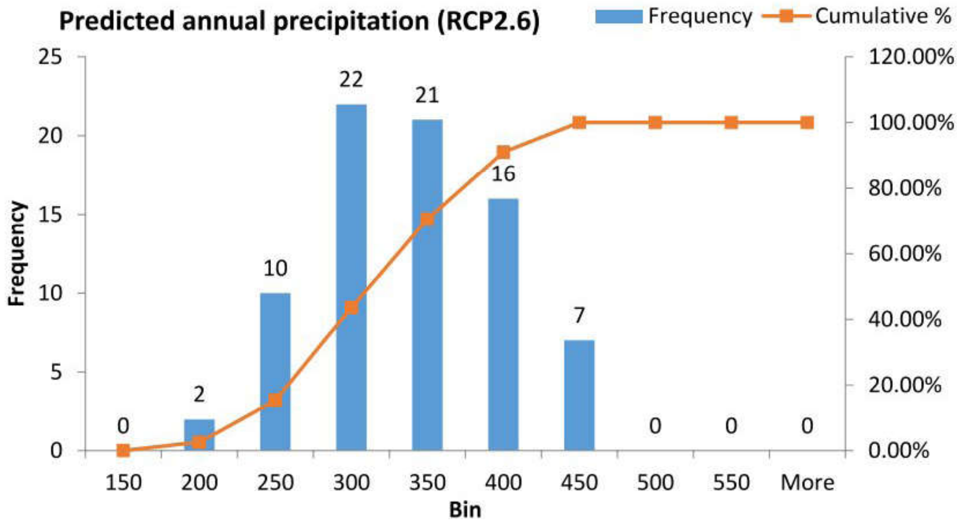


Fig. 14 Predicted and cumulative annual precipitation frequency in Tabriz in the future period (2022–2100) at RCP 2.6

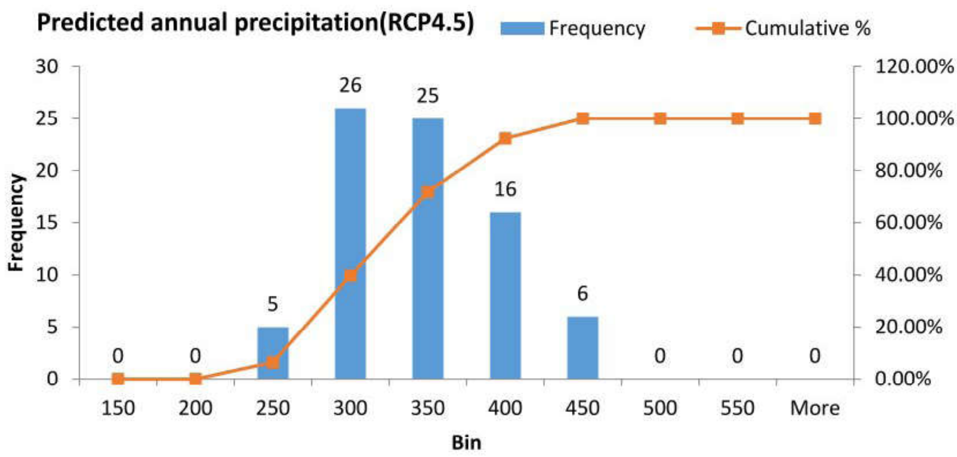


Fig. 15 Predicted and cumulative annual precipitation frequency in Tabriz in the future period (2022–2100) at RCP 4.5

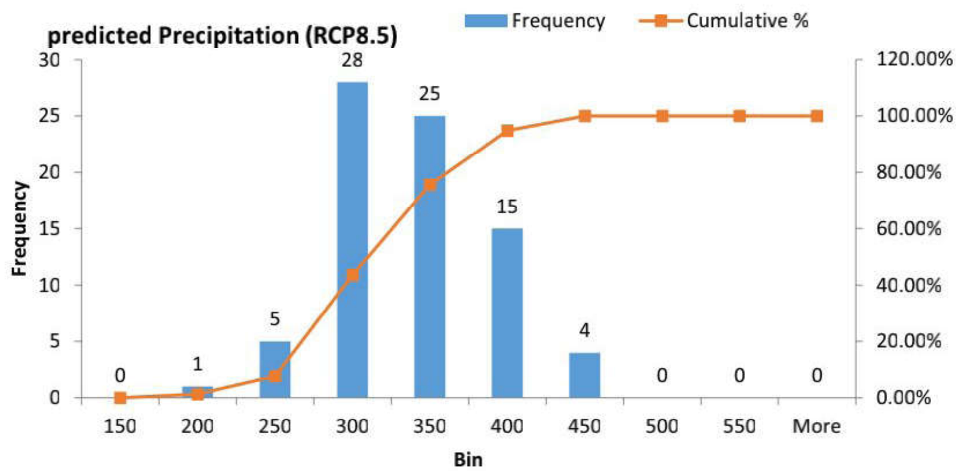


Fig. 16 Predicted and cumulative annual precipitation frequency in Tabriz in the future period (2022–2100) using the RCP 8.5 scenario

slopes are upward and changes between 0.018 and 0.490 for the monthly temperature series in Tabriz. The steepest slope is equal to 0.048 that belonged to the March and June temperatures. The trend line slope of annual monthly temperature in Tabriz is equal to 0.035 (Table 14 and Fig. 17.).

Table 11 Summary of results for monthly and annual precipitation, their trends and change points in the past and future periods (RCP 2.6) in Tabriz

Month/annual	Precipitation (mm) (1951–2022)	Precipitation (mm) (2022–2100) (RCP 2.6)	Trend direction (1951–2022)	SIG/NS	Trend direction (2022–2100) (RCP 2.6)	SIG/NS	Change point (1951–2022)	Change point (2022–2100) (RCP 2.6)
Jan	21.73	25.87	↓	NS	↑	NS	No	No
Feb	24.64	23.97	↓	NS	↑	SIG	Downward (1988)	No
Mar	38.51	43.36	↑	NS	↑	NS	No	No
Apr	51.99	51.10	↑	NS	↑	NS	No	No
May	41.65	40.86	↑	NS	↑	NS	Upward (1984)	No
Jun	16.09	22.10	↓	NS	↓	NS	No	No
Jul	5.79	3.23	↑	NS	↓	NS	No	Downward (2054)
Aug	3.42	9.76	↓	NS	↓	NS	No	No
Sep	7.65	14.83	↓	NS	↑	NS	No	No
Oct	21.46	26.96	↓	NS	↑	SIG	No	Upward (2061)
Nov	27.71	28.29	↑	NS	↑	NS	No	No
Dec	24.11	25.78	↓	NS	↑	NS	No	No
Annual	284.74	316.13	↓	NS	↑	SIG	Downward (1982)	Upward (2061)

SIG statistically significant, *NS* not statistically significant

Table 12 Summary of results for monthly and annual precipitation, their trends and change points in the past and future periods (RCP 4.5) in Tabriz

Month/annual	Precipitation (mm) (1951–2022)	Precipitation (mm) (2022–2100) (RCP 4.5) (mm)	Trend (1951–2022)	SIG/NS	Trend (2022–2100) (RCP 4.5)	SIG/NS	Change point (1951–2022)	Change point (2022–2100) (RCP 4.5)
Jan	21.73	27.39	↓	NS	↓	NS	No	No
Feb	24.64	26.41	↓	NS	↑	NS	Downward (1988)	No
Mar	38.51	44.03	↑	NS	↑	NS	No	No
Apr	51.99	53.76	↑	NS	↑	NS	No	No
May	41.65	48.79	↑	NS	↑	NS	Upward (1984)	No
Jun	16.09	18.62	↓	NS	↑	NS	No	No
Jul	5.79	3.07	↑	NS	↓	NS	No	Upward (2080)
Aug	3.42	3.60	↓	NS	↓	NS	No	No
Sep	7.65	11.34	↓	NS	↓	NS	No	No
Oct	21.46	27.28	↓	NS	↑	NS	No	NO
Nov	27.71	27.17	↑	NS	↓	NS	No	No
Dec	24.11	27.45	↓	NS	↑	NS	No	No
Annual	284.74	318.9	↓	NS	↑	NS	Downward (1982)	No

SIG statistically significant, *NS* not statistically significant

The Mann–Kendall (MK) trend test for future temperature (present and future period)

Results of the MK trend test for monthly and yearly average temperature time series were introduced in the period 2022–2100 for Tabriz station at 95% confidence level, in Tables 15, 16 and 17 for three RCP scenarios. Results revealed that based on all three scenarios upward trend witnessed for annual air temperature of Tabriz. However, these trends are not significant for RCP 2.6 and RCP 8.5 scenarios. The slope of annual air temperature series in scenarios of RCP 4.5 and RCP 8.5 is similar and equal

Table 13 Summary of results for monthly and annual precipitation, their trends and change points in the past and future periods (RCP 8.5) in Tabriz

