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Determining historic (1950 - 2000) average precipitation and temperature for Pakistan by using climate downscaling technique

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ABSTRACT

There is an immense hydropower potential in Pakistan. To utilize those resources effectively, it's compulsory to know about climate history that helps in hydropower project feasibility. For that, there is an assessment required of a specific site from a hydrology perspective i.e. water level or evaporation rate, where spatial data regarding different parameters such as precipitation and temperature is compulsory. Based on this, a climate downscaling technique is used in this paper that requires the input time series data sets of temperature and precipitation, based on 30 arc seconds and 0.5˚ resolution. A downscaled dataset has been generated by using time series input data sets of the Global Precipitation Climatology Centre (GPCC) and Climate Research Unit (CRU) that are of 0.5˚ resolution. Along with such low-resolution datasets, a 30˚ high-resolution time series data sets of WorldClim are also used for temperature and precipitation. A downscaled historical (1950 - 2000) gridded data of precipitation and temperature for Pakistan is generated through the statistical climate downscaling technique to interpolate the coarse resolution data into fine spatial resolution data with the help of Piecewise Cubic Hermite Interpolation Polynomial (PCHIP) interpolation scheme. These downscaled historical precipitation and temperature data in ASCII format are programmed in MATLAB, defining the boundary region of Pakistan to calculate their average annual, seasonal, and monthly temperature and precipitation values. The average annual, seasonal, and monthly precipitation and temperature historical data are plotted for Pakistan using a spreadsheet generated in MATLAB. Such plotted data can be used in the prediction of water stream flow rate and evaporation rate by using hydrology models in the future that help in assessing the hydropower of the Pakistan before commencement of the hydro projects.

1. Introduction

Hydropower is considered a substantial source for generating electricity due to the utilization of basic technology. It is cost-competitive in most regions and is receiving immense attention as compared to other renewable technologies due to increasing demand for energy [1]. The selection of turbines depends on both quantitative and qualitative criteria. The quantitative factors demand detailed information concerning the particular location of the hydropower project, which includes parameters like topography, water flow, and prevailing site conditions. The flow rate, head, and power requirements must be known, and which type of turbine will be suited for that particular site. In qualitative criteria, information regarding climate, civil work requirements, maintenance needed after installation, and how easily the setup will be installed is required [2].

Prior installation of hydropower systems, an assessment of hydropower resource potential for a particular site is needed [3]. The evaluation of the hydropower potential of a specific site is primarily dependent on its hydrology, topography, and socioeconomics. The spatial data regarding these parameters are obtained through remote sensing techniques that help in site assessment [4]. The most important factor is climate change due to variations in precipitation and temperature that have an impact on the hydropower resources of a particular region [3].

The average monthly precipitation and temperature data are usually used in scrutinizing hydrologic and agricultural parameters. In most regions, there is a high-resolution data of 10 arc minutes (about 18.5 km) for monthly precipitation and mean temperature that are scatological as compared to the downscaling method used in [5] paper. Fine spatial resolution data (approximately ≤ 1 km2) are needed to determine variation in the environment of a specific site because information is lost at low resolution due to mountains and the high climate gradient of that site [6].

1.1 Input Data Required for Downscaling

1.1.1 30 Arc second climatology data

To see the orographic effect on precipitation and temperature, it is better to use 30-arc-second climatology data [7, 8]. This is because of the absence of some meteorological stations in some grids. The time series data set obtained from WorldClim is produced through an algorithm used in the ANUSPLIN 4.3 package that accompanied latitude, longitude, and elevation as independent variables and uses station records to fit the climate surface [7, 8]. Some other algorithms such as regression used in PRISM consider factors like aspect, slope, coastal proximity, and effectiveness of orographic [9].

The PRISM climatology performs better than WorldClim in representing spatial heterogeneity of precipitation especially for mountain regions. This is because of the high gradient aspect and slope of such regions. The advantage of WorldClim is that it is available globally relative to PRISM. The uncertainties in precipitation and temperature data available on WorldClim were checked before publishing by two techniques i.e. data partitioning and cross-validation. In the former technique, there is an uncertainty of about 2 ˚C and 50 mm in temperature and precipitation data, whereas in the latter technique, such uncertainty decreases to 0.4 ˚C and 10 mm [6]. In this paper, the time series precipitation and temperature data sets are used as inputs obtained from WorldClim.

