Future flow scenario of Subansiri River and its Impact on Power Potential of Subansiri Lower Hydro Electric Project

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Abstract: During its course, the river Brahmaputra is joined by important tributaries from the Himalayan ranges of Arunachal Pradesh and Bhutan in the north. Out of these tributaries, the river Subansiri is considered as the major one which contributes around 10% of the total annual discharge of Brahmaputra. The Subansiri river system has its practical importance as it holds high water resources as well as hydropower potential for the country. The change in runoff of the river due to the change in climate will have impact on the performance of the Subansiri Lower Hydrelectric Project (SLHEP). SLHEP is one of the biggest hydroelectric projects under construction in India. It is an interstate project involving Assam and Arunachal Pradesh. The dam site is 2.3 km upstream of Gerukamukh village on Assam/Arunachal Pradesh border across the river Subansiri. The location of dam site on river Subansiri is 27°33′15′′ N latitude and 94°15′30′′ E longitude. The project has a 116m high concrete gravity dam with an installed capacity of 2000MW. The full reservoir level (FRL) of the project is EL 205.0m corresponding to a storage capacity of 1365.0 Mm³ and maximum water level (MWL) is 208.25 m with storage volume of 1470.0 Mm³. The present study aims to analyse the future power potential of SLHEP by using simulation model up to the year 2099 for four different time frames viz. 2020-39, 2040-59, 2060-79 and 2080-99. The future rainfall over the Subansiri basin has been determined using multiple non-linear regression-based statistical downscaling technique.APHRODITE gridded rainfall data available at 0.25° x 0.25° resolutions from 1960 to 2007 at 24 different locations have been used as the predictand and climatic parameters of HadCM3 GCM of resolution 2.5° x 3.75° (latitude by longitude) have been used as the predictors. The predictor selection has been done by Pearson Correlation method. An ANN model was run using the time series analysis to determine the runoff of the river till 2099 and the method selected is the Non-linear Autoregressive with Exogenous Input (NARX). The coefficient of correlation (R) values obtained are 0.94, 0.81 and 0.73 respectively for training, validation and testing phase. It has been found that for the futuretime periods, the runoff shows decreasing trends. The calculated future runoff has been analysed and used as the inflow to the reservoir. Different polynomial equations have been developed to establish the Capacity-Area-Elevation relationships for the reservoir. The constraints considered for the simulation are continuity constraint, reservoir storage constraint and release constraint. From the simulation model, it has been observed that, similar to the future runoff trends obtained from the ANN model, the power potential of the project also shows decreasing trends for all the future time frames. Also, compared to the historical period 1990-2014, for the other future time frames, the power will be decreased continuously from 2020 to 2099. Compared to 1990-2014, the power potential during 2020-39, 2040-59, 2060-79 and 2080-99 will decrease by 19.72%, 23.98%, 28.99% and 29.06% respectively.

Key words: Subansiri, Statistical Downscaling, ANN, NARX

1. INTRODUCTION

Rivers have been altered for human development for many years and it is now almost impossible to find a river that has not been modified for one purpose or another (Sheail, 1988). Dams are one of the major ways where river systems have been directly altered (McCartney, 2009). Construction of dams modifies the downstream flow regime by altering the discharge of a river.

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The river Subansiri is one of the major north bank tributaries of river Brahmaputra. It flows through Tibet for 170 km, 250 km through Arunachal Pradesh after which it enters Assam at Dulangmukh in Dhemaji district and flows for another 130 km through the plains of Assam before it merges with the River Brahmaputra near Jamugurighat in Assam. The Subansiri river system has its practical importance as it holds high water resources as well as hydropower potential for the country. SLHEP is one of the biggest hydroelectric projects under construction in India. It is an interstate project involving Assam and Arunachal Pradesh. The location of dam site on river Subansiri is 27°33′15′′ N latitude and 94°15′30′′ E longitude. The project has a 116m high concrete gravity dam with a surface powerhouse of 2000MW capacity. The river length is approximately 126 km from the dam site to the confluence with Brahmaputra near Jamuguri (Bakalial et al. 2014). The reservoir storage capacity is 1365 Mm³. It is expected that there will be a diurnal variation of the river flow which may have some negative impacts at the downstream. Devastating flood associated with intense rainfall in the upper catchment of Subansiri is a common phenomenon. There is a possibility that the construction of the dam will further increase the downstream discharge leading to the downstream areas more susceptible to flood and erosion.