Month/annual	Precipitation (mm) (1951–2022)	Precipitation(mm) (2022–2100) (RCP 8.5)	Trend (1951–2022)	SIG/NS	Trend (2022–2100) (RCP 8.5)	SIG/NS	Change point (1951–2022)	Change point (2022–2100) (RCP 8.5)
Jan	21.73	26.93	↓	NS	↓	NS	No	No
Feb	24.64	24.59	↓	NS	↑	SIG	Downward (1988)	No
Mar	38.51	46.79	↑	NS	↓	NS	No	No
Apr	51.99	51.14	↑	NS	↓	NS	No	No
May	41.65	46.28	↑	NS	↑	NS	Upward (1984)	No
Jun	16.09	19.36	↓	NS	↓	NS	No	No
Jul	5.79	4.76	↑	NS	↑	NS	No	No
Aug	3.42	5.77	↓	NS	↑	NS	No	No
Sep	7.65	9.93	↓	NS	↓	NS	No	No
Oct	21.46	24.17	↓	NS	↓	NS	No	No
Nov	27.71	31.19	↑	NS	↓	SIG	No	No
Dec	24.11	23.79	↓	NS	↓	NS	No	No
Annual	284.74	315.45	↓	NS	↓	NS	Downward (1982)	No

SIG statistically significant, *NS* not statistically significant

Table 14 Results of the Mann–Kendall trend test for observed monthly and yearly mean air temperature (1951–2022) in Tabriz station

Month/annual	*Z*	*b* (mm per year)	Trend/direction	SIG/NS
Jan	1.578	0.024	↑	NS
Feb	2.571	0.044	↑	SIG
Mar	3.59	0.048	↑	SIG
Apr	3.45	0.035	↑	SIG
May	4.35	0.035	↑	SIG
Jun	3.59	0.048	↑	SIG
Jul	4.98	0.044	↑	SIG
Aug	5.05	0.044	↑	SIG
Sep	4.68	0.035	↑	SIG
Oct	3.24	0.03	↑	SIG
Nov	2.18	0.018	↑	SIG
Dec	1.16	0.019	↑	NS
Annual	0.016	0.035	↑	SIG

SIG statistically significant, *NS* not statistically significant

to 0.002 °C/yr. On a monthly scale, in scenario RCP 2.6, there are downward trends for the average temperature in September, October and December and these trends are statistically significant at 0.05 level.

In monthly scale, in scenarios 4.5, trends of average annual temperature in months January, August, September, October, November and December are downward and not significant at 0.05 level. In this scenarios, trends of temperature in the April are upward and significant at 0.05 level. All the other months showed an upward trend for average temperature in the RCP 4.5 scenario (Table 16).

On a monthly scale, trends of average temperature in the months August, September, October, November and December are downward and not significant at 0.05 level, in scenarios 8.5. All the other months showed an upward trend for the average temperature in the RCP 8.5 scenario (Table 17).

Pettitt homogeneity test for observed average temperature (past and present period)

To find the breaks and change points in the monthly and annual temperature data series, the non-parametric Pettitt test has been done in the past period (1951–2022) (Table 18). So, change points in January (1993), February (1998), March (1997), April (1997), May (1994), June (1996), July (1999), August (1994), September (1997), October (1996) and November (1984) with upward trends being detected. As computed, the *p* value is lower than the significant level of alpha = 0.05 (Table 18). Also, Fig. 18 shows the Pettitt test output for Tabriz. The assessment revealed a sudden increase in the temperature data series in 1995. However, the average temperature before the change point is equal to 11.759 °C and after the break point increased to 13.318 °C. The estimated increase in average temperature is about 1.559 °C or 13.26% of the average temperature value before the change point (Fig. 18).

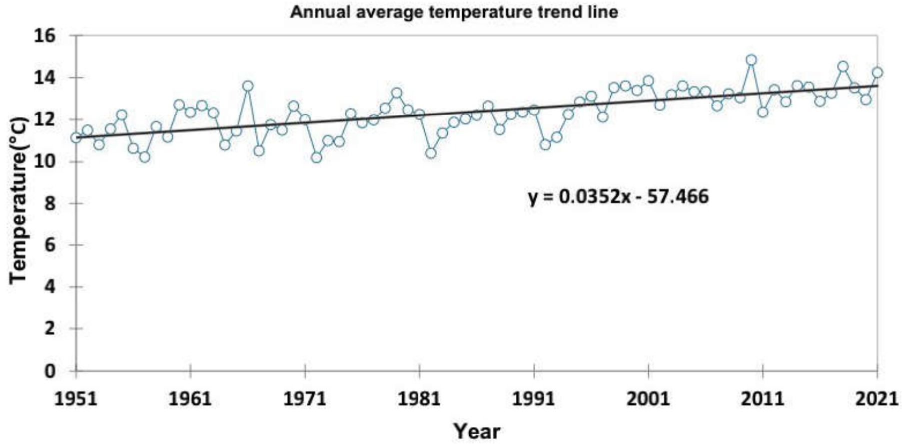


Fig. 17 Annual average temperature trend line in Tabriz station

Table 15 Results of the Mann–Kendall trend test for monthly and yearly predicted temperature (2022–2100) in Tabriz station for the RCP 2.6 scenario

Month/annual	*Z*	*b* (mm per year)	Trend/direction	SIG/NS
Jan	−0.064	0.000	↓	NS
Feb	1.664	0.006	↑	NS
Mar	1.384	0.005	↑	NS
Apr	1.304	0.007	↑	NS
May	1.690	0.008	↑	NS
Jun	3.300	0.013	↑	NS
Jul	1.600	0.004	↑	NS
Aug	−1.020	−0.002	↓	NS
Sep	−2.930	−0.012	↓	SIG
Oct	−2.578	−0.010	↓	SIG
Nov	−0.631	−0.003	↓	NS
Dec	−2.582	−0.009	↓	SIG
Annual	0.089	0.000	↑	NG

SIG statistically significant, *NS* not statistically significant

Table 16 Results of the Mann–Kendall trend test for monthly and yearly predicted temperature (2022–2100) in Tabriz station for the RCP 4.5 scenario

Month/annual	*Z*	*b* (mm per year)	Trend/direction	SIG/NS
Jan	−1.249	−0.003	↓	NS
Feb	1.502	0.006	↑	NS
Mar	1.91	0.009	↑	NS
Apr	2.55	0.011	↑	SIG
May	3.01	0.013	↑	NS
Jun	3.755	0.015	↑	NS
Jul	0.986	0.002	↑	NS
Aug	−0.9017	−0.003	↓	NS
Sep	−1.672	−0.005	↓	NS
Oct	−0.6477	−0.002	↓	NS
Nov	−1.64	−0.007	↓	NS
Dec	−1.384	−0.004	↓	NS
Annual	2.324	0.002	↑	SIG

SIG statistically significant, *NS* not statistically significant

Pettitt homogeneity test for predicted precipitation (present and future period)

In this study, 39 Pettitt homogeneity tests were carried out using XLSTAT 2022 software for predicted monthly and yearly temperature time series for the three RCPs scenarios. These tests have been done at a 95% confidence level. Table 19 presents the results of Pettitt tests conducted for future temperature series in Tabriz. Table 19 indicates that there are five change points in the March (2036), May (2039), September (2040), October (2042) and December (2047) for the average temperature data series in the RCP2.6 (Table 20). Also, change points in April (2039), May (2086) and June (2045) have been detected in the RCP 4.5. In addition, change points in March (2038), April (2039), May (2086) and June (2045) have been observed in the RCP8.5 (Table 21).

Temperature index (TI) and weighted temperature index (WTI) (past and present period)

Figure 19 shows the temperature index, and Fig. 20 shows the weighted temperature indexes in Tabriz during the study time period. The analyzing of these indexes indicated an anomaly between warm and cold periods and must be noticed that maximum warm period compared the base period lasted 36 years during the past studied years (1951–2021) (Fig. 19). As can be seen from Fig. 20, there was cold periods in 1951–1960, 1961, 1963–1977, 1981–1989. However, relatively hot years prevailed in 1961–1962, 1978–1980, 1990 and 1955 to 2022. Also, All

Table 17 Results of the Mann–Kendall trend test for monthly and yearly predicted temperature (2022–2100) in Tabriz station for the RCP 8.5 scenario

Month/annual	Z	b (mm per year)	Trend/ direction	SIG/NS
Jan	1.321	0.005	↑	NS
Feb	1.329	0.007	↑	NS
Mar	2.91	0.016	↑	NS
Apr	2.024	0.01	↑	NS
May	2.81	0.013	↑	NS
Jun	2.89	0.009	↑	NS
Jul	0.347	0.001	↑	NS
Aug	− 0.8636	− 0.002	↓	NS
Sep	− 1.363	− 0.005	↓	NS
Oct	− 1.05	− 0.005	↓	NS
Nov	− 2.413	− 0.01	↓	NS
Dec	− 1.253	− 0.005	↓	NS
Annual	1.445	0.002	↑	NS

SIG statistically significant, *NS* not statistically significant

Table 18 Results of Pettitt test for monthly and yearly observed temperature (1951–2022) in Tabriz station

Month/annual	Chang point year	p value (two-tailed)	Shift
Jan	1993	0.019	Upward
Feb	1998	0.009	Upward
Mar	1997	0.000	Upward
Apr	1997	0.032	Upward
May	1994	0.000	Upward
Jun	1996	0.000	Upward
Jul	1999	0.039	Upward
Aug	1994	0.000	Upward
Sep	1997	0.001	Upward
Oct	1996	0.006	Upward
Nov	1984	0.005	Upward
Dec	–	–	No
Annual	1994	0.000	Upward

the years from 1995 to 2022 have positive *WTI*. It seems that the occurrence of a hot period at that time is the result of climate change in Tabriz.

