# Technical Approach and Methodology for Projected Data Preparation

## *(i) Interpolation and gridding of archived observed meteorological data*

Meteorological data is observed at stations which are maintained by the Department of Hydrology and Meteorology, Government of Nepal. This network of observation stations is not regularly spaced, particularly over the complex terrain of northern mountainous region of Nepal. This irregular network creates an information gap which ultimately hinders development plans/projects. A solution for overcoming this data sparseness over the complex terrain was spatial interpolation of the observed meteorological data into a high-resolution grid using appropriate technique.

Detail summary of data interpolation:

- Years to be gridded - Rainfall: 1961-2009
  Temperature: 1971-2009
- Gridding Domain - 80.0°E – 88.25 °E; 26.25°N – 30.5°N
- Grid intervals - 0.1° Lat/Lon
- Timeline - 01 April – 30 June 2011
- Actions were taken;
  - The data series which passes homogeneity tests were used for the construction of gridded data sets over Nepal.
  - An inverse square distance weighted averaging method and Kriging algorithm within Surfer software were used to interpolate observed meteorological data.

An inverse square distance weighted averaging method and Kriging algorithm within Surfer software were used to transfer the randomly distributed station data to regularly spaced gridded data. SURFER is a contouring and 3D surface mapping program. It quickly and easily converts data into outstanding contour, 3D surface, 3D wireframe, vector, image, shaded relief, and post maps. These methods have the advantage of treating the non-uniform distribution of observation network. However, both of methods do not consider altitudinal effects explicitly while gridding. The gridded data users are therefore cautioned while using data particularly from the high altitude regions of Nepal due to sparse observational networks at these regions. GrADS was used as an alternative option for mapping of interpolated observed meteorological data and to convert gridded data sets to netCDF format to be used in climate data portal.

**Summary of activities of Climate Data Digitization, Quality Control, interpolation, gridding and Statistical Analysis of Historical Meteorological Data**

| Task | No. of Years | No. of Stations | Parameters | Software to be used | Timeline | Remarks |
|---|---|---|---|---|---|---|
| ***Climate data digitization*** | All available prior to 1987 | 37 | Wind speed, Evaporation, Soil moisture, Sunshine duration | Microsoft Excel/ GW Basic | 15 January – 30 April 2011 | |
| ***Quality control of observed data*** | All available up to 2009 | All | All | RHtests V3 and RClimdex | 01 March – 31 May 2011 | Missing values of the temporal data series of rainfall was filled by statistical probability distribution function and temperature series was filled by hierarchical polynomial regression technique. |
| ***Interpolation and gridding of archived observed meteorological data*** | Rainfall: 1961-2009 Temperature: 1971-2009 | All | Rainfall, Mean, Max and Min Temperature | ANUSPLIN, SURFER and GrADS | 01 April – 30 June 2011 | Gridding Domain: 79.0°E – 90.0 °E; 25°N – 32.0°N, Grid intervals: 0.1° Lat/Lon |
| ***Statistical analyses of observed data*** | 1961-2009 | 37 | Rainfall, Mean, Max and Min Temperature | RClimDex | During June 2011 | Types of analyses: Mean - monthly, seasonal, annual, Standard Deviation (SD)/ , Coefficient of Variation (CV), Trends/ Inter & Intra -annual variability, Frequency of rainy days. |