1.1.2 0.5˚ Resolution based monthly dataset

Any low-resolution monthly dataset can be used as inputs for downscaling. There are different models used to produce low-resolution monthly datasets such as the Tropical Rainfall Measurement Mission (TRMM) that covers the geographical area of 50˚ south and north [10], the Reanalysis model (ERA) [11], and the National Centers for Environmental Prediction (NCEP) [12]. Each model has some limitations where TRMM does not perform well to obtain data of precipitation for mountain regions. Similarly, reanalysis is used only for atmospheric studies, and data sets by NCEP are unable to grid on 2.5˚ spatial resolution [5]. In this paper, the time series temperature data sets are used as low-resolution input, obtained from Climate Research Unit (CRU) version 3.2. Initially, gridded data sets of 0.5˚ resolution are produced by CRU from stations of a particular region. The anomaly values at cells are calculated by CRU for specific periods where partial anomaly cells are filled by using a triangulated linear interpolation technique [13]. The number of stations available varies from region to region and can be seen in Fig. 1 of [5] paper. Another monthly precipitation time series data set used in this paper is from Global Precipitation Climatology Centre (GPCC) version 6 and is used as inputs to obtain downscaled precipitation grids through statistical climate downscaling. GPCC also interpolates station data on grids by the SPHEREMAP method. The advantage of GPCC over CRU is that their database contains more number of stations than CRU [14].

In this paper, a climate downscaling package [18], introduced by Mosier is used for determining monthly mean precipitation and temperature for Pakistan within the temporal range of 1950 to 2000. A downscaled dataset has been generated for precipitation and temperature for Pakistan by using time series input data sets of GPCC and CRU that are based on 0.5˚ resolution. Along with such low-resolution datasets, a 30˚ high-resolution time series data sets of WorldClim are also used for temperature and precipitation. PCHIP interpolation scheme is used to interpolate the coarse resolution data into fine spatial resolution data. A program is written in MATLAB for reading such a downscaled gridded dataset of monthly precipitation and temperature. The average is calculated for monthly downscaled gridded data of temperature and precipitation within a period of 1950 – 2000. Lastly, the annual, seasonal and monthly average precipitation, and temperature have been plotted in MATLAB for Pakistan which lies in a historical period of 1950 – 2000.

2. Methodology

The procedure adopted in this paper for determining historical precipitation and temperature data for Pakistan is comprehensively shown in a flow chart as shown in Fig. 1.

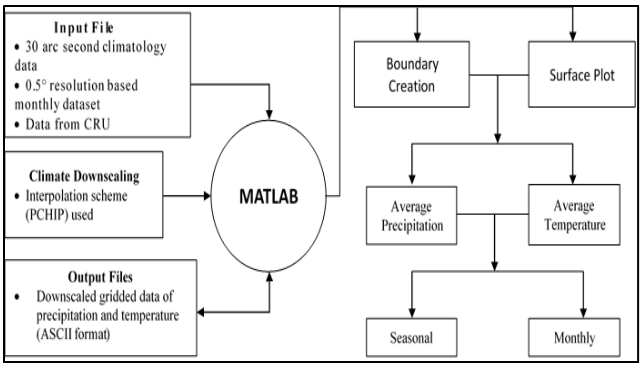

Fig. 1 Flow Chart Describing Method For Determining Historic Precipitation And Temperature Data (1950 - 2000)

The files described in section A are used as inputs in the downscaling tool. The historical gridded precipitation and temperature data within the range of 1950 – 2000 has been generated by using the Mosier downscaling package for Pakistan based on a 30-arc-second resolution. Such gridded precipitation data is generated by downscaling monthly total precipitation gridded time series data (30 arc seconds resolution) of WorldClim on a 0.5˚ precipitation gridded data obtained from GPCC. The GPCC records data from stations where each grid consists of variable station numbers [16,17]. Similarly, a 30 arc seconds downscaled monthly mean temperature gridded data is generated by downscaling monthly mean temperature (30 arc seconds resolution), obtained from WorldClim on mean temperature obtained from the Climate Research Unit (CRU) [18].