Temperature index (TI) and weighted temperature index (WTI) (present and future period)

In this section, the Temperature Index (TI) and Weighted Temperature Index (WTI) were computed for the future period using the three RCPs scenarios for Tabriz (Figs. 21, 22, 23, 24, 25, 26). The positive amounts in both indexes show warm years, but the negative values show cold years. As can be seen from Fig. 21, 42 years have positive (TI) and 37 years have negative (TI) (Fig. 21). Also, as shown from Fig. 22, 40 years have positive (WTI) and 39 years have negative (WTI) for RCP 2.6. In addition, in Fig. 23, 38 years have positive (TI) and 41 years have negative (TI) in the RCP 4.5. Also, as indicated from Fig. 24, 36 years have been positive (WTI) and 43 years have been negative (WTI) in the RCP 4.5. Also, 40 years have negative (TI) and 39 years have positive (TI) in RCP 8.5. In addition, 46 years have positive (WTI) and 33 years have negative (WTI). The overall results obtained from the (Figs. 21, 22, 23, 24, 25, 26) show that cold and hot periods repeat frequently in the three RCP scenarios during the period between 2022 and 2100.

Analyzing observed temperature

Monthly temperature Figure 27 shows the average monthly temperature of Tabriz city during the past studies period from 1951 to 2022. As shown in Fig. 27, the month of January has the minimum average temperature (− 2.06 °C), and the month of July has the maximum temperature (25.99 °C) between all the months. As indicated in Fig. 27, in five months (January, February, December, March and November), the average monthly temperature is less than (7 °C). In three months (April, May and October), the average monthly temperature is between 11 and 17 °C. In four months (June, July, August and September), the average temperature is between 21 and 26 °C.

Annual temperature Figure 28 shows the average annual air temperature in Tabriz. As can be seen from Fig. 28, the minimum, average and maximum value of the average temperature at Tabriz station are equal to 10.21 °C, 12.35 °C and 14.84 °C, respectively. Based on the data series, in 32 years out of the whole studied period (1951–2022), air temperature is less than the average temperature and in the other years, annual mean air temperatures are more than average. In general, the examination of Fig. 28 shows that from 1994 to 2022, the average annual temperature was more than 12 °C. But, in the years before 1994, the average annual temperature was mostly less than 12 °C.

Analyzing predicted temperature

Monthly temperature Observed and predicted average monthly temperature (°C) compared each other in Tabriz with the three different RCPs scenarios are reported in Fig. 29. As it can be seen from Fig. 29, in all the three scenarios (RCP 2.6, RCP 4.5, RCP 8.5) the average monthly temperature will be more than the observed average monthly temperature except in March and December.

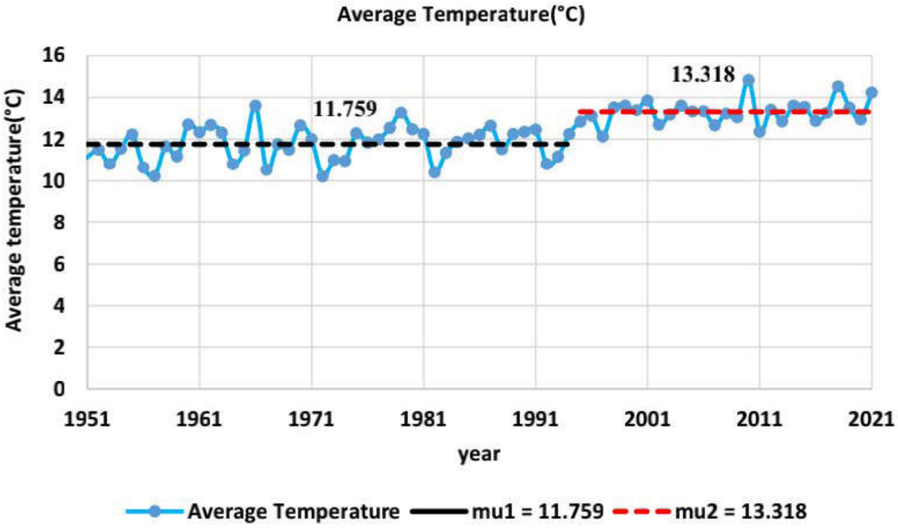


Fig. 18 Annual temperature time series showing sudden change in 1995 in Tabriz station

Table 19 Results of Pettitt homogeneity tests conducted for monthly and yearly predicted future temperature (2022–2100) in Tabriz station for RCP 2.6

Scenario RCP 2.6			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	2036	0.043	Upward
Apr	No	–	No
May	2039	0.017	Upward
Jun	No	–	No
July	No	–	No
Aug	No	–	No
Sep	2040	0.003	Downward
Oct	2042	0.002	Downward
Nov	No	–	No
Dec	2047	0.004	Downward
Annual	–	–	No

Table 20 Results of Pettitt homogeneity tests conducted for monthly and yearly predicted future temperature (2022–2100) in Tabriz station for RCP 4.5

Scenario RCP 4.5			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	No	–	No
Apr	2039	0.024	Upward
May	2086	0.035	Upward
Jun	2045	0.003	Upward
July	No	–	No
Aug	No	–	No
Sep	No	–	No
Oct	No	–	No
Nov	No	–	No
Dec	No	–	No
Annual	No	–	No

Annual temperature Figure 30 shows the average annual air temperature in Tabriz with the definition of the three RCPs scenarios in the future time period. As can be seen from Fig. 30, the maximum average annual air temperature of Tabriz city is equal to 13.54 °C in 2091 and the minimum average annual air temperature of Tabriz city is equal to 12.34 °C in 2034 based on RCP 8.5. In addition, the maximum average annual air temperature of Tabriz city is equal to 13.54 °C in 2087 and the minimum average annual air temperature of Tabriz city is equal to 12.33 °C in 2061 based on RCP 4.5. At RCP 2.6, the maximum average annual air temperature of Tabriz city is equal to 13.28 °C in 2098 and the minimum average annual air temperature of Tabriz city is equal to 12.42 °C in 2028. Finally, Fig. 30 shows that in most of the predicted years (2022–2100) in all RCPs, the average temperature is between 12.5 and 13.5 °C.

Analysis of observed and predicted annual temperature frequencies

Figure 31 shows observed annual average temperature (°C) frequency and cumulative temperature frequency in Tabriz in the past studied period (1951–2022). As shown in that figure, in 9 years, the observed annual average temperature is

Table 21 Results of Pettitt homogeneity tests conducted for monthly and yearly predicted future temperature (2022–2100) in Tabriz station for RCP 8.5

Scenario RCP 8.5			
Month/annual	Chang point at year	*p* value (two-tailed)	Shift direction
Jan	No	–	No
Feb	No	–	No
Mar	2038	0.03	Upward
Apr	2039	0.024	Upward
May	2086	0.035	Upward
Jun	2045	0.003	Upward
July	No	–	No
Aug	No	–	No
Sep	No	–	No
Oct	No	–	No
Nov	No	–	No
Dec	No	–	No
Annual	No	–	No

less than 11 °C, in 24 years it is less than 12 °C, in 51 years it is less than 13 °C, in 69 years it is less than 14 °C and in 3 years it is more than 14 °C.

Figure 32 indicates the predicted annual average temperature (°C) frequency and cumulative temperature frequency in Tabriz in the future period (2022–2100) at RCP 2.6. As shown in that figure, in 71 years, the predicted annual average temperature is between 12 and 13 °C, in 7 years it is between 13 and 14 °C.

Figure 33 indicates the predicted annual average temperature (°C) frequency and cumulative temperature frequency in Tabriz in the future period (2022–2100) at RCP 4.5. As shown in that figure, in 68 years, the predicted annual average temperature is between 12 and 13 °C, in 9 years it is between 13 and 14 °C. Also, only in 1 year it is more than 14 °C. Also, Fig. 34 shows the predicted annual average temperature (°C) frequency and cumulative temperature frequency in Tabriz in the future period (2022–2100) at RCP 8.5. As shown in that figure, in 68 years, the predicted annual average temperature is between 12 and 13 °C, in

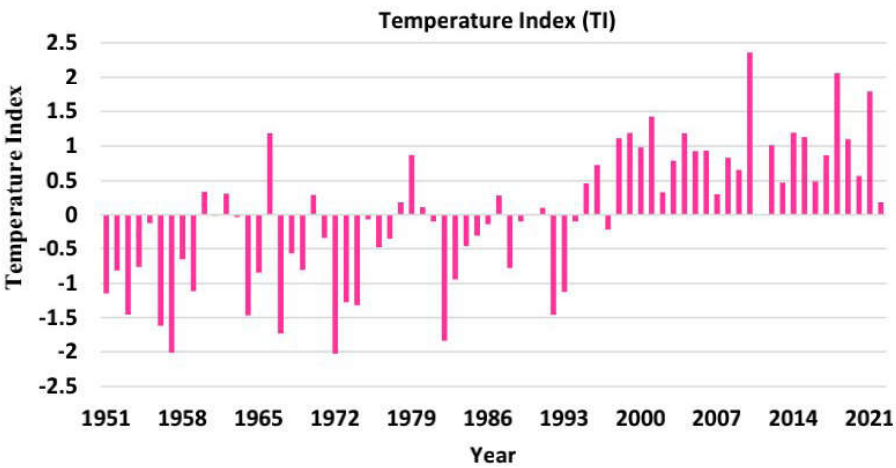


Fig. 19 Temperature index (TI) for average annual data series in Tabriz in the period 1951–2022