Apart from that, the change in runoff of the river due to the change in climate will have impact on the performance of the SLHEP. Climate change will cause changes in temperature, precipitation pattern and other climatic variables (Changchun et al. 2008). As per studies, the North-Eastern, Northern and Himalayan regions of India are likely to be severely affected by a stronger warming in the future. Also, as the Subansiri basin is highly influenced by the Southwest monsoon rainfall during May to October, the climate change that results in variation in intensity of the monsoon, will affect both high and low flows in the basin. Accurate estimation of runoff is important for flood forecasting, reservoir operation, watershed management, water supply and design of hydrologic and hydraulic structures. For estimation of direct runoff from a watershed produced by a given precipitation, various models are available. Artificial neural network (ANN) is one of the most simple but robust models for mapping the non-linear relation between rainfall and runoff even though it cannot represent the physical process of the catchment (Hsu et al. 1995). The neural network is one of the tools used for methodological analysis of hydrological forecasting. It can be thought of as a computational pattern that involves searching and matching procedures, which permits forecasting without an intimate knowledge of the physical process.

In this study, an ANN model has been developed to determine the future runoff of the Subansiri river. The ANN model uses the non-linear autoregressive model with exogenous inputs (NARX) network for obtaining the runoff. Chang et al. (2014) developed three ANN models to make forecasts on the evolution of water level at floodwater storage pond (FSP). The results demonstrated that the NARX has higher applicability than the BPNN and the Elman NN. Fereidoon and Koch (2018) applied the NARX neural network to predict continuous rainfall series across the Karkheh river basin, Iran and found that NARX model has a high potential for real-time rainfall prediction. The data derived from Global Climate Model (GCM) have been used to generate the future rainfall over the basin. The rainfall thus predicted had been used to develop rainfall-runoff model for predicting the runoff of the river. Considering this runoff as the inflow to the reservoir, the future power potential of Subansiri Lower Hydroelectric Project has been analyzed using simulation model. Continuity constraint, storage constraint and reservoir release constraint are the three different constraints considered in the model. The results were analyzed for four different future time steps viz. 2020-39, 2040-59, 2060-79 and 2080-99.Fig.1 shows the Subansiri River basin along with the map of India and the Brahmaputra River basin.

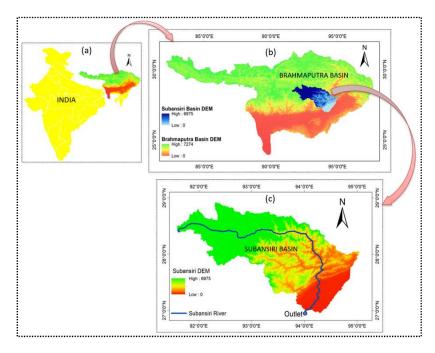


Fig.1 Study area showing (a) India with Brahmaputra basin, (b) Brhamaputra and Subansiri basins and (c) The Subansiri basin

1.1 Principal features of Subansiri Lower Hydroelectric Project

The full reservoir level (FRL) of the project is EL 205.0m corresponding to a storage capacity of 1365.0 Mm³ and maximum water level (MWL) is 208.25 m with storage volume of 1470.0 Mm³. The flood cushion of about 441.6 Mm³ is provided for the period of high inflow like June, July and August months, which the volume between EL 205.0 m and EL 190.0 m. The maximum draw down level (MDDL) is 181.0 m with storage volume of 720 Mm³. Height of dam above river bed level is 116.0 m and from the deepest foundation level is 133.0 m.Maximum tailrace water level is 112.0 m and normal tailrace water level is 108.96 m whereas minimum tailrace water level is 105.0 m. The probable maximum tailrace water level is 122.5 m.

2.MATERIALS AND METHODS

2.1 Data used

Rainfall data:TheAsian Precipitation Highly Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE) daily gridded rainfall data of spatial resolution 0.25° x 0.25° from 1960 to 2007 has been used in this study. In order to carry out spatial analysis, 24 APHRODITE grids were selected over theSubansiribasin. APHRODITE project develops high resolution daily gridded precipitation datasets for Asia(Mitra et al. 2003; Rajeevanet al. 2006). The basic algorithm adopted is based on the model developed by Xie et al. 2007.