In the climate downscaling method, the Piecewise Cubic Hermite Interpolation Polynomial (PCHIP) interpolation scheme is used whose function is to interpolate anomaly grids of precipitation and temperature from their coarse spatial or temporal resolution to coordinates of high resolution. PCHIP restricts the range of interpolated surfaces according to climatology datasets. The downscaled data produced by PCHIP for precipitation and temperature is better compared to bilinear and cubic spline interpolation [5]. The downscaled gridded data of precipitation and temperature obtained by the Mosier tool are in ASCII formats. The ASCII files are read in MATLAB and surface plots have been plotted for them as shown in the following section.

To calculate the average temperature and precipitation within a specified boundary region of Pakistan, a shape file is read in MATLAB, where the shape file is used to specify the boundary around Pakistan. Lastly, annual, seasonal, and monthly average precipitation and temperature are plotted through a spreadsheet that accompanies average monthly historical data (1950 - 2000) of precipitation and temperature. A spreadsheet is generated in Excel format through MATLAB code.

3. Results

3.1 Surface Plot and Boundary Region

One of the surface plots of downscaled gridded data of the 1950 year for January precipitation is shown in Fig. 2. Similarly, the surface plot for downscaled gridded temperature data for January in the year 1950 is shown in Fig. 3. More surface plots can also be plotted for other years with their respective months to see the variation in temperature and precipitation in different regions of Pakistan. A boundary is also specified around the Pakistan region through a program to obtain the total average precipitation and temperature within a specified boundary.

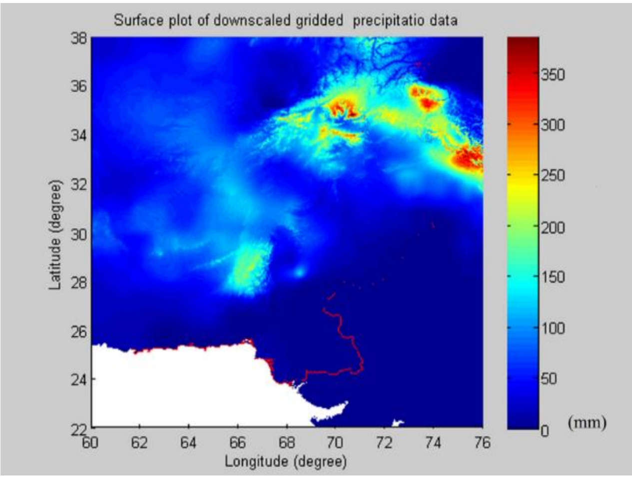

Fig. 2. Surface Plot Of Downscaled Gridded Precipitation Data For January Month

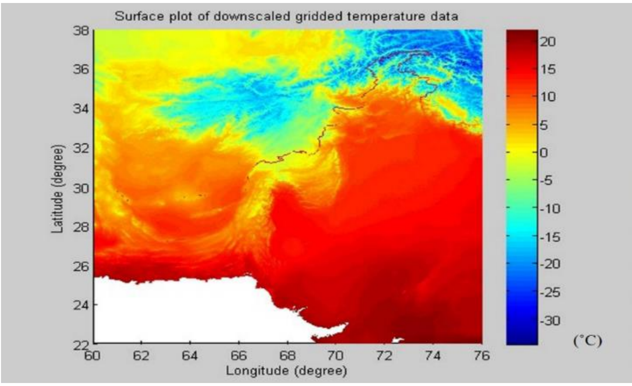

Fig. 3. Surface Plot Of Downscaled Gridded Temperature Data For January Month

3.2 Annual Average Precipitation and Temperature

A program is written in MATLAB to obtain annual average precipitation and temperature within the Pakistan boundary region for a temporal range of 1950 to 2000. The annual average precipitation and temperature are shown in Fig. 4 and Fig. 5 respectively.