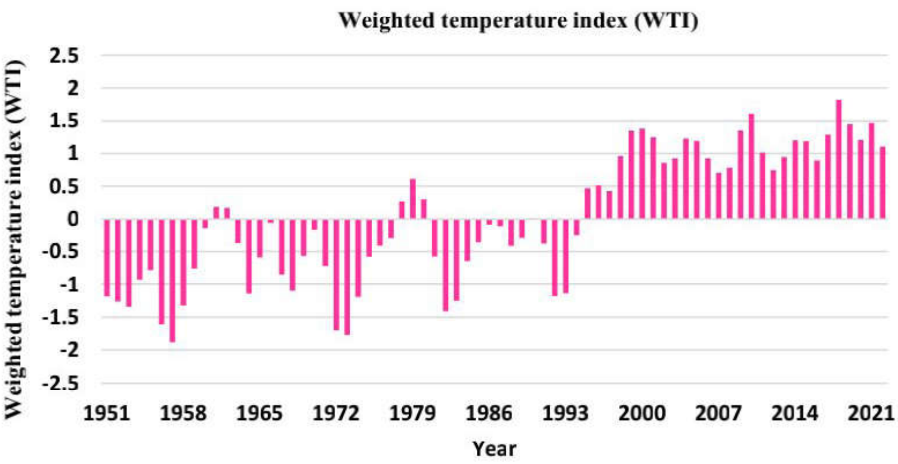


Fig. 20 Weighted temperature index (WTI) for average annual temperature in Tabriz in the period 1951–2022

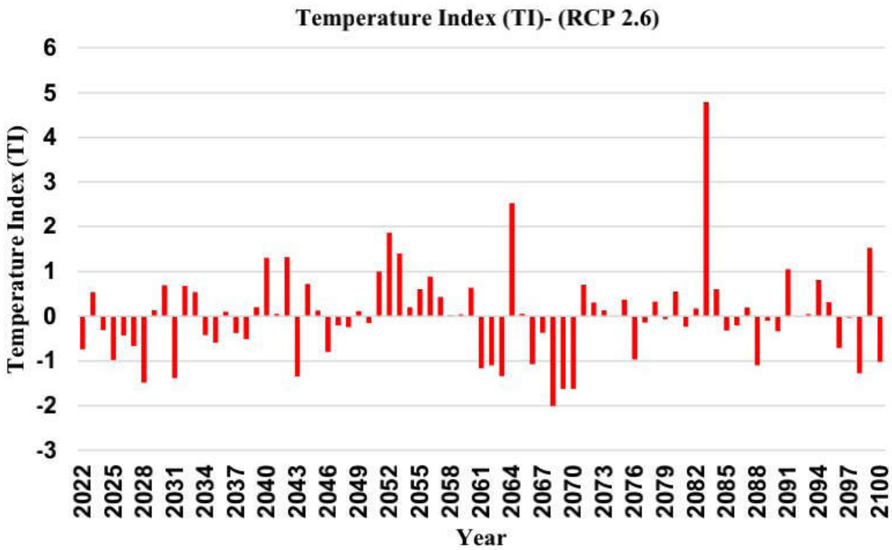


Fig. 21 Temperature Index (TI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 2.6 scenario)

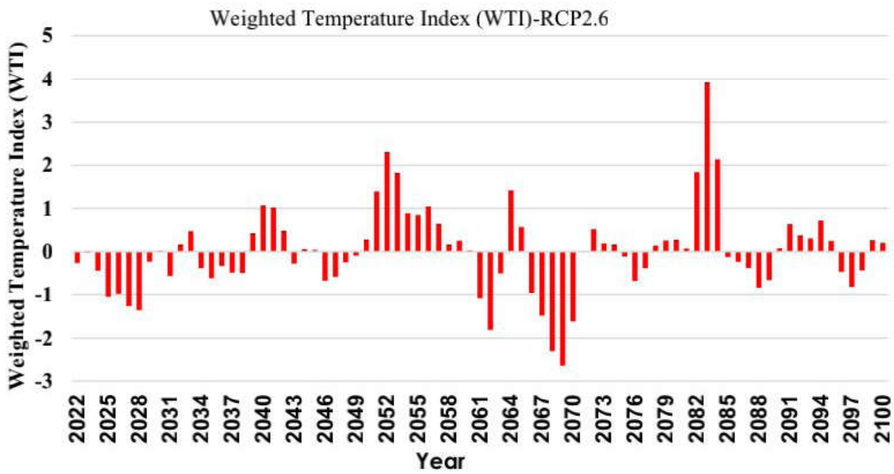


Fig. 22 Weighted Temperature Index (TI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 2.6 scenario)

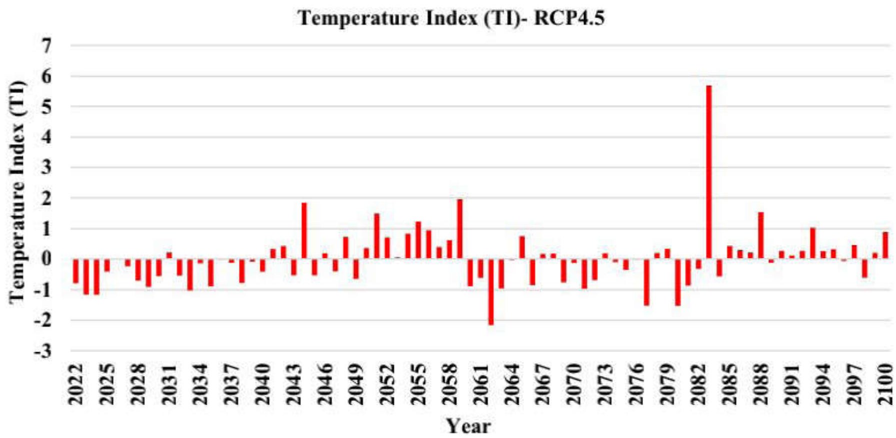


Fig. 23 Temperature Index (TI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 4.5 scenario)

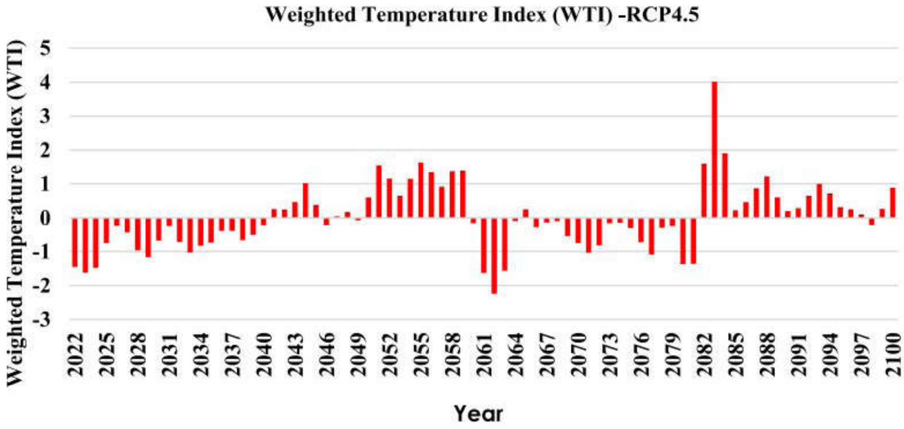


Fig. 24 Weighted Temperature Index (WTI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 4.5 scenario)

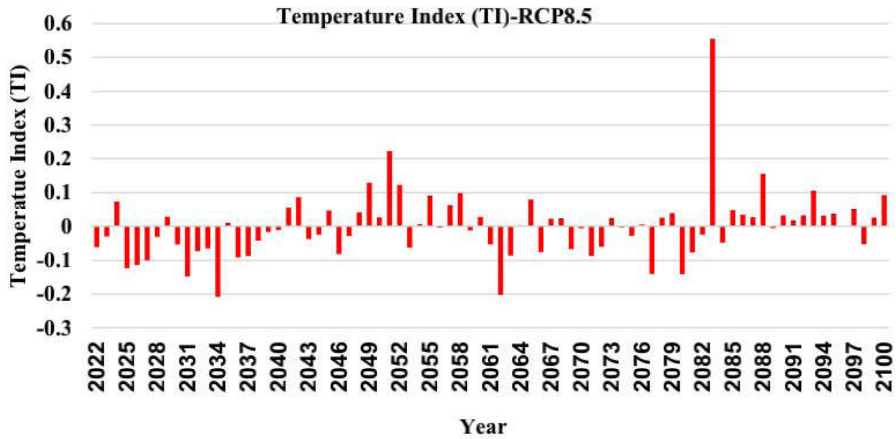


Fig. 25 Temperature Index (TI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 8.5 scenario)

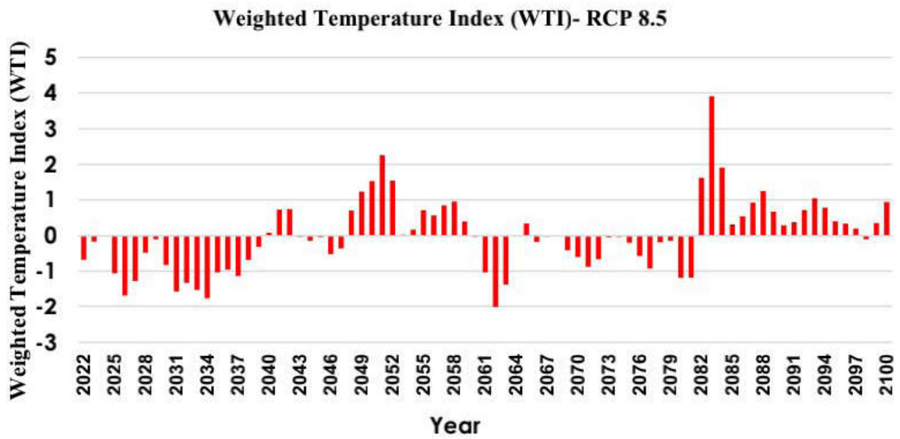


Fig. 26 Weighted Temperature Index (WTI) for average annual temperature in Tabriz in the period 2022–2100 (RCP 8.5 scenario)

9 years it is between 13 and 14 °C. Also, it is more than 14 °C only in one year.

