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ANALYSIS OF CLIMATE CHANGE IMPACT ON RESERVOIR STORAGE USING SDSM TOOL: A CASE STUDY of GANGAPUR DAM, NASHIK, INDIA

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ABSTRACT

Climate change has a great impact on the agriculture sector. Nashik is one of the important districts in India concerning the agriculture and horticulture production. In Nashik district due to climatic changes agricultural and horticultural crops affected much because of insufficient storages in the reservoir. Gangapur is one of the important dams of Nashik district with 15, 960 hectors land under its command area. Because of variations in rainfall, Gangapur reservoir shows variation in its storage. Hence, it is necessary to know the future rainfall and possible changes in the storages. Dam storage is a function of rainfall, runoff, infiltration, catchment characteristics, evaporation, etc. However, for rough estimation of dam storage in future, based on the rainfall occurrences, it is tried to correlate the dam storage with rainfall. Using the approach of regression analysis, the correlation between rainfall and storage is developed using the data during 1971 to 2012. There after climate variations during 2017 to 2050 are predicted using SDSM tool to get a brief idea about future rainfall and associated storage. To calibrate and validate the model, past climatic data is collected from Indian Metrological Department (IMD) is used in the present study. The Representative Concentration Pathways adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014 has been used for forecasting the future climate scenario. Trend analysis is carried out using Mann Kendal Test and Sen's Slope Test. Obtained result shows the mix trends in maximum temperature under three RCPs. Whereas, rainfall shows decrease in precipitation under all three RCPs. Accordingly, the storage trend of Gangapur reservoir shows decreasing trend under all three RCPs up to 2050.

Keywords: Climate Change, Agriculture, SDSM, Scenarios, RCP.

1. INTRODUCTION

Nashik is the uppermost agriculture and horticulture producer district in India. The socio-economic development of the rural area of the Nasik district is mostly depending on the grape crop due to its export potential. In the year 2016, India exported 1, 56,218 metric tons of the grapes to European and Arabian countries which cost the amount of 15513 Million Indian Rupees. There is the 2 % export contribution of the grape crop among all fruits cultivated in India, out of that 90 % grapes are export only from the Nashik district (APDEA).

Globally, impact of climate change shows decrease in precipitation and increase in temperature (IPCC, 2007). In the Indian subcontinent, large variations are observed in the precipitation occurrences. Due to the variations and lager gap in precipitation occurrences, there are chances of having metrological drought, agricultural drought, and hydrological drought. There is continued to be intense disputes on whether climate change is the art of a natural cycle or due to human activities (Bowden, W. B., 1986). The complex nature of the climate system and our incomplete understanding of working, certainly raise questions and misgivings on any definitive interpretation and the conclusion of climate change (Hunink J.E., 2010).

Change in climate has become the burning issue among the global scientific community since the last two decades because of its potential serious impacts on human, environment and society, as per report of the Intergovernmental Panel Climate Change (IPCC 2013). It was found the rise of 0.85°C in the average global temperature since 1880 until 2012 (IPCC 2013). It was reported that such system of climate change will have a strong effect on regional and local hydrological systems in many regions (Dibike and Coulibaly 2002, Hu et al. 2006).

Several climate prediction models are reported in the literature. General circulation models (GCMs) were reported to acquire climate data on the global scale or large scale. The Representative Concentration Pathways (RCPs) are new scenarios and it is the latest iteration of the scenario process. These are four pathways such as RCP 8.5, 6, 4.5, and 2.6. The last is stated to as RCP3-PD (PD is Peak and Decline and numbers denote forcing for every RCP). The RCPs were developed using the combined efforts of the researchers from different disciplines involved in climate research (Van Vuuren, et. al. 2011). They were named based on the radiative forcing target 8.5, 6, 4.5 and 2.6 W/m^2, levels of the 21st century end. All Representative Concentration Pathway (RCP) were expressed the subsequent radiative forcing and specific emission path (Wayne 2013).

Due to coarser resolution of GCMs, it becomes essential to demonstrate this data to regional or local scale. There are the large number of such models are available, which explore the relationship between large scale to local scale. In this study to predict future climate, statistical downscaling models (SDSM) is used (Wilby R.L. 2002) and the trend analysis is carried out using Mann Kendal Test and Sen's Slope Test. Using SDSM different climate scenarios under different climatic conditions are possible to generate. In this paper climate change impact is studied particular on the Gangapur dam.