### *(ii) Downscaling of Climate Change Projections - Dynamic Climate Downscaling over a Spatial Domain*

General Circulation Model (GCM) provides regularly spaced, coarse resolution (1-4 degrees ~ 100-400 km) climatological and meteorological information, in 3-dimensional gird, by integrating hydrodynamic equations, which are derived from three basic conservation laws and ideal gas law. Atmospheric processes, which deals with fine spatial scale, such as clouds, convective precipitation, etc. may not perfectly resolve in GCMs as the detailed topography and land-use are not properly represented. GCM results are more representative over the countries, where the topography is flat and away from the coastlines due to the fact that minimal and unified local forcing over a large region. Nevertheless, GCM results would be acceptable for climate change adaptation studies, developing general trends of rainfall and temperature, etc. but not for more specific analytical tasks such as forecasting of changes in agriculture yields at farm level, estimating surface runoff, river discharges at basin level etc. Therefore, climate information derived from GCMs need to be downscaled for a country like Nepal, as it has a varying topography towards northern parts of the country. Regional Climate Model (RCM) is the most reliable option for downscaling coarse resolution GCMs outputs to fine resolutions (12, 20 and 25 km) grid in incorporating local topography in Nepal and neighborhood. PRECIS, RegCM4 and WRF models were used for downscaling of GCMs climate information over Nepal.

PRECIS is a primitive equation hydrostatic model which developed by UK Met office runs with 19 levels in hybrid vertical coordinate (Simmons and Burridge, 1981; Simon et al., 2004). It generally runs with 50 km horizontal resolution with the option of fining to 25 km. RegCM4 is the latest version (released in July 2010) of RegCM adopted from the first generation model of RegCM of NCAR, USA by the Physics of Weather and Climate (PWC) of International Centre for Theoretical Physics (ICTP) of Italy. It is a community model and widely used in many countries for climate studies over the past few years (older version-RegCM3). WRF is a next generation mesoscale numerical weather forecasting community model, which has the potential to simulate meteorological phenomena ranging from meters to thousands of kilometers (Wang, et al., 2008). Advance Research WRF (ARW) is a dynamic solver (Skamarock, 2005), which is compatible with the WRF system. It integrates the compressible, non-hydrostatics Euler equations, which are cast in flux form (Ooyama, 1990) with terrain-following mass vertical coordinates (Laprise, 1992). A dedicated team from

BCCR of Bergen, Norway, TERI of New Delhi, India, ITC of Netherland and ADPC of Bangkok, Thailand were involved in downscaling of future climate projections and model validation activities with RCMs. Lateral Boundary Conditions (LBCs) from several GCMs were used with different emission scenarios (SRES) to project future climate changes over Nepal due to continued anthropogenic inputs of greenhouse gases. A1B is regarded as "medium" and A2 is regarded as "high" emission trajectory as proposed under the SRES.

Detail summary of downscaling of future climate projections:

- PRECIS, RegCM4 and WRF models were run in a bigger domain to capture land-sea interaction, large scale features such as monsoon effect, western disturbances, easterly waves, etc. The same domain was used as 68.0°E-100.0°E; 01°S-38.0°N for three models and horizontal resolutions were 25, 20 and 12 km respectively