Summary of results for observed and predicted temperature time series.

A summary of obtained results from this research for monthly and annual temperature time series has been expressed in Tables 22, 23, 24 in the past (1951–2022) and future period (2022–2100). By using these tables, we can quickly view and compare the obtained results. In

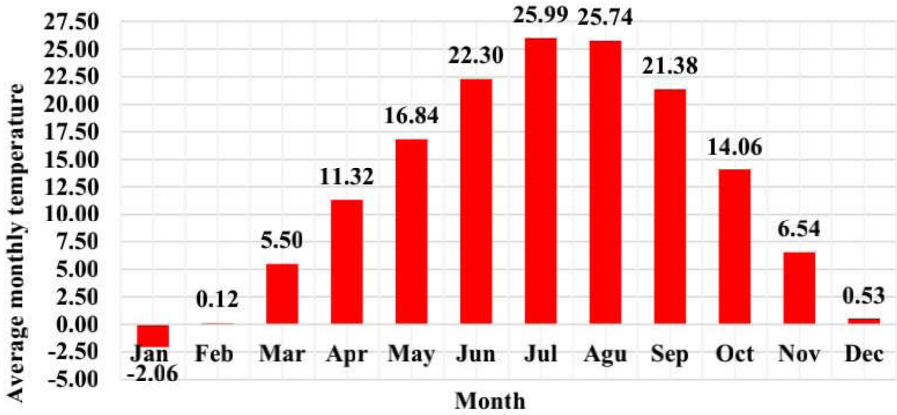


Fig. 27 The monthly observed average temperature in Tabriz from 1951 to 2022

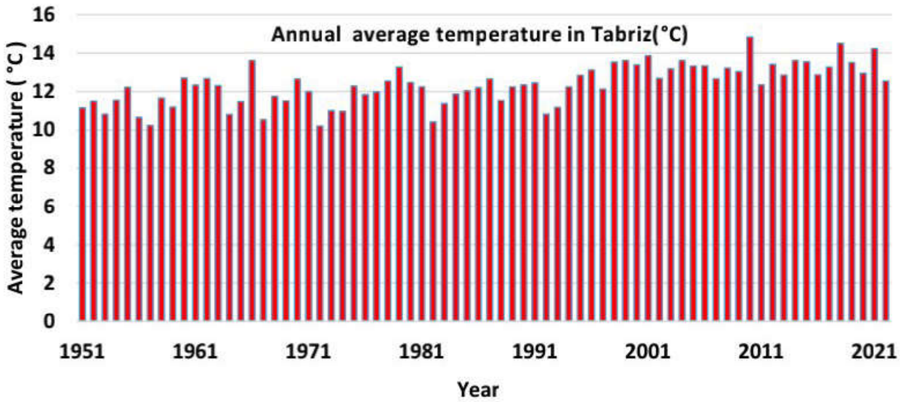


Fig. 28 Annual average temperature time series in Tabriz from 1951 to 2022

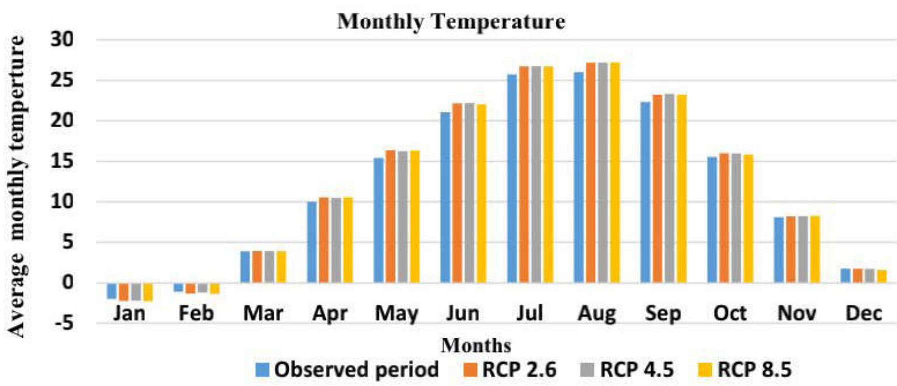


Fig. 29 Observed and Predicted average monthly temperature (°C) in Tabriz

Table 22, the observed monthly and annual temperature time series with RCP 2.6 results were analyzed. In Table 23, the observed monthly and annual temperature time series with RCP 4.5 results has been assessed. In Table 24, the observed monthly and annual temperature time series with RCP 8.5 has been compared.

Discussion

In this manuscript, to analyze climate change in Tabriz city in the past (1951–2022) and future period (2022–2100), two important climate variables (precipitation and temperature) have been assessed using a new hybrid method (Statistical Downscaling Method by using SDSM software, MK trend test, Pettitt Homogeneity test, precipitation index (PI) and temperature index (TI),

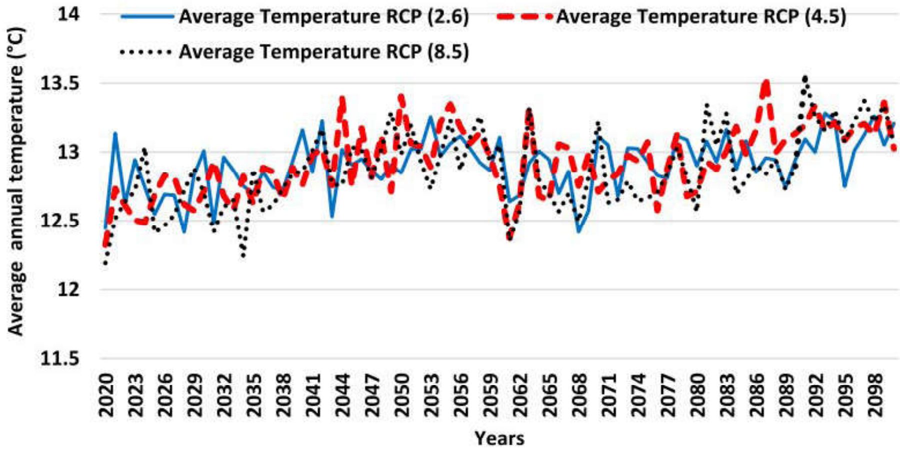


Fig. 30 Predicted annually temperature (°C) in Tabriz using the three RCP scenarios over the future time period (2022–2100)

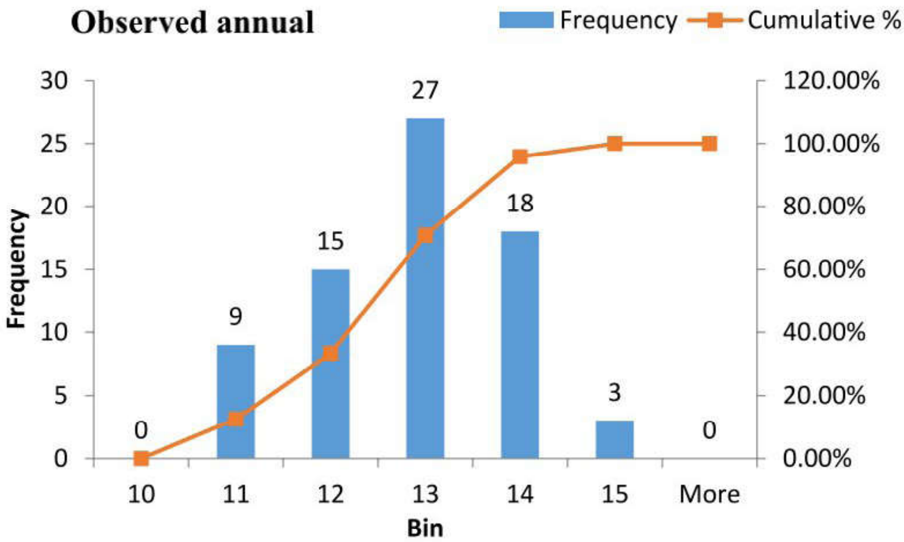


Fig. 31 Observed and cumulative annual average temperature (°C) frequency in Tabriz in the past studied period (1951–2022)