2. MATERIALS AND METHODS

2.1 Details of Gangapur Dam and Data Collection

Gangapur dam is locate at Latitude 20^{o}38'N, Longitude 73^{o}19'E, and it is an earthen dam constructed during 1954 to 1963. The total catchment area of the dam is 357.4 Sq.km and average annual rainfall is 1766 mm. The total dam length is 3810 m. and maximum height of the dam is 36.57m. The total Gross storage of the dam is 215.88 MCM and total live storage is 203.76 MCM, Submergence Area 2231Ha. The length of the waste weir is 102 m. There are total 9 radial gates of size (9.15 x 6.10 m.) having the discharge capacity of 2294 cumec. The dam has two canals, the left bank canal is 64 Km. long and right bank canal is 30 Km. long. The total irrigable area of this dam is 15960 Ha. Due to deposition of silt storage capacity of Gangapur Dam is reduced to 15.94 MCM also due to increase in residential zone (civilization) in command area of Nashik, Right Bank canal is closed since 2006. That land is given to Nashik Municipal Corporation for laying pipeline for drinking water from Gangapur Dam to the city. The water from Gangapur Dam is used for irrigation through Left Bank canal, domestic purpose of Nashik Municipal Corporation and industrial purpose M.I.D.C. Satpur, and Thermal Power station Eklhare.

The local scale observations are taken at the IMD station situated at Nashik, Maharashtra, India with station index no. 92921. The input data to the SDSM model or the local observation point attribute are the observed maximum temperature and precipitation at the Indian Meteorological Department (IMD) station situated at the Nashik, Maharashtra and the coordinates of the station is in between 20^{0}04'19" N latitude and 73^{0}54'05" E longitude. SDSM (Statistical Downscaling Model) 4.2.9 is used in the present study to downscale the future climate scenario. This tool is freely available for evaluating the local effect of climate change with the help of statistical downscaling robust technique. The model can be downloaded from http://co-public.1boro.ac.uk/cocwd/SDSM/ website with the registered e-mail address.

2.2 Observed Data Sets

Observed minimum temperature, maximum temperature, and daily precipitation data collected from IMD (India Meteorological Department), Pune for the single index station (Nashik, index no. 92921). The data during the period 1976 - 2005 is being used in the present study.

2.2.1 Structure of predictor files

The text file of one column per grid (box) obtained with the long-term standardized daily value of the time series. According to the T42 Gaussian grid, 128 x 64 grid cells are covering global domain. This grid is even closely even with latitude 2.8125° and along with the horizontal resolution of 2.8125° longitude. The predictors related to all grid cells are denoted using the consistent folder “BOX_iiiXjjY”, where longitudinal denoted as iii and latitudinal index denoted as jj. This folder consist five sub-folder; three of them included RCP 8.5, 4.5, and 2.6 data for duration 2006-2100 and other two included NCEP-NCAR data for the duration 1961-2005 and CanESM2 historical data for the same duration respectively. Each sub-folder mentioned above contains 26 types of CanESM2 predictors. Time series data of each scenario whether it is historical or future scenarios are already normalized except surface wind direction (thgl). The longitude and latitude coordinates belong to the grid box center. The organized predictors are ready towers this way to use as data input in models of statistical downscaling.

2.2.2 Data used in calibration and validation

The 26 atmospheric variables have been used during validation and calibration of the Statistical downscaling model, that have downloaded from the internet site http://www.cccsn.ec.gc.ca/?page=pred-canesm2. The geographical extent BOX_027X_ 41Y has been selected to the cover area with clear effect on the patterns of circulation that govern the observed weather pattern in the area of research study.

2.2.3 Data used in scenario generation

After validation and calibration of model, SDSM has been used to downscale the large scale Canadian Earth System Second Generation Model (CanESM2) predictor variables derived using the CMIP5 model output comprises scenario experiments for RCP 8.5, 4.5, and 2.6 from 29 climate models. These representative concentration pathways are available to the duration 2006-2100. Only experiments of driven concentration are applied and simply the single collaborative member among each selected model. A snapshot of the study area with latitude and longitude coordinates to retrieve the grid cell of predictors taken from the site www.cccsn.ec.gc.ca/?page=pred-canesm2.

2.3 Methodology

The adopted methodology in the present study is carried out in five steps. These are (1) obtaining observed climate data and missing data analysis, (2) using GCMs generating future climate scenarios, (3) establish the statistical relationship between GCM data and observed data, (4) generating future scenario based on established statistical relationships and (5) trend analysis for future scenarios. The detail insight on the methodology is described here under in Figure 1.

