Generation of rainfall for Mosul city using statistical downscaling method (SDSM)

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Abstract. This study deals with the application of statistical downscaling method for precipitation. Daily historical rainfall data for Mosul city during the period (1986 - 2014) and the National Centre for the Environmental Prediction (NCEP) re-analysis data are used to calibrate the model. The scatter plot and correlation matrix are used to investigate the degree of association between the selected predictors and predictand. Prior model calibration the fourth root power transform facility is selected for daily precipitation in order to produce none linear regression model. The results obtained from Statistical Downscaling Method (SDSM) model were compared with the observed data. The simulation from Hadly Centre climate model (Had-CM3) emission scenario have been used for future periods. The generation of future climate scenario used 10 years (2026-2035) of daily time scale under HadCM3 predictor data.

1. Introduction
Meteorological data is essential for studying the crucial climate changes, and its effect on water resources system, planning and management. Climate changes and the human activity are the most important reasons producing shift in hydrological cycle. Climate change leads to variation in rainfall intensity and evaporation, such variation has significant impact on regional hydrologic process [1]. Changes in land use due to human activities lead to an increase in the concentration of greenhouse gases emitted toward earth’s atmosphere. This unbalance of energy leads to global warming [2]. Excessive rainfall is often related to flood events which are presumed as the most significant natural hazards. Changes in river flow, flood and drought events are often related to rainfall statistics, intensity, duration, and frequency. The valuation report submitted by the Intergovernmental Panel on Climate Change (IPCC) refers that; it's most possible that the tendency of extreme precipitation values will continue to increase. This conclusion depends on the application of numerical Global Climate Model (GCM) with different emission scenarios [3]. Since the results of (GCM) model are based on a grid with large scale (250 to 600 km) [4], the results with such coarse resolution are not fit enough to be used directly on a regional scale, whatever the degree of model resolution. Consequently, techniques have been developed to downscale the climate model results [5]. Downscaling techniques are used to bridge the spatial and temporal resolution gaps between what climate modellers are currently able to provide and what impact assessors require. The most applied approaches of downscaling techniques are: weather typing, dynamic downscaling, transfer functions, and stochastic weather generator approaches [6]. The SDSM model is being largely used to downscale the most significant climate variables such as precipitation and temperatures. The SDSM model develops a statistical relationship between large scale GCM outputs (predictors) and local scale variables (predictand) [7]. The main objectives of this study are downloading HadCM3 GCM and calibrate the SDSM model and its adaptability in downscaling precipitation and forecast the rainfall for climate scenarios for next 10 years (2026-2035).

2. Description of the study area:
Mosul city is one of the major cities in Iraq. It lies in the northern part of the country with land area about 437 km$^2$. Observed Rainfall data for the city is collected from the Iraqi Meteorological Organization and Seismology during the period (1986 – 2014). The location of rainfall station is (43.09$^\circ$) longitude and (32.19$^\circ$) latitude as shown in figure 1.

Figure 1. District of meteorological station.

3. Methodology:
The directories of NCEP_1991_2001 and HadCM3 (H3B2) _ 1961_2099 (H3B2 is the IPCC emission scenario B2) contain 41 and 139 years of daily predictors data, respectively. This data is obtained from a zip file assigned for every grid box, according to the coordinate of the site location. All the information can be downloaded from the website: http://www.cis.uvic.ca/scenarios/index.cgi?Scenarios. Because of the spatial differences between the NCEP predictor data (2.5$^\circ$ x 2.5$^\circ$) during the period 1961_2001 and the HadCM3 grid resolution (2.5$^\circ$ x 3.75$^\circ$), the NCEP data must be re-gridded to accommodate with the grid system of HadCM3.

4. Statistical downscaling model (SDSM):
SDSM is a hybrid multiple linear regression and stochastic weather generator [9]. It’s a regression approach performing a linear or nonlinear relationship between predictors and predictand, and generates regression parameters. These calibrated weights along with the NCEP predictors data are used by the stochastic weather generator to simulate up to 100 daily time series for better correlation with the observe data [10]. In SDSM, the combination of the correlation matrix, partial correlation, p value, and scatter plots are utilized to adapt the most appropriate predictors. Two types of optimization methods are provided by the SDSM: ordinary least square and the dual simplex. The ordinary least square method (OLS) has advantage over the dual simplex method (DS) as the (OLS) produces comparable results with the (DS) and it's faster than dual simplex [11]. The model calibration offers three types of temporal resolution: the monthly model with a set of parameters assigned for each month, seasonal model with four set of different parameters, one for each season, and annual model.
with one set of parameters during the year. There are two types of sub models: conditional and unconditional. Rainfall data is not normally distributed in opposite of temperature data which has a normal distribution. Consequently, the conditional process is the setting used for model calibration. Thereby transform facility applied to predictand in case of conditional models to adjust data distribution to the normal form before using the data in subsequent equations. The fourth power root might be selected before utilizing data in regression equation [12].