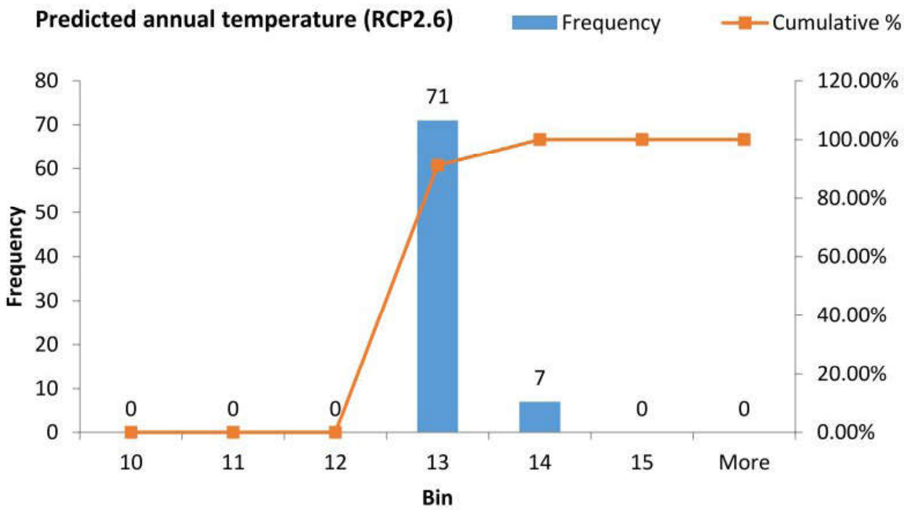


Fig. 32 Predicted and cumulative annual average temperature (°C) frequency in Tabriz for RCP 2.6 in the future studied period (2022–2100)

weighted precipitation index (WPI), weighted temperature index (WTI) and frequency analysis) in Tabriz city. Results indicate that in the base period (1951–2022), in the monthly and annual precipitation time series, a statistically significant trend has not been observed. But, in the annual precipitation time series, a change point

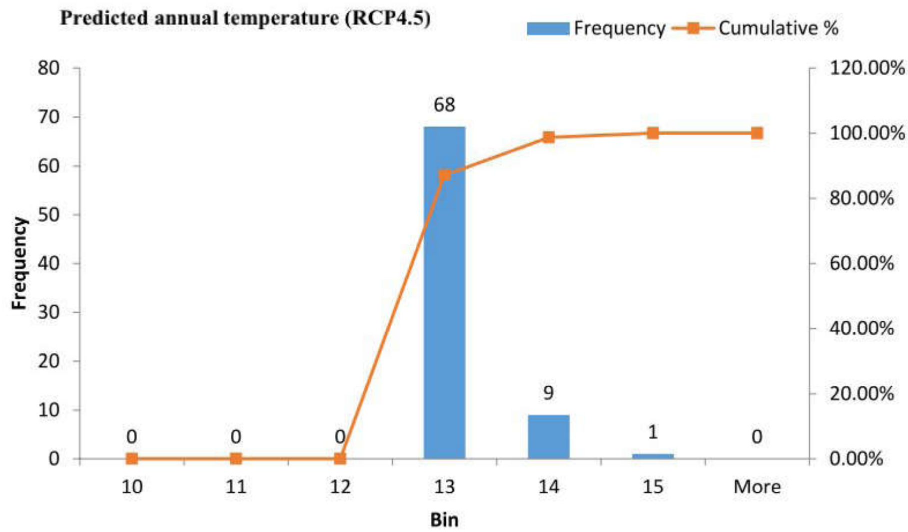


Fig. 33 Predicted and cumulative annual average temperature (°C) frequency in Tabriz for RCP 4.5 in the future studied period (2022–2100)

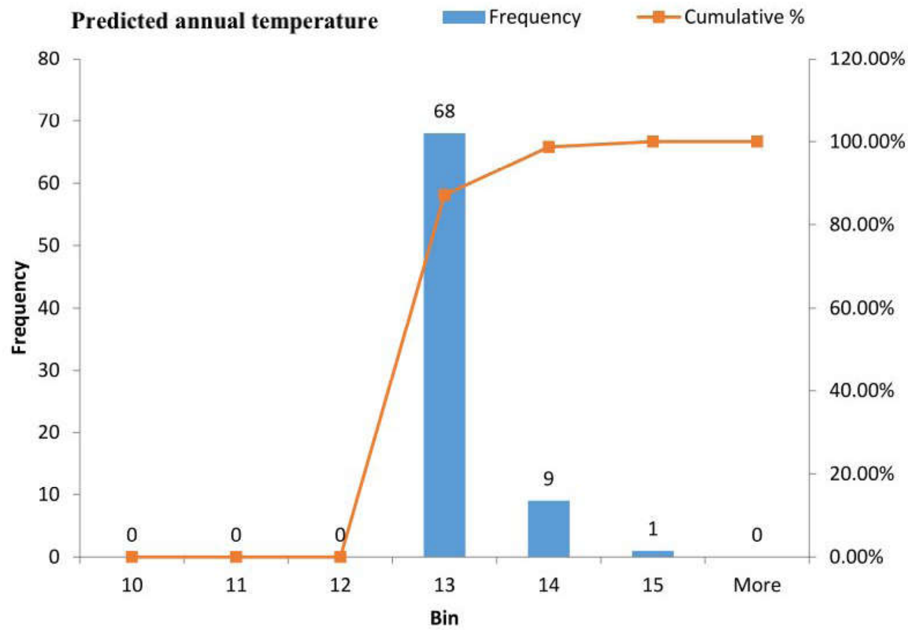


Fig. 34 Predicted and cumulative annual average temperature (°C) frequency in Tabriz for RCP 8.5 in the future studied period (2022–2100)

has been observed in 1982 with a downtrend until 2022. So, the value of annual precipitation has been reduced from 316.32 to 261.51 mm in the period between 1982 and 2022. Also, an increasing trend has been observed for the average air temperature data series in all months that are statistically significant. In addition, a change was detected to the annual average temperature in 1994. So that the average annual air temperature has been reached 13.32 °C from 1994 to 2022.

For future periods, a statistically significant trend for the monthly precipitation in February and October has been predicted. Also, a downward change point in July (2054) and an upward change point in October (2061) in RCP 2.6 have been detected. Also, no trend has been anticipated for RCP 4.5 for the monthly and annual precipitation. In addition, in RCP 8.5, a statistically significant decreased trend has been observed for February.

In addition, five change points are anticipated in March (2036), May (2039), September (2040), October (2042) and December (2047) at RCP 2.6 for the average temperature time series. It also predicted three change points in April (2039), May (2086) and June (2045) in RCP 4.5. And, four change points in March (2038), April (2039), May (2086) and June (2045) have been detected in RCP 8.5.

Assessing (TI), (WTI), (PI) and (WPI) indexes indicate that in the future, dry and warm periods will be more than the wet and cold periods. Also, it is concluded that climate changes have occurred in the past years and have continued

Table 22 Summary of results for monthly and annual temperature, their trends and change points in the past and future periods (RCP 2.6) in Tabriz

Month/annual	Temperature (°C) (1951–2022)	Temperature (°C) (2022–2100) (RCP 2.6)	Trend (1951–2022)	SIG/NS	Trend (2022–2100) (RCP 2.6)	SIG/NS	Change point (1951–2022)	Change point (2022–2100) (RCP 2.6)
Jan	−2.06	−0.35	↑	NS	↓	NS	1993 (upward)	No
Feb	0.12	−0.84	↑	SIG	↑	NS	1998 (upward)	No
Mar	5.50	2.68	↑	SIG	↑	NS	1997 (upward)	2036 (upward)
Apr	11.32	8.61	↑	SIG	↑	NS	1997 (upward)	No
May	16.84	14.56	↑	SIG	↑	NS	1994 (upward)	2039 (upward)
Jun	22.30	20.25	↑	SIG	↑	NS	1996 (upward)	No
Jul	25.99	24.87	↑	SIG	↑	NS	1999 (upward)	No
Aug	25.74	26.48	↑	SIG	↓	NS	1994 (upward)	No
Sep	21.38	23.80	↑	SIG	↓	SIG	1997 (upward)	2040 (downward)
Oct	14.06	17.94	↑	SIG	↓	SIG	1996 (upward)	2042 (downward)
Nov	6.54	10.65	↑	SIG	↓	NS	1984 (upward)	No
Dec	0.53	4.16	↑	NS	↓	SIG	–	2047 (downward)
Annual	12.35	12.73	↑	SIG	↑	NG	1994 (upward)	–

SIG statistically significant, *NS* not statistically significant

Table 23 Summary of results for monthly and annual temperature, their trends and change points in the past and future periods (RCP 4.5) in Tabriz

Month/Annual	Temperature (1951–2022) (°C)	Temperature (2022–2100) (RCP 4.5) (°C)	Trend (1951–2022)	SIG/NS	Trend (2023–2100) (RCP 4.5)	SIG/NS	Change point (1951–2022)	Change point (2023–2100) (RCP 4.5)
Jan	−2.06	−1.78	↑	NS	↓	NS	1993 (upward)	No
Feb	0.12	−0.48	↑	SIG	↑	NS	1998 (upward)	No
Mar	5.50	4.64	↑	SIG	↑	NS	1997 (upward)	No
Apr	11.32	11.03	↑	SIG	↑	SIG	1997 (upward)	2039 (upward)
May	16.84	16.72	↑	SIG	↑	NS	1994 (upward)	2086 (upward)
Jun	22.30	22.64	↑	SIG	↑	NS	1996 (upward)	2045 (upward)
Jul	25.99	26.47	↑	SIG	↑	NS	1999 (upward)	No
Aug	25.74	26.78	↑	SIG	↓	NS	1994 (upward)	No
Sep	21.38	22.49	↑	SIG	↓	NS	1997 (upward)	No
Oct	14.06	15.32	↑	SIG	↓	NS	1996 (upward)	No
Nov	6.54	7.79	↑	SIG	↓	NS	1984 (upward)	No
Dec	0.53	1.55	↑	NS	↓	NS	–	No
Annual	12.35	12.76	↑	SIG	↑	SIG	1994 (upward)	No