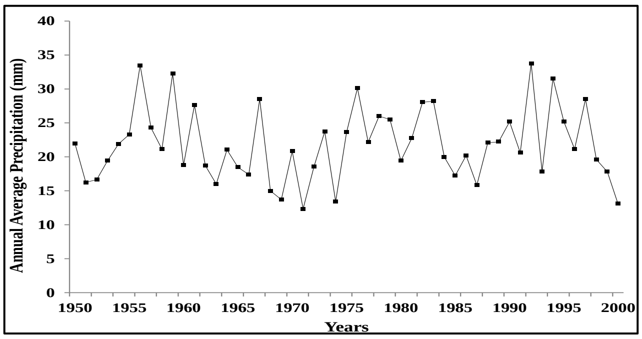

Fig. 4. Annual Average Precipitation (1950 - 2000)

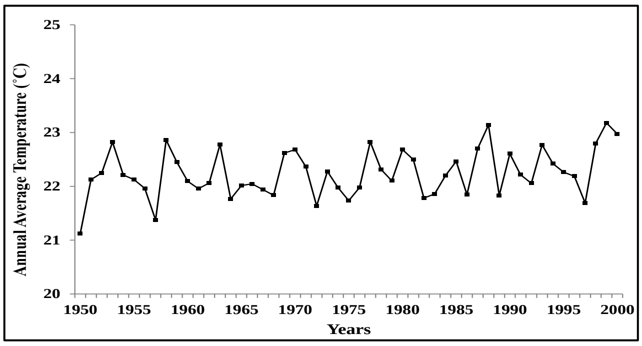

Fig. 5. Annual Average Temperature (1950 - 2000)

3.3 Seasonal Variation Throughout Historic Period

The climatology throughout the Pakistan region is calculated throughout, from 1950 to 2000 by writing a MATLAB program. The climatology from average precipitation and temperature perspective is calculated for each month as shown in Fig. 6 and Fig. 7 respectively.

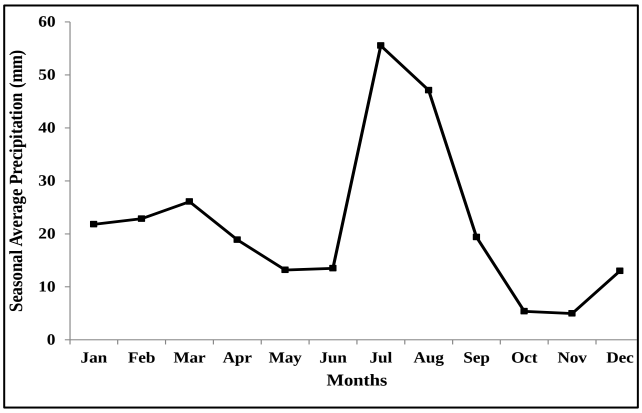

Fig. 6. Seasonal Average Precipitation Over 12 Months

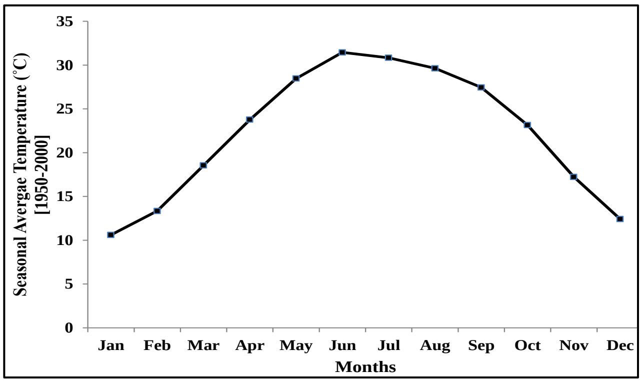

Fig. 7. Seasonal Average Temperature Over 12 Months

3.4 Monthly Based Average Precipitation and Temperature

A program is written in MATLAB for calculating monthly average precipitation and temperature for a period of 1950 to 2000 as shown in Fig. 8 and Fig. 9.