5. Model Run:

5.1 Quality control, transformation, and screening of predictors:
Prior to model calibration, the following steps are applied; first is quality control function, used to check the data and identify outlier and any missing data value was coded as (-999) and saved with (.DAT) file extension. The second is data transformation for rainfall data, the fourth root is recommended, and finally screen variable operation is applied to select the most sensible set of predictors. In this study each predictor was selected based on high correlation with the predictand (rainfall) and the magnitude of their probability (p value) at significant level of (0.05). For Mosul city the predictor variables have better correlation with predictand (rainfall), are mslp (mean sea level pressure), ncep500eu (500 hPa geopotential height), ncep8zeu (850 hPa divergence), nceptempeu (mean temperature at 2 m). Figure 2 illustrate various steps for climate scenario generation.

![Figure 2. Climate scenario generation (adapted from SDSM 4.2 user manual).](image-url)
5.2 Model calibration:
This operation is summarized by specified predictand, with the screened predictor variables, and using an ordinary least square optimization algorithm, yields estimation of the parameter of multiple regression equation for monthly model. The 4 predictor variables selected in the previous section were utilized to calibrate the model with the observed rainfall data for the period from 1/1/1986 to 31/12/2005. Applying an ordinary least square optimization, the model parameters of multiple regression equations were calculated for monthly models. Figure 3 shows the histogram of residuals, which show nature of normal distribution.

![Figure 3. Histogram of residuals.](image)

5.3 Weather generator:
The operation of weather generation produces ensembles of synthetic daily weather series for the period starts from 1/1/2005 to 31/12/2014. Given predictor variables (NCEP reanalysis) and the parameter file result from model calibration, moreover ensemble size of 20 was used for synthesis. The facility of Weather generator enables verification of model calibration and synthesis of artificial time series for the period starting from 1/1/2005 to 31/12/2014.

6. Results and discussion
6.1 Model validity:
The model validity can be examined by comparison of the simulated ensembles of synthetic weather series from 1/1/2005 to 31/12/2014 (10 years) with the observed rainfall data for the same period. The operation of summary statistics in SDSM mode enables to use the ensemble mean to obtain the monthly averages for the simulation of weather series. These mean values compared with the observed daily rainfall, using compare results in SDSM model, yields bar as shown in figure4, which reveals well representation of the simulated and observed data for the same period. Also figure 5 shows relation between simulated and the observed data with R² of 0.98 which is a good fit.
6.2 Approach of scenario generation:
This operation is based on using HadCM3 predictor variables to produce ensemble of synthetic daily series, first for current climate forcing during the period (1986-2014). One of the best advantage of scenario generator is to compare current climate forcing (1986-2014), with the observed data. Quantile-Quantile plot shows the relation between the observed daily rainfall and the ensemble mean downscaled from HadCM3 for the period from 1/1/1986 to 31/12/2014 as shown in figure 6.
Figure 6. Plot of observed daily transform rainfall versus the ensemble mean downscaled from HadCM3 for the period 1986–2014.

The second scenario was used to generate the ensemble of synthetic daily weather series using HadCM3 atmospheric predictor's variables for the period (2014 – 2035) for Mosul city. This future annual rainfall scenario has been compared with the baseline period 1986–2014 for the probability of changing rainfall trend in future. The annual rainfall would be increased by 23% during the period (2014 – 2035) under H3B2 scenario as shown in figure 7. With the aid of the time series plot which is corresponding to scenario state generated by the operation SDSM especially during the last months of the year as shown in figure 8.

Figure 7. Average rainfall during different scenarios.
Figure 8. 2026 -2035 daily time series of rainfall for Mosul station.

7. Conclusion:
An evaluation of the anticipated future changes in the characteristics of precipitation for Mosul city was done considering 20 ensemble of GCM output of HadCM3 SRES B2a emission scenario with the applied of statistical downscaling (SDSM) modeling approach. The downscaling of rainfall data scenario refers a future increasing during the next 20 years period. Analysis of data provides a convenient agreement between observed and downscaled data, despite the difficulty in adjusting model calibration. Better results of model calibration are accessed from adjusting the values of variance inflation and bias correction. This is due to the nature of rainfall, which is considered a random variable, resulting from uncertain process.

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