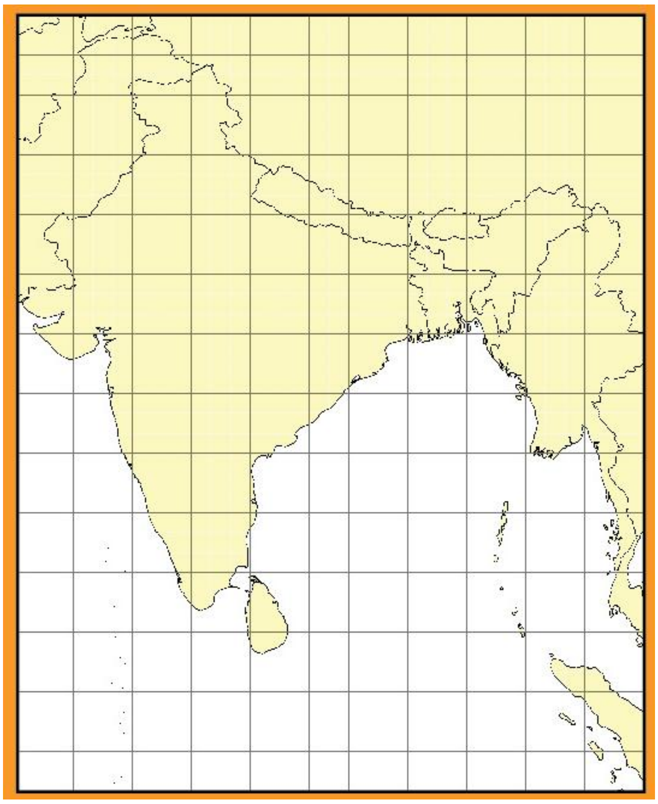


Figure: Model domain

- Model results were extracted for smaller domain over Nepal for visualization through the web portal. The smaller domain size was 79.0°E-90.0°E; 25.0°N-32.0°N

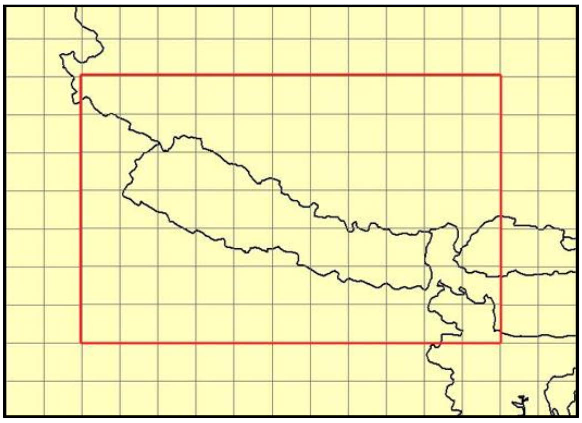
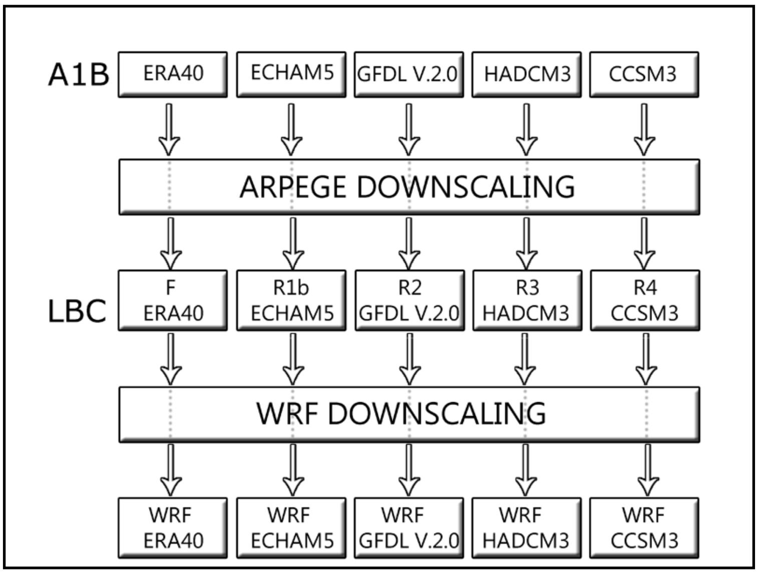


Figure: Visualize domain in the web portal

- The future climate projections were downscaled for the period 2030 to 2060 (mid 21st century) for Nepal with A1B and A2 scenarios.
- In order to evaluate the performance of the RCMs (PRECIS, RegCM4 and WRF), the RCMs will also be forced with hindcast data from the GCMs for the baseline period from 1971 to 2000. Downscaled hind-cast data were compared with the observed digitized station data in Nepal and model biases at 96 meteorological stations were calculated and documented.

- **Executing of WRF (12 km resolution) model** for downscaling of future climate over Nepal was done at BCCR in Bergen Norway (joint venture partner of this project) with their Cray XT4 super computer facilities. LBCs with ECHAM05 (R1b) GCM by Max-Planck-Institute), GFDL2.0 (R2) GCM by the National Oceanic and Atmospheric Administration), CCSM (R3) GCM by the UK Met Office) and HadCM3 (R4) GCM by the National Centre for Atmospheric Research) with A1B scenario were used to accomplish the work. Validation for the baseline (ERA40 (F) run for 1971-2000), bias calculation, at about 96 meteorological stations, graphical representation of downscaled products, etc. were also done at BCCR under the supervision of lead climate scientist.