GCM parameters:Monthly climate parameters of HadCM3 GCM of A2 scenario available at a spatial resolution of 2.5° x 3.75° (latitude by longitude) have been used as the predictors.A2 scenario represents a very heterogeneous world with continuously increasing global population. The predictors were selected based on correlation coefficient values determined by Pearson Correlation method at all the 24 APHRODITE grids (Barman and Bhattacharya, 2015). Apart from being one of the major models used in the IPCC third (2001) and fourth (2007) assessments, HadCM3 also contributes to the fifth assessment

(2013). The major advantage of the model, at the time it was developed, was its good simulation of current climate without using flux adjustments and it still ranks high compared to other models in this respect (Reichler and Kim 2008). Another advantage of HadCM3 is its capability to capture time-dependent fingerprint of historical climate change in response to natural and anthropogenic forcings (Scott et al. 2000).

Discharge data: Daily discharge data of Subansiri river from 1990 to 2014 at Khabulighat gauge station has been used in this study. The data has been collected from the Water Resources Department, Govt. of Assam.

Data used for the simulation of the reservoir:

- a) Monthly runoff of Subansiri river, simulated by the ANN model up to the year 2099 have been used as the inflow to the reservoir.
- b) Maximum water level (MWL): 208.25m
- c) Full reservoir level (FRL): 205m
- d) Maximum draw down level (MDDL): 181m
- e) Tailrace water level: 108.96m
- f) Dead storage: 720 Mm³
- g) Storage capacity of the reservoir at FRL: 1365 Mm³
- h) Plant capacity: 2000 MW
- i) Efficiency: 90%
- j) Minimum downstream release: 6 m³/s

2.2Methodology

2.2.1 Downscaling of rainfall using statistical downscaling techniques and its prediction

Barman and Bhattacharyra (2015) have carried out a study for predicting the future rainfall of the Subansiri basin. Rainfall at 24 locations over Subansiri catchment had been considered. They used multiple linear and non-linear regression based statistical downscaling techniques and also adopted the ANN model. These techniques were compared on the basis of Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Coefficient of determination (R²), Mean Absolute Percentage Error (MAPE) and Root Mean Square Percentage Error (RMSPE). The study showed thatwith minimum values of all these errors, multiple non-linear regression based downscaling technique outperformed the multiple linear regression and the ANN model. Table 1 shows the average error values for the downscaling techniques. Owing to its better performance, the non-linear regression based statistical downscaling technique has been used to predict rainfall in the Subansiri basin up to the year 2099 for four different time frames viz., 2020-39, 2040-59, 2060-79 and 2080-99 at all the 24 APHRODITE grids.

Errors

Downscaling Methods

	MAE	RMSE	\mathbb{R}^2	MAPE	RMSPE
Multiple Linear Regression	41.88	58.33	0.79	33.81%	48.22%
MultipleNon-linear Regression	37.71	55.04	0.83	29.49%	44.21%
Artificial Neural Network	40.99	56.99	0.81	32.55%	46.23%

Table1. Average values of MAE, RMSE, R², MAPE and RMSPE

2.2.2 Development of the ANN based rainfall-runoff model

To perform the analysis, first the entire Subansiri catchment hasbeen divided into eleven different sub-catchments. Fig.2 shows these sub-catchmentsalong with the APHRODITE rainfall points that fall in each sub-catchment. An ANN model was run using the time series analysis. The method selected is the Non-linear Autoregressive with External (Exogenous) Input (NARX). NARX is a recurrent dynamic network, with feedback connections enclosing several layers of the network (Khamis and Abdullah 2014). The NARX model is based on the linear ARX model and itpredictstimeseries y(t) from past values of that time series and past values of another time series x(t), called the external or exogenous time series (Billings 2013). Mathematically, it can be defined as,

$$y(t) = f(x(t-1), ..., x(t-d), y(t-1), ... y(t-d))(1)$$

For the present study, y(t) is the runoff at the final outlet, x(t) is the average rainfall at each sub-catchment and d represents the tapped delay linesthat store previous values of the x(t) and y(t) sequences. Monthly time series data have been used in the present study. The model was constructed using neural network toolbox in MATLAB 8.3 (R2014a). Testing, training and validation were performed for the period 1990 to 2014, for which observed discharge data are available. Out of the total data, 70% were selected for training and 15% each for validation and testing. The number of neurons in the hidden layer was determined by trial and error method. Based on the coefficient of determination (R) values, the numbers of neurons in the hidden layers selected were 15 and number of delays selected was 1 as the optimum network. The network was created and trained in open loop form. After training, the network was converted to closed loop form for multi-step prediction up to 2099. Closed loop converts neural network open-loop feedback to closed loop. In this study, the monthly runoff has been predicted for four different time frames viz., 2020-2039, 2040-2059, 2060-2079 and 2080-2099 taking 1990-2014 as the base period.