SIG statistically significant, *NS* not statistically significant

until now in Tabriz city. In addition, according to detailed analysis of precipitation and temperature, it is predicted this climate change will continue in future periods in Tabriz. However, some other researchers have also studied Tabriz city with other global climate models. Their results indicate some similarities and differences with the article. Zarghami et al. (2009) studied the temperature and precipitation variables during the period between 1951 and 2008 in Tabriz. They used the LARS-WG model and a stochastic weather generator using the HADCM3 model and three emission scenarios of A1B, A2 and B1 on different horizons of 2020, 2055 and 2090 in Tabriz. They reported that, in the A2 scenario, the average annual temperature increases approximately 3 °C and annual precipitation will be reduced by about 5% until the middle of this century. These changes shift the climate type of the city from« semi-arid» to «arid» in the De Martonne system (Jafarpour et al. 2023). Anyway, the obtained results in this research largely confirm the climate changes in Tabriz city based on statistics and detailed analysis of observed and predicted time series using an innovative method. Therefore, it is essential that decision makers use the appropriate measures for mitigation of climate

Table 24 Summary of results for monthly and annual temperature, their trends and change points in the past and future periods (RCP 8.5) in Tabriz

Month/annual	Temperature (°C) (1951–2022)	Temperature (°C) (2022–2100) (RCP 8.5)	Trend (1951–2022)	SIG/NS	Trend (2023–2100) (RCP 8.5)	SIG/NS	Change point (1951–2022)	Change point (2023–2100) (RCP 8.5)
Jan	−2.06	−1.91	↑	NS	↑	NS	1993 (upward)	No
Feb	0.12	−0.52	↑	SIG	↑	NS	1998 (upward)	No
Mar	5.50	4.6	↑	SIG	↑	NS	1997 (upWARD)	2038 (upward)
Apr	11.32	11.07	↑	SIG	↑	NS	1997 (upward)	2039 (upward)
May	16.84	16.69	↑	SIG	↑	NS	1994 (upward)	2086 (upward)
Jun	22.30	22.60	↑	SIG	↑	NS	1996 (upward)	2045 (upward)
Jul	25.99	26.51	↑	SIG	↑	NS	1999 (upward)	No
Aug	25.74	26.75	↑	SIG	↓	NS	1994 (upward)	No
Sep	21.38	22.49	↑	SIG	↓	NS	1997 (upward)	No
Oct	14.06	15.23	↑	SIG	↓	NS	1996 (upward)	No
Nov	6.54	7.80	↑	SIG	↓	NS	1984 (upward)	No
Dec	0.53	1.56	↑	NS	↓	NS	–	No
Annual	12.35	12.74	↑	SIG	↑	NS	1994 (upward)	No

SIG statistically significant, *NS* not statistically significant

change effects in Tabriz. Because changes in precipitation and temperature will surely affect water resources, urban sustainability, agriculture, industry, the economy, society etc. Also, it is anticipated that pressure on water resources will strongly increase in the future years. And, the people who live in this city will have exposure to risky water conditions.

Conclusion

In this study, two main climatic parameters (precipitation and air temperature) in the historical period (1951–2022) and in the future period (2022–2100) have been assessed in Tabriz city, which is located in the northwest of Iran. In this research, a combined method with the use of several main methods was used for analysis, and more complete and detailed results were obtained. However, the methodology used in this paper can be used as a suitable model in other regions for climate change studies. Also, the obtained results show that the annual average temperature has increased in the past. And, it is also predicted it will rise in the future. Also, annual precipitation decreased in the past, from 1994 to 2022. But in the future period, it shows a statistically significant increase in scenario 2.6, and no trend is predicted in other scenarios. These results imply that city inhabitants, organizations and companies will encounter many water-related problems in upcoming years. In fact, climate change will affect the urban water supply in the following years in the city. So, there is a need for the presentation of cultural programs to enhance the culture of inhabitants through efficient use of water. Changing the old rusty water supply pipes with new ones should be started seriously as soon as possible in Tabriz. Moreover, prevention of mixing rainfall with city sewage is needed. These strategies can save water for different sectors such as agriculture, industry and so on. However, it is recommended to conduct similar studies for other metropolitan cities in Iran that are located in water-scarcity places.

Acknowledgements This work is based upon research funded by Iran National Science Foundation (INFS) under the project no. 4013231, which is appreciated. Historical data of urban water consumption are provided by the water and Wastewater Company of Tabriz, which is greatly acknowledged.

Funding This work funded by Iran National Science Foundation (INFS) under the project No. 4013231.

Availability of data and materials The meteorological Tabriz station data between 1951 and 2022 will be available by communication with corresponding author.

Declarations

Conflict of interest There is no conflict of interest.

Ethical statement This paper complies with the ethical standards of research and methodology.

Consent to participate Not applicable.

References

Abbasnia M, Toros H (2016) Future changes in maximum temperature using the statistical down-scaling model (SDSM) at selected stations of Iran. Model Earth Syst Environ 68:1–7. https://doi.org/10.1007/s40808-016-0112-z

Adachi SA, Kimura F, Kusaka H, Inoue T, Ueda H (2012) Comparison of the impact of global climate changes and urbanization on summertime future climate in the Tokyo metropolitan area. J Appl Meteorol Climatol 51(8):1441–1454. https://doi.org/10.1175/JAMC-D-11-0137.1

Allison I, Barry RG, Goodison BE (2001) Climate and cryosphere (CliC) project science and co-ordination plan, version 1. Joint Planning Staff for WCRP, World Meteorological Organization

Aung MT, Shrestha S, Weesakul S, Shrestha PK (2016) Multimodal climate change projections for the Belu River Basin, Myanmar under representative concentration pathways. J Earth Sci Clim Change 7:323. https://doi.org/10.4172/2157-7617.1000323

Bárdossy A (1997) Down-scaling from GCMs to local climate through stochastic linkages. J Environ Manag 49:7–17

Barry RG, Carleton AM (2013) Synoptic and dynamic climatology. Routledge, London

Bastin J-F, Clark E, Elliott T, Hart S, Van den Hoogen J, Hordijk I et al (2019) Understanding climate change from a global analysis of city analogues. PLoS ONE 14(7):e0217592. https://doi.org/10.1371/journal.pone.0217592

Bathiany S, Scheffer M, Van Nes EH, Williamson MS, Lenton TM (2018) Abrupt climate change in an oscillating world. Sci Rep. https://doi.org/10.1038/s41598-018-23377-4

Behboudi D, Mohammadzadeh P, Feizizadeh B, Pooranvari A (2018) Multi-criteria-based readiness assessment for developing spatial data infrastructures in East Azerbaijan Province, Iran. J Geogr Info Sci 2:322–333

Chapman S, Thatcher M, Salazar A, Watson JEM, McAlpine CA (2019) The impact of climate change and urban growth on urban climate and heat stress in a subtropical city. Int J Climatol. https://doi.org/10.1002/joc.5998

Conway D, Wilby RL, Jones PD (1996) Precipitation and air flow indices over the British Isles. Clim Res 7:169–183

Dinpashoh Y, Jhajharia D, Fakheri SK (2011) Trends in reference crop, evapotranspiration over Iran. J Hydrol 399:422–433

Dinpashoh Y, Mirabbasi R, Jhajharia D, Zare Abianeh H, Mostafaeipour A (2014) Effect of short-term and long-term persistence on identification of temporal trends. J Hydrol Eng 19:617–625

Duan R, Huang G, Li Y, Zhou X, Ren J, Tian C (2020) Stepwise clustering future meteorological drought projection and multilevel factorial analysis under climate change: a case study of the Pearl River Basin, China. Environ Res 196:110368. https://doi.org/10.1016/jenvres.2020.110368

El Hafyani M, Essahlaoui N, Essahlaoui A, Mohajane M, Van Rompaey A (2023) Generation of climate change scenarios for rainfall and temperature using SDSM in a Mediterranean environment: a case study of Boufakrane river watershed, Morocco. J Umm Al-Qura Univ Appll Sci 9:436–448. https://doi.org/10.1007/s43994-023-00052-7

El Ouali A, Dichane Z, Roubil A, El Ouardi H, El Hmaidi A, Lahrach A (2023) Hydrological modeling and Impact of Climate Change on Water Resources in the Ziz Valley, Central High Atlas, Morocco. Ecol Eng Environ Technol 24:192–210. https://doi.org/10.12912/27197050/168335

García-Cueto OR, Santillán-Soto N, López-Velázquez E, Reyes-López J, Cruz-Sotelo S, Ojeda-Benítez S (2019) Trends of climate change indices in some Mexican cities from 1980 to 2010. Theoret Appl Climatol 137:775–790