- **Executing of PRECIS (25 km resolution) model** was done at TERI of New Delhi, India (resource partner) with its dedicated file servers (1 TB hard disk, 8GB RAM and quad core performance). Fifth generation model of Max Plank Institute of Germany (ECHAM05-MPI) was used as LBCs for PRECIS with SRES A1B. The sea surface boundary conditions would be taken directly from ocean component of the ECHAM05 model. Validation work with the baseline (1971-2000), bias calculation at about 96 meteorological stations, graphical representation of downscaled products and other relevant work were also done at TERI, New Delhi, India. This work was carried out by the modeling expert at TERI in coordination with lead climate scientist and post-doctoral scientist in ADPC.
- **RegCM4 (20 km resolution),** new version of RegCM4 released in July 2010, was run at ADPC with its IBM Power 755 High Performing computer with ECHAM05-MPI under A1B and ECHAM04-MPI under A2 SRES. Relevant baseline validation, bias calculation at about 96 meteorological stations and other relevant work were done at ADPC under the supervision of post-doctoral scientist.
- **Executing of PRECIS (25 km resolution) model** was done at ADPC-Bangkok with its dedicated high-end PC. Hadley Centre model (HadCM3Q0) was used as LBCs for PRECIS with SRES A1B. The sea surface boundary conditions were taken directly from ocean component of the HadCM3Q0 model. Validation work with the baseline (1971-2000), bias calculation at about 100 meteorological stations, graphical representation of downscaled products and other relevant works were also done at ADP

## Details of Downscaling of Climate Change Projections

| Institute | RCM | GCM | Scenario | Performed Domain | Result Extracted Domain | Horizontal Resolution (Km) | Validated Period | Downscaled Period | Outputs | Utilized Technology |
|---|---|---|---|---|---|---|---|---|---|---|
| BCCR | WRF | Era40, ECHAM05, GFDL2.0, CCSM and HadCM3 | A1B | 68.0°E 100.0°E; 01°S-38.0°N | 79.0°E-90.0°E; 25.0°N-32.0°N | 12 | 1971 to 2000 | 2030 to 2060 | Rainfall, Mean, Max and Min Temperature , Sea Level Pressure and Ground Wind | Cray XT4 super computer |
| TERI | PRECIS | ECHAM05 | A1B | -do- | -do- | 25 | -do- | -do- | Rainfall, Mean, Max and Min Temperature , RH, Sea Level Pressure and Ground Wind | High-end PC |
| ADPC | PRECIS | HadCM3Q0 | A1B | -do- | -do- | 25 | -do- | -do- | -do- | High-end PC |
| ADPC | RegCM4 | ECHAM05 and ECHAM04 | A1B and A2 | -do- | -do- | 20 | 1960-1990 | 2030-2060 and 2040-2070 | -do- | IBM Power 755 |

### *(iii) Calibration of Rainfall and Temperature data*

**Calibration Methods:**

The simulated rainfall and temperature data were extracted at the coordinates of the observed meteorological stations for the study area. The extracted data are processed on daily, monthly and annual scales, and objectively compared with the observed data on the same scale.