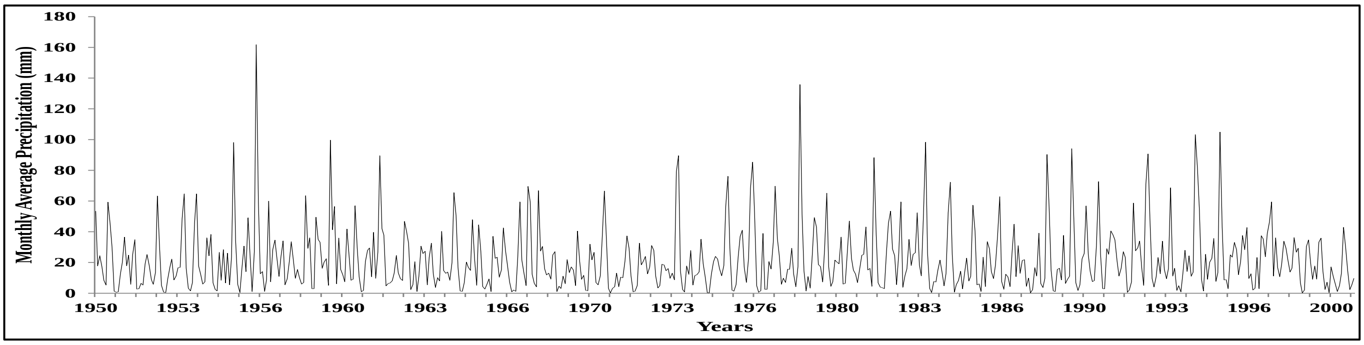

Fig. 8. Monthly Based Average Precipitation (1950- 2000)

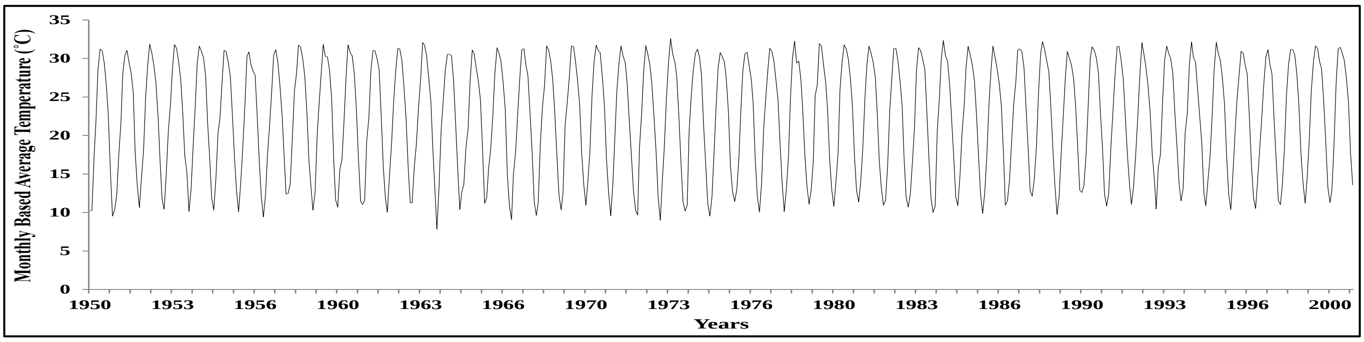

Fig. 9 Monthly Based Average Temperature (1950- 2000)

4. Discussion

Fig. 2 and Fig. 3 show surface plots for temperature and precipitation covering the region of Pakistan with 60˚ west, and 76˚ east longitude and 22˚ south, 38˚ north latitude. Such surface plot is only shown for January month and can be plotted for other months in the same way. The boundary of the Pakistan region encompasses only specific grid cells that contain data regarding precipitation and temperature.

In Fig. 2, the precipitation surface plot indicates the high precipitation values in the northern regions, especially in mountainous areas of Gilgit-Baltistan and Khyber Pakhtunkhwa, where the precipitation level observed is more than 200 mm. Such precipitation level leads to the probability of snowfall due to cold temperatures values below -10°C up to -30°C in certain areas as shown in Fig. 3 thus resulting in the accumulation of snow in northern regions.