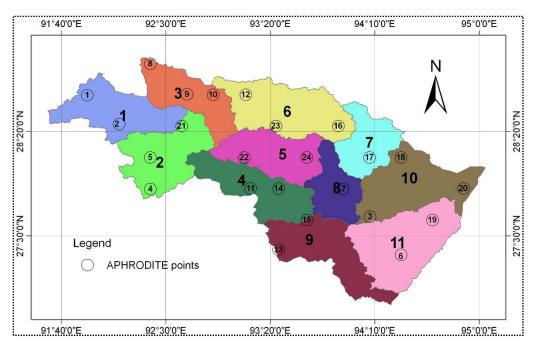


Fig.2The Subansiri basin witheleven sub-catchments

2.2.3 Reservoir simulation model

Reservoir simulation method is the most widely used method because of its mathematical simplicity and flexibility. In case of reservoir operation for hydropower generation of a power

plant that has a storage reservoir, the head, flow and storage are all interdependent (Vedula and Majumdar, 2005). The data required for simulation are, the inflow series at a reservoir; the storage-area-elevation relationship for the reservoir; and, the power plant efficiency.

2.2.3.1 Capacity-Area-Elevation relationship for the reservoir

Fig.3 shows the relationship between reservoir capacity vs. elevation, area vs. elevation, and, reservoir capacity vs. area determined by the method of curve fitting. The polynomial equations developed for the relationships are,

Reservoir capacity and reservoir elevation relationship

Elevation (m) =
$$-5 \times 10^{-5} S_t^2 + 0.130 \times S_t + 112.3$$
 (2)

Where, S_t is the reservoir capacity in Mm³.

Reservoir area and reservoir elevation relationship

Elevation
$$(m) = -0.086 \times A_t^2 + 5.949 \times A_t + 97.06$$
 (3)

Where, A_t is the reservoir area in Mm².

Reservoir capacity and reservoir area relationship

$$Area (Mm^2) = -8 \times 10^{-6} S_t^2 + 0.031 \times S_t + 2.113$$
(4)

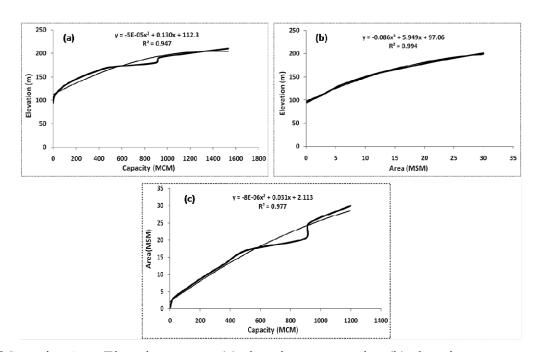


Fig.3Capacity-Area-Elevation curves: (a) elevation vs. capacity, (b) elevation vs. area and (c) area vs. capacity

2.2.3.2 Problem formulation

2.2.3.2.1 Hydropower Generation

The expression for hydropower generation is given by the formula,

$$kWH_t = 2725 R_t H_t \eta (5)$$

For a period of one month, the expression becomes,

$$P = \frac{(2725 \times R_t \times H_t \times \eta)}{(1000 \times 30 \times 24)} \text{MW}$$

$$= 0.003785 R_t H_t \eta \text{ MW}$$
(6)

Thus,

$$R_t = \frac{P}{0.003785H_t\eta} \tag{8}$$

Where,

P= power in MW

 R_t = release to penstock in MCM in period t

 H_t = net head in m in period t

 η = plant efficiency

2.2.3.2.2 Constraints

The following constraints have been considered during the simulation process:

a) Continuity constraint

$$S_{t+1} = S_t + Q_t - R_t - R_m (9)$$

Where,

 S_{t+1} = storage in Mm³ at the end of the time period t or beginning of time period t+1; S_t = storage in Mm³ at the beginning of the period t;

 Q_t = reservoir inflow in Mm³ during the period t;

 R_t = release required in the period t to generate the specified power corresponding to the net head;