***For RegCM4***

The regression coefficients (slope and intercept) are obtained for rainfall, and for maximum and minimum temperature of both observed and simulated datasets. The obtained regression coefficients are used in the calibration of the RCM output as described by Islam (2009) and Islam et al. (2008, 2010). The expressions for the calibration of rainfall and temperatures are as follows:

$$\text{Calibrated}_{\text{Rainfall}} = \alpha_{\text{Rainfall}} (\text{RegCM}_{\text{Rainfall}}) + \beta_{\text{Rainfall}} \quad (1)$$

$$\text{Calibrated}_{\text{Tmin}} = \alpha_{\text{Tmax}} (\text{RegCM}_{\text{Tmin}}) + \beta_{\text{Tmin}} \quad (2)$$

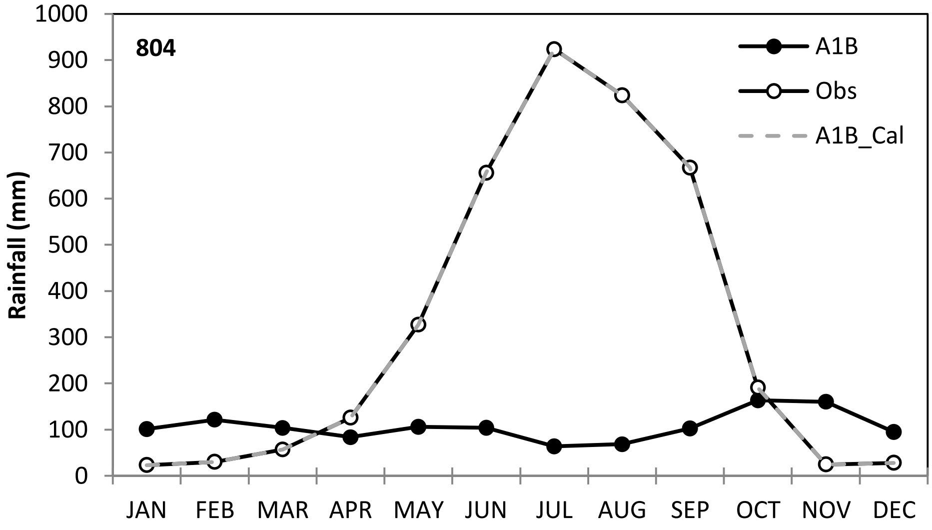
$$\text{Calibrated}_{\text{Tmax}} = \alpha_{\text{Tmin}} (\text{RegCM}_{\text{Tmax}}) + \beta_{\text{Tmax}} \quad (3)$$

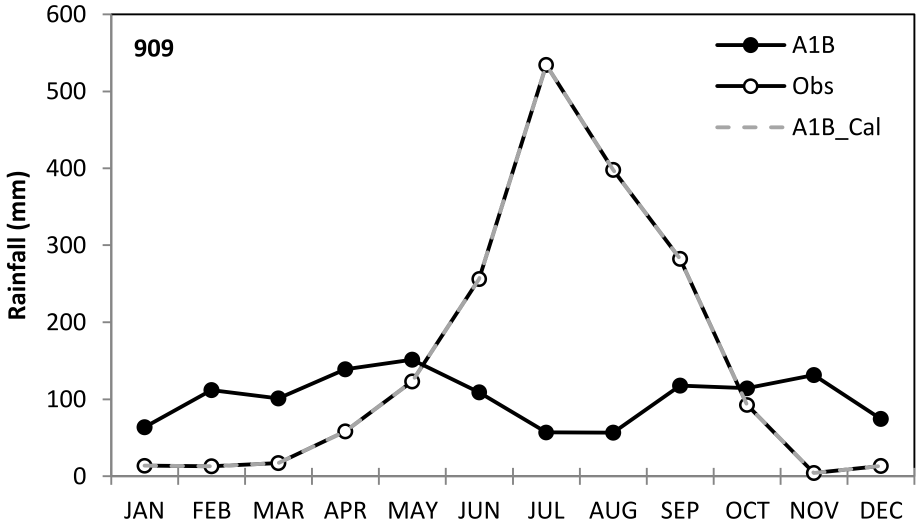
where Calibrated is the variable to be obtained after calibration, $\alpha$ is the slope and $\beta$ is the intercept. The corresponding subscripts are used for the rainfall, and the minimum and maximum temperatures. The calibration using regression equations (1-3) are termed as RegCM-REGN.