Conversely, the southern region such as Sindh and even parts of Baluchistan face precipitation of less than 50 mm with markedly higher temperatures, fluctuating between 10°C and 20°C, which shows an absence of snowfall and a dependence on upstream inputs from the snow-fed rivers located in the northern region, which is indicative of arid and semi-arid conditions throughout the winter season.

The Fig. 4 and Fig. 5 shows variation in annual average precipitation and temperature for a specific time period. In Fig. 4, the annual average precipitation is found to be maximum in 1992, whereas minimum annual average precipitation was observed in 1971. By comparing Fig. 4 and Fig. 5, there is a minor variation in annual average temperature and nearly the same throughout the temporal range, whereas the maximum temperature was recorded in 1999.

The annual average precipitation and temperature variation convey important points regarding the temporal sustainability of hydropower. The annual average precipitation indicates high precipitation in the years 1992 and 1995 respectively, showing the possibility of snowpacks in the winter season at subsequently low temperatures especially in northern areas, while their melting starts in the summer season which clearly shows the change in the water stream flowrate that affects the supportive water flow systems for power generation. Similarly in the late 1990s,.the pattern of warming would affect the timing and amounts of water flows due to higher temperatures causing an acceleration of snowmelt and evaporation which likely restricts the hydropower output. The correlation between annual average precipitation and temperature indicates the importance of water management strategies and adaptive means to achieve optimum hydropower efficiency with climate variabilities.

The seasonal-based average precipitation is calculated for each year as shown in Fig. 6 and it is observed that the highest precipitation occurs in July and August. This is because of the monsoon period that starts from June through September [19], while the lowest precipitation is reported in the dry months of October and May respectively. There is a moderate temperature observed in cool dry weather during December and February as shown on Fig. 7. During the monsoon period, the seasonal-based average temperature is maximum resulting in melting down the snow in the northern region which causes more water stream flow rate in the rivers. From a hydropower feasibility perspective, such data would help in reservoir storage management and play an essential role during the monsoon and dry months period. There is an expected increase in the storage of the reservoir in the monsoon due to high precipitation and the reserved water can be utilized during peak energy demand while, during the dry season, there is a need for storage capacity planning to ensure the availability of power generation throughout the year.

Fig. 8 shows the monthly average precipitation within the temporal range of 1950 – 2000 which provides critical insights regarding hydropower project feasibility. The peaks in precipitation values during certain years (1956, 1976 and 1980) have been perceived along with prolonged periods of lower rainfall. The variation in the precipitation values will lead to facing challenges in generating consistent power from hydropower stations. This is because of the reduced water availability in the dry months, while extreme precipitation peaks would result in overwhelming the reservoirs and infrastructure. However, there is no consistent decrease in precipitation value which ensures stability in water availability over the decade and is beneficial for the hydropower planning on a long-term basis. Thus, Fig. 8 highlights the significance of diverse management, seasonal scheduling, and infrastructure reliability for the viability and sustainability of hydropower projects.

In the case of monthly average temperature, it is found that the average temperature is almost within the range of 10 – 32 ˚C as shown in Fig. 9. Such a consistent cycle of the temperature with constant variation reflects the seasonal dynamics stability and plays a vital role for hydrological processes, where the low and high temperatures tend to snow accumulation and snow melting in northern areas respectively. Such patterns have been consistent over five decades and based on these, it would provide a reliable foundation in planning long-term hydropower projects. On the other hand, any future warming tendencies may alter these dynamics that require adaptive measures for ensuring hydropower reliability.

5. Conclusion

From the above results, it is revealed that knowing the history of precipitation and temperature can assist in the prediction of stream flow rate and the amount of water lost from rivers due to evaporation by using different hydrological models. Pre-assessment of such parameters will assist in the prediction of future trends regarding rainfall and temperature severity which is essential for determining the feasibility of hydropower projects in a particular area before their inauguration.

The research advances the methodological progress of climate downscaling techniques by offering high-resolution climate data that can serve as a basis for determining dam practicability from a hydropower perspective. The application of the downscaled data in hydropower feasibility studies can be emphasized in future research, taking into consideration case studies with diverse geographical locations. Additionally, incorporating such results into hydrological and economic models could improve their use in regional water resource management and sustainable energy planning.

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