 R_m = minimum downstream release = 6 m³/s= 15.55 Mm³.

b) Reservoir storage constraint

Reservoir storage cannot be lowered below the dead storage volume of 720 Mm³. The maximum storage of the reservoir should not be greater than full reservoir level (FRL) volume of 1365 Mm³.

$$S_d < S_{t+1} < S_{max} \tag{10}$$

Where,

 S_d = storage capacity of the reservoir at MDDL= dead storage volume = 720 Mm³; S_{max} = storage capacity of the reservoir at FRL = 1365 Mm³.

c) Release constraint(Rai, M.R., 2010)

Release from the reservoir should be such that at the end of time t the reservoir storage level does not go above FRL.

$$R_{t max} = S_{t-1} + Q_t - S_d - R_m (11)$$

Where,

 $R_{t max}$ = maximum release in time t.

3. RESULTS AND DISCUSSION

3.1 Future average rainfall analysis over the Subansiri basin

The average rainfall of all the 24 APHRODITE points have been calculated and analyzed the future trends of rainfall over the Subansiri river basin for the four different future time steps. Fig. 4 shows the trends of rainfall for (a) 2020-39, (b)2040-59, (c) 2060-79 and (d) 2080-99.

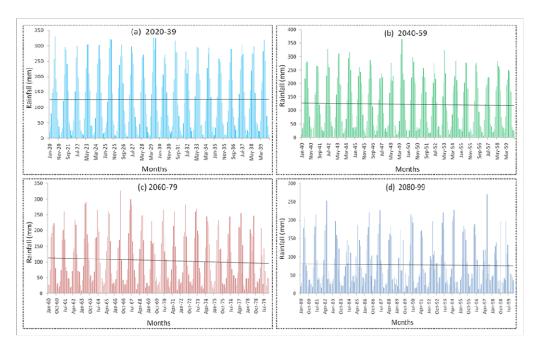


Fig. 4 Trends showing change in average rainfall over Subansiri catchment for in (a) 2020-39, (b)2040-59, (c) 2060-79 and (d) 2080-99

It is seen from the graphs that the rainfall during the period 2020-39 remains almost the same. The linear trend lines for other three timeframes indicate that there will be decreasing trends of rainfall for 2040-59, 2060-79 and 2080-99. There is a possibility that the period 2060-79 will experience the highest decrease in rainfall over the Subansiri River basin.

3.2Runoff analysis for ANN based rainfall-runoff model

The ANN based rainfall-runoff model has been analyzed for future four different time frames. The coefficient of correlation (R) values obtained are 0.94, 0.81 and 0.73 respectively for training, validation and testing phasewith an overall R value of 0.89. R value which are less than 0.35 represents weak correlations, 0.36 to 0.67 represent moderate correlations, and 0.68 to 1.0 represents strong correlations (Weber 1970; Mason 1983). Thus, the overall R value of 0.89 obtained for the model shows a strong correlation between observed and the simulated data. The average runoff predicted for each month for different time periods is presented as bar diagram in Fig.5. It is observed that except for August and September, for the remaining months, runoff for the time frame 2020-39 decreases compared to the base period 1990-2014. Again, compared to 2020-39, the runoff first increases for 2040-59 and then decreases from 2060 to 2099 for January, February, March, April, September, October, November and December. For May, June and August, runoff increases from 2020 to 2099. There is a possibility of occurrence of 5000-6000 cumec of runoff during 2060-79 and 2080-99 for June, July and August.

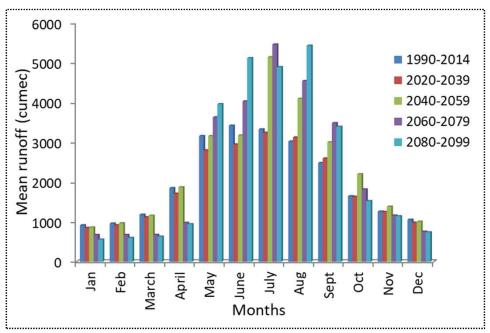


Fig.5Bar diagram representing runoff of Subansiri for different time frames as obtained from ANN based rainfall-runoff model

The above results were for the average runoff value of each month for the entire individual periods. The linear trends of future runoff have also been analyzed for the four different time periods. The trends are shown in Fig.6. It is seen from the plots that no significant change in runoff will occur during 2020-39. However, for other three time periods, the runoff shows a decreasing trend. It is due to the fact that the rainfall during these time periods also showed decreasing trends. Thus, less the rainfall, less will be the runoff and vice versa.