The rainfall obtained by RegCM4 is not free from uncertainties. There is a large bias between the simulated and observed rainfall over Nepal. Examples are shown in following figure for station code 804 and 909. For station 804, simulation largely underestimates from May to September and overestimates from November to February. For station 909, RegCM4 underestimates rainfall largely from June to September (monsoon season) and overestimates from November to February. However, after bias correction simulated and calibrated rainfall exactly follows the annual cycle of the observed data. Similar results are obtained for all stations throughout the country and calibration factor for rainfall in Nepal is presented in a separate table. Using the calibration factor presented in the same table, one can project the rainfall from the RegCM4 output for the SRES scenarios.

Similar to rainfall, maximum and minimum temperature calibration factors are provided in separate tables respectively. For both the rainfall and temperature, the calibration factor to be subtracted from the model generated scenarios to obtain bias free model output.

**Projection=Model - Calibration Factor**




Example of RegCM simulated rainfall (A1B) compared with observed (Obs) data before and after (A1B_Cal) calibration for station 804 and 909.

***For PRECIS and WRF***

***Temperature:*** The correction of temperature involves shifting and scaling to adjust the mean and variance (Leander and Buishand, 2007 and W. Terink et al, 2010) because temperature is known to be normally distributed. So that following three approaches were tested for the data in period 1970-1995 and verified for the data in period 1996-2000.

The three approaches are:

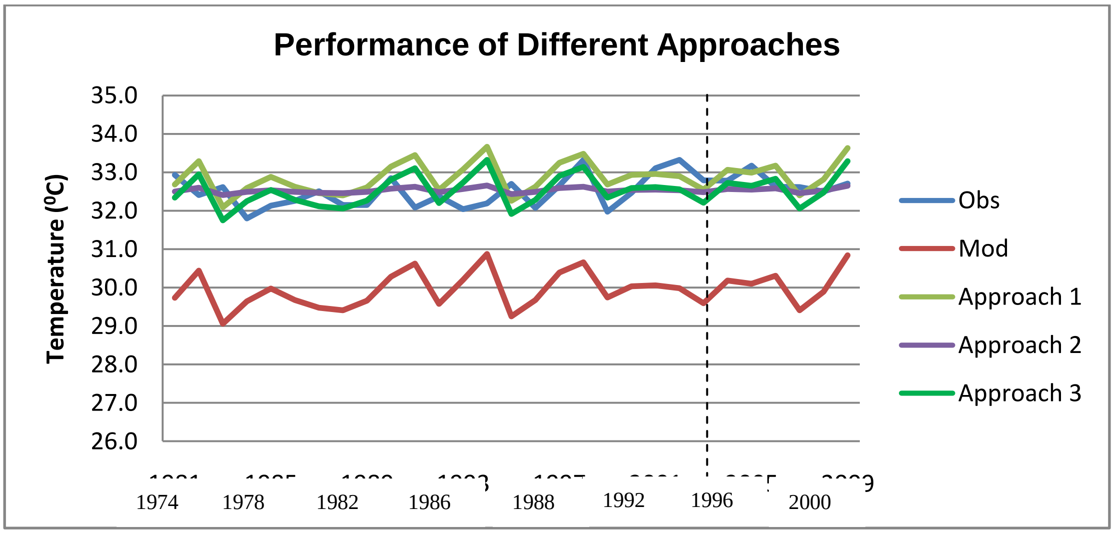
$$\mathbf{T^* = \bar{T}_{obs} + SD(T_{obs})/SD(T_{mod})(T_{mod} - \bar{T}_{obs}) + (\bar{T}_{obs} - \bar{T}_{mod})}$$ **----- (1),** developed by W. Terink et al, 2010

Where T* is the value to be obtained after calibration. $T_{obs}$ and $T_{mod}$ are the observed and model monthly temperature respectively. In this equation over bar denotes the average over the considered period and SD the standard deviation.

