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Prediction of Inflow to the Ujjani Dam Reservoir using Linear Regression and Hybrid Model

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Abstract

Assessment of impact of climate change is very essential for the areas where the water scarcity is the main issue. Ujjani dam one of the largest dams of Maharashtra state in India is constructed on Bhima River in 1980 which supplies water to downstream cultivable area of Solapur and Pune district. In this study statistical downscaling model was developed for downscaling and projecting the temperature and rainfall by considering the GFDL-CM3 (GCM) model under scenario RCP 6.0. Statistical downscaling models showed a very good correlation (R2) between NCEP predictors and hydro metrological predictands. Using the projected values of temperature and rainfall, inflow to the reservoir was predicted by developing the three different models namely; Multiple linear Regression, Artificial Neural Network and Wavelet Neural Network. The models were evaluated by using mean square error criteria. It is observed that there is a change in rainfall pattern, it increases in the months of September to December however it decreases in the months of June to August, and this is due to corresponding changes in rainfall. The inflow to the reservoir has been predicted in three different time period viz 2020-29, 2050-59 and 2080-89.

Keywords

Statistical downscaling; Multiple linear regressions; Artificial neural network; Wavelet neural network; Ujjani dam

Introduction

The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern hemisphere. The globally averaged combined land and ocean surface temperature data show a warming of 0.70 C over the period of 1900 to 2000 [1]. Many studies identified that due to rise in temperature, changes have been in observed in rainfall and stream flow quantity and pattern. Climate change will cause change in temperature, precipitation pattern and other climate variables [2]. The areas under semiarid and arid regions where the survival of people is totally dependent on rainfall, it is very essential to study the effect of climate change over these hydrological parameters. In this study, the effect of climate change to the inflow of Ujjani dam reservoir is evaluated. Ujjani dam reservoir supplies water to downstream area of Solapur district in Maharashtra in India where the average annual rainfall is very less about 50 cm and temperature goes to 480 C in the month of April. The objective of the study is to assess the change in monthly inflow to the reservoir due to climate change.

To project the temperature and precipitation downscaling methodology has been used. Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) models has been developed using hydro metrological data. Relationship between predictands (rainfall, temperature) and predictors (atmospherically variables) was established using MLR and ANN techniques. Developed models have been used for projection of temperature and precipitation using General Circulation Model (GCM) variables. These projected temperature and precipitation were used for prediction of probable inflow to the reservoir. Prediction of inflow was done by using three types of models namely, MLR, ANN and Wavelet Neural Network (WNN). The model which shows better evaluation performance has been used to assess the change in monthly inflow to the reservoir. The results were analyzed for three different future time periods viz 2020-29, 2050-59 and 2080-89.

Study Area and Data Analysis

Study area

Ujjani dam built across Bhima River in 1980 in Solapur district of Maharashtra. It is an earth cum gravity dam. It's height above the lowest foundation is about 56.40 m and 2540 m long. Its gross storage capacity is 3320 km^3 and reservoir surface area is 290 km^2 , effective storage capacity is 1520 km^3 . It is multipurpose dam constructed for irrigation, water supply and hydroelectric power generation. Its designed spillway capacity is about 18010 m^3/s [3]. The basin area on upstream side of Ujjani dam is called as Upper Bhima basin. Upper Bhima basin shown in fig.1 is located within the coordinates of 17.18N to 19.24N latitude and 73.20E to 76.15E longitude [4].

Data collection

Three types of data have been used for this study.

Observed temperature and precipitation data: Observed temperature and rainfall (Predictands) data has been collected from Indian Metrology Department, Pune. It is available at 10 x 10 grids. Data of four grid stations as mentioned in paper lying within the Upper Bhima basin has been acquired. Data has been collected from January 1969 to December 2015 period.

National Centre for Environmental Protection (NCEP) data: NCEP data (Predictors for Training) is basically the data of observed atmospheric variables. Spatial resolution of this data is about 2.50 x 2.50.

Global climate model data: GCM (Predictors for Forecasting) data for GFDL-CM3 model was downloaded from https://esgf-node.llnl.gov web site on monthly basis considering RCP 6.0 scenario.

Statistical downscaling of temperature and rainfall and its prediction

Statistical downscaling has been carried out by using MLR and ANN techniques for the Upper Bhima basin considering four stations within it [5]. It has been observed that ANN based downscaling technique was outperformed the MLR by considering the coefficient of Determination as an evaluation criterion. The coefficient of correlation R^2 value in a strong correlation between observed and simulated values [6]. R^2 value less than 0.35 represents weak correlation, between 0.36 to 0.67 represents moderate correlation and greater than 0.67 to 1 represents strong correlation [7,8]. Owing to its better performance the ANN technique has been used to predict temperature and rainfall using GFDL-CM3 (GCM) in the Upper Bhima basin up to the year 2100 in three different time frames viz 2020-29,2050-59 and 2080-89 at all four grids. In this study RCP 6.0 scenario is considered. RCP 6.0 stand for Representative Concentration Pathway and 6.0 W/m^2 will be radioactive forcing in the year 2100 relative to 1750 [9].

Development of rainfall-runoff model

Rainfall runoff model was developed using MLR, ANN and Wavelet Neural Network (WNN). The inputs to the model were considered as temperature and rainfall at four stations within Upper Bhima basin. The training and testing of the model were carried out by using historical data of temperature, rainfall and stream flow (runoff) at gauging station. The model was evaluated using mean square error criteria. The model which gives least mean square error was selected for prediction of inflow to the reservoir.

Results and Discussion

Results were obtained from the calibration of the three models namely MLR, ANN and WNN. The projected rainfall and temperature were used as input to the calibrated and tested MLR model. The future probable values of inflow were predicted by simulation of the model. From the simulated results, the mean square value was obtained.

Similarly, the inflows are predicted by using optimal ANN model using the inputs as the projected temperature and rainfall from 2006-2100. In WNN model, discrete wavelet transformation was used with various types of wavelets such as Daubechies wavelet of order 4 (DB4), Coiflet-2 and Symhlet-4 wavelet selected as mother wavelet considering the similarity with the time series signals.

The effects of various decomposition levels on model efficiency have in the form of approximations and details also investigated to optimize the result. The optimum result from the discrete wavelet transformation and detail sub signals at different levels explained in the study. The inflow to the reservoir using the three models was compared with the observed values for the period 2006-2015. It is seen in Vinet F explain MLR model is giving comparatively closure results with the observed values and mean square error by the MLR modelgiven by Giorgi (2006) lesser as compared to ANN and WNN model. Therefore, MLR model has been used for the prediction of inflow from 2006 to 2100.

Conclusion

Downscaling technique, the future rainfall and temperature over Upper Bhima basin has been predicted from 2006 to 2100 for three different time periods viz 2020-2029, 2050-59 and 2080-89. Decrease in rainfall from June to August has been observed however there is an increase in rainfall in the months of September to December. Using this predicted temperature and rainfall as input, inflow to the reservoir has been simulated using MLR, ANN and WNN models for three different time periods. Increase in runoff has been observed in September to December, this is because of increase in rainfall have direct impact on runoff. MLR showed better performance according to MSE criteria. These observed changes in inflow pattern have to be considered in reservoir operation schedule. In projection of rainfall and temperature ANN based model performing better than MLR model, this is because of nonlinear relation between predictors and predictands. However, in prediction of reservoir inflow out of three models namely MLR, ANN and WNN, it has been observed that MLR outperformed the other two models. Hence it shows that for prediction of variable use of model depends on the nature of data, any particular model is not suit for the all forecasting results.

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