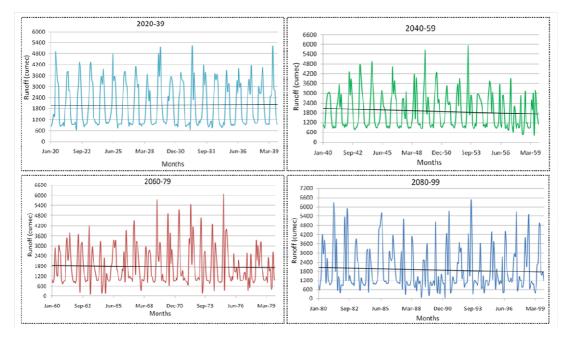


Fig.6 Trends showing future runoff simulated by ANN based rainfall-runoff model for different time periods

3.3Future power potential of SLHEP

The future power potential of the Subansiri Lower Hydroelectric Project has been determined by simulating the reservoir for hydropower generation. The power potential has been determined for the four different time frames. Fig.7 shows the power in MW determined for the different time periods.

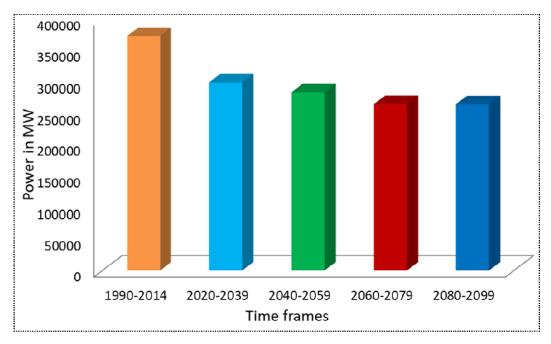


Fig.7 Future power obtained at different time frames for SLHEP

Compared to the historical period 1990-2014, where power obtained during this period was 372982 MW, the future power obtained for SLHEP will gradually decrease from 2020-2099. Power obtained for 2020-39, 2040-59, 2060-79 and 2080-99 are, 299414MW, 283533MW, 264851MW and 264590MW respectively. From this analysis it can be said that, as compared to 1990-2014, the power potential during 2020-39, 2040-59, 2060-79 and 2080-99 will decrease by 19.72%, 23.98%, 28.99% and 29.06% respectively.

Trend analyses have been done for these future time steps as shown in Fig.8. It can be observed that for each of the time period, the power potentials show decreasing trends. The runoff for these period also showed decreasing trends. This runoff has been used as the inflow to the reservoir Hence, because of the decrease in inflow, the power generation also decreases.

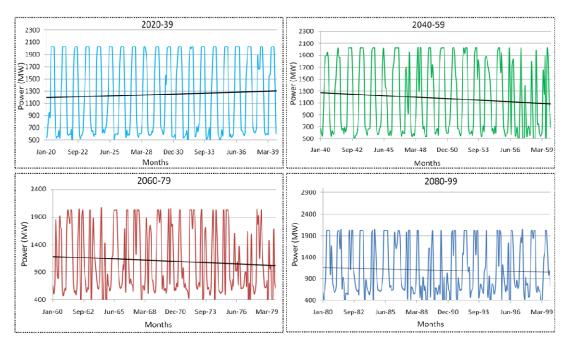


Fig.8 Trend analysis of future power potential of SLHEP

4.CONCLUSIONS

In this study, using this multiple non-linear based statistical downscaling technique, the future rainfall over Subansiri basin has been predicted up to the year 2099 for four different time frames viz. 2020-39, 2040-59, 2060-79 and 2080-99. No significant change has been observed for the period 2020-39, while for the other three timeframes, the rainfall show decreasing trends. Using this predicted rainfall as the input, the runoff of Subansiri River has been simulated using an ANN model. Decreasing trend of runoff of Subansiri have been observed for the four different time frames which is because rainfall have direct impact on runoff and rainfall over the basin also showed decreasing trends in future. The future power potential of Subansiri Lower Hydroelectric Project has been analyzed using simulation model. Continuity constraint, storage constraint and reservoir release constraint are the three different constraints considered in the model. This runoff has been used as the inflow to the reservoir for the simulation. It has been observed from the study that, the future power potential of SLFEP decreases for all the four time periods compared to the base period 1990-2014.

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