Gilbert RO (1987) Statistical methods for environmental pollution monitoring. Wiley, New York

Goodarzi M, Mahdian MH, Ghermezcheshmeh B (2021) Assessment of climate change using SDSM downscaling Model (a case study: west of Iran). Water Harvest Res J 4:29–39. https://doi.org/10.22077/jwhr.2019.2720.1029

Goodess CM, Palutikof JP (1998) Development of daily rainfall scenarios for southeast Spain using a circulation-type approach to down-scaling. Int J Climatol 18:1051–1083. https://doi.org/10.1002/(SICI)1097-0088(199808)18:10%3c1051::AID-JOC304%3e3.3.CO;2-T

Harpham C, Wilby RL (2005) Multi-site down-scaling of heavy daily precipitation occurrence and amounts. J Hydrols 312:235–255

Hassan WH, Hashim FS (2020) The effect of climate change on the maximum temperature in Southwest Iraq using HadCM3 and CanESM2 modelling. SN Appl Sci 2:1494. https://doi.org/10.1007/s42452-020-03302-z

Hessami M, Quarda TBM, Gachon P, St-Hailaire A, Selva F, Bobee B (2004) Evaluation of statistical downscaling method over several regions of eastern Canada. In: 57th Canadian water resources association annual congress

Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis for monthly water quality data. Water Resour Res 18:107–121

Hodson TO (2022) Root-mean-square error (RMSE) or mean absolute error (MAE): when to use them or not. Geosci Model Dev 15:5481–5487

IPCC (2023) Sections. In: Core Writing Team, Lee H, Romero J (eds) Climate change 2023: synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland, pp 35–115. https://doi.org/10.59327/IPCC/AR6-9789291691647

Jafarpour M, Adib A, Lotfirad M et al (2023) Spatial evaluation of climate change-induced drought characteristics in different climates based on De Martonne Aridity Index in Iran. Appl Water Sci 13:133. https://doi.org/10.1007/s13201-023-01939-w

Jaiswal RK, Lohani AK, Tiwari HL (2015) Statistical analysis for change detection and trend assessment in climatological parameters. Environ Process 2:729–749. https://doi.org/10.1007/s40710-015-0105-3

Jhajharia D, Dinpashoh Y, Kahya R, Choudhary R, Singh VP (2014) Trends in temperature over Godavari River basin in Southern Peninsular India. Int J Climatol 34:1369–1384

Jianping H, Minxes J, Yongkun X, Shanshan W, Yongli H, Jinjiang R (2016) Global semi-arid climate change over last 60 years. Clim Dyn 46:1131–1150

Junk J, Matzarakis A, Ferrone A et al (2014) Evidence of past and future changes in health-related meteorological variables across Luxembourg. Air Qual Atmos Health 7:71–81. https://doi.org/10.1007/s11869-013-0229-4

Kashif A, Muhammad Zeeshan Q, Huaming S, Muntasir M, Haider M, Ijaz Y (2022) A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environ Sci Pollut Res 29:42539–42559. https://doi.org/10.1007/s11356-022-19718-6

Kendall MG (1975) Rank correlation methods, 4th edn. Charles Griffin, London

Kilsby C, Cowpertwait P, O'Connell P, Jones P (1998) Predicting rainfall statistics in England and Wales using atmospheric circulation variables. Int J Climatol 18:523–539

Kim JW, Chang JT, Wilks BNL, DS, Gates WL, (1984) The statistical problem of climate inversion: determination of the relationship between local and large-scale climate. Mon Weather Rev 112:2069–2077

Li D, Xie H, Xiong L (2014) Temporal change analysis based on data characteristics and nonparametric test. Water Resour Manag 28:227–240

Liu Z, Ciais P, Deng Z, Lei R, Davis SJ, Feng S, Zheng B, Cui D, Dou X, Zhu B (2020) Near real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nat Commun 11:5172. https://doi.org/10.1038/s41467-020-18922-7

Lizarralde G, Bornstein L, Robertson M, Gould KD, Herazo B, Petter AM, Paez H, Helena Díaz JH, Olivera A, Gonzalez G, Lopez O, Lopez A, Ascui H, Burdiles R, Bouchereau K (2021) Does climate change cause disasters? How citizens, academics, and leaders explain climate-related risk and disasters in Latin America and the Caribbean. Int J Disaster Risk Reduct 58:102173

Mann HB (1945) Non-Parametric Test against Trend. Econometrica 13:245–259. https://doi.org/10.2307/1907187

Mansouri Daneshvar MR, Ebrahimi M, Nejadsoleymani H (2019) An overview of climate change in Iran: facts and statistics. Environ Syst Res 8:1–10. https://doi.org/10.1186/s40068-019-0135-3

Melki A, Abida H (2018) Inter-annual variability of rainfall under an arid climate: case of the Gafsa region, south west of Tunisia. Arab J Geosci 11:543. https://doi.org/10.1007/s12517-018-3868-9

Miyamoto Y (2024) Climate change in global cities. In: Yan W, Galloway W, Shaw R (eds) Resilient and adaptive Tokyo. Springer, Singapore. https://doi.org/10.1007/978-981-99-3834-6_3

Nazarenko L, Schmidt GA, Miller RL, Tausnev N, Kelley M, Ruedy R, Russell GL, Aleinov I, Bauer M, Bauer S (2015) Future climate change under RCP emission scenarios with GISS ModelE2. J Adv Model Earth Syst 7:244–267. https://doi.org/10.1002/2014MS000403

Ouhamdouch S, Bahir M (2017) Climate change impact on future rainfall and temperature in semi-arid areas (Essaouira Basin, Morocco). Environ Process 4:975–990. https://doi.org/10.1007/s40710-017-0265-4

Pettitt AN (1979) A non-parametric approach to the change-point problem. Appl Stat 28:126–135. https://doi.org/10.2307/2346729

Saemian P, Elmi O, Bramha DV, Tourian MJ, Sneeuw N (2020) Analyzing the Lake Urmia restoration progress using ground-based and space borne observations. Sci Total Environ 739:139857. https://doi.org/10.1016/j.scitotenv.2020.139857

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63:1379–1389

Shakeri H, Motiee M, McBean E (2020) Projection of important climate variables in large cities under the CMIP5–RCP scenarios using SDSM and fuzzy down-scaling models. J Water Clim Change 12:7. https://doi.org/10.2166/wcc.2020.332

Shukla R, Khareb D, Dwivedic AK, Pal Rudraa R, Palmated SS, Ojhab CSP, Singh VP (2023) Evaluation of statistical down-scaling model's performance in projecting future climate change scenarios. J Water Clim Change 14:3595. https://doi.org/10.2166/wcc.2023.207

Soudi M, Ahmadi H, Yasi M, Hamidi SA (2018) Sustainable restoration of the Urmia Lake: History, threats, opportunities and challenges. Eur Water 60:341–347

Spinoni J, Barbosa P, Cherlet M, Forzieri G, McCormick N, Naumann G, Vogt JV, Dosio A (2021) How will the progressive global increase of arid areas affect population and land-use in the 21st century? Glob Planet Change 205:103597. https://doi.org/10.1016/j.gloplacha.2021.103597

Tabari H, Shifteh Somee B, Rezaeian Zadeh M (2011) Testing for long-term trends in climatic variables in Iran. Atmos Res 100(1):132–140. https://doi.org/10.1016/j.atmosres.2011.01.005

Theil H (1950) A rank-invariant method of linear and polynomial regression analysis, I, II, III. Nederl Akad Wetensch Proc 53:386–392, 512–525, 1397–1412

Von Storch H (1999) On the use of "Inflation" in statistical downscaling. J Clim 12:3505–3506. https://doi.org/10.1175/1520-0442(1999)012<3505:OTUOII>2.0.CO;2

Wilby RL, Dawson CW, Barrow EM (2001) SDSM – a decision support tool for the assessment of regional climate change impacts. Environ Model Softw 17:145–157

Wilby RL, Dawson CW, Barrow EM (2002) SDSM a decision support tool for the assessment of regional climate change impacts. Environ Model Softw 17:145–157. https://doi.org/10.1016/S1364-8152(01)00060-3

Wilby RL, Tomlinson OJ, Dawson CW (2003) Multi-site simulation of precipitation by conditional resampling. Clim Res 23:183–194

Wilby LR, Dawson CW (2007) SDSM 4.2 user manual, a decision support tool for the assessment of regional climate change impacts. http://sdsm.org.uk/SDSMManual.pdf

WWC-EAP: water & waste water company of East Azerbaijan Province (2020) Annual water consumption report of East Azerbaijan Province's cities. https://en.abfaazarbaijan.ir.

WWC-EAP: water & waste water company of East Azerbaijan Province (2021) Annual water consumption report of East Azerbaijan Province's cities. https://en.abfaazarbaijan.ir

Zarghami M, Hassanzadeha Y, Babaeianb I, Kanani R (2009) Climate change and water resources vulnerability; case study of Tabriz City. In: SENSE symposium on climate proofing cities, Amsterdam/Volendam

Zhang Y, You Q, Chen C, Ge J (2016) Impacts of climate change on stream flows under RCP scenarios: a case study in Xin River Basin, China. Atmos Res 178–179:521–534. https://doi.org/10.1016/j.amosres.2016.04.018