$$\mathbf{T^* = \alpha T_{mod} + \beta}$$ **-------- (2),** developed by Islam M. Nazrul et al, 2009

The regression coefficients (**α** (slope) and **β** (intercept)) are obtained using a scatter plot of temperature from both model estimation and observation for considered period.

$$\mathbf{T^* = (T_{mod} - \bar{T}_{mod}) * (SD(T_{obs})/SD(T_{mod})) + \bar{T}_{obs}}$$ **----- (3),** developed by Cheng et al, 2007




First approach was selected as best performed approach for the bias correction for temperature in this study by evaluating mean and trend with same parameters of

observed values. (see the look-up tables for calibration factors for each model respectively)

***Precipitation:*** For the calibration of precipitation data linear as well as non-linear approaches were experienced to adjust both the biases in the mean and variability, leads to better reproduction of observed fluctuations.

The three approaches are:

$\mathbf{P^* = SD(P_{mod}) \times P_{mod}\ ^\wedge CV(P_{obs})}$ **----- (1),** described by W. Terink et al, 2010

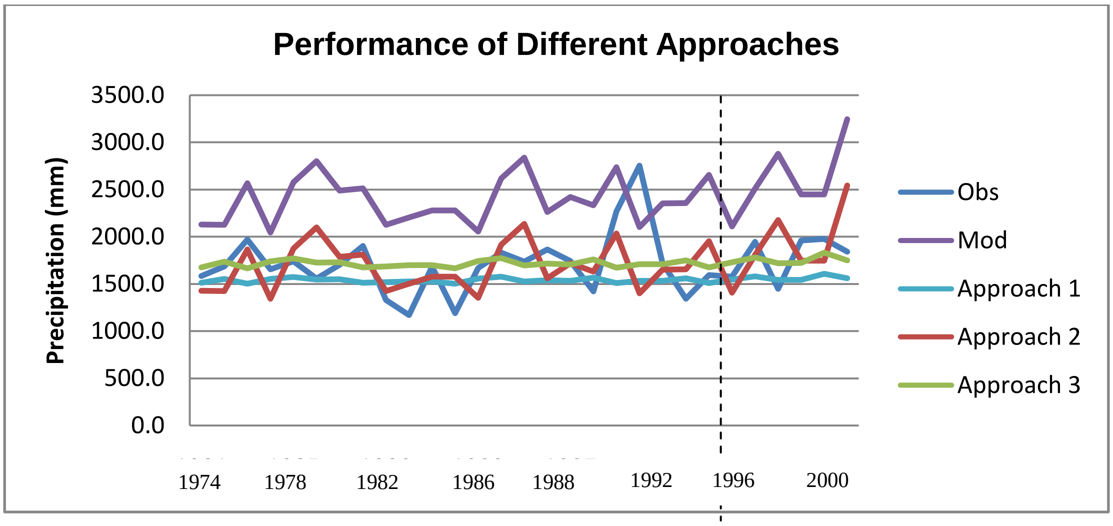
Where P* is the value to be obtained after calibration. $P_{obs}$ and $P_{mod}$ are the observed and model monthly precipitation respectively. In this equation CV denotes the coefficient of variation over the considered period and SD the standard deviation.

$\mathbf{P^* = \overline{P}_{obs} + (P_{mod} - \overline{P}_{mod})}$ **----- (2),** introduced by WCRP, 2011

Where over bar denotes the average over the considered period

$\mathbf{P^* = \alpha P_{mod} + \beta}$ **-------- (3),** developed by Islam M. Nazrul et al, 2009

The regression coefficients (**α** (slope) and **β** (intercept)) are obtained using a scatter plot of rainfall from both model estimation and observation for considered period.




Second approach was selected as best performed approach for the bias correction in this study by evaluating mean, standard deviation, trend and coefficient of variation with same parameters of observed values. (see the look-up tables for calibration factors for each model respectively).