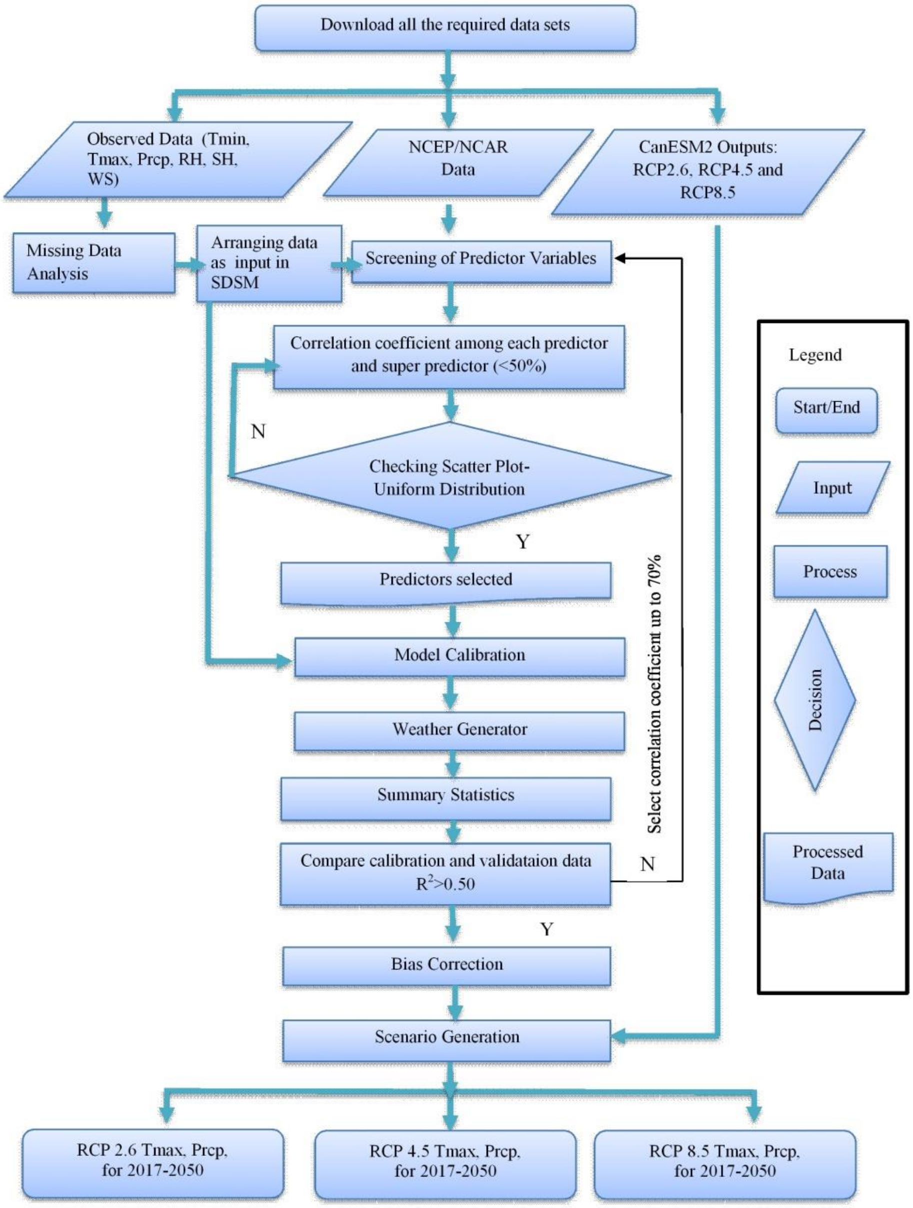

Figure 1: Flow chart of SDSM

2.4 Trend Analysis Using Mann-Kendall Test

When a time series data value x_i is assumed to follow the model then Mann-Kendall test is useful (Gilbert 1987) Equation (1).

$$x_i=f(t_i)+\mathcal{E}_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here f(t) represent the decreasing function of time or continuous monotonic increasing, εi represent the zero mean distribution.

2.5 Trend Analysis Using Sen's Slope Trend Analysis Method

To estimate the true slope, Sen's nonparametric method is used of an existing trend (as per year change). Wherever the trend may be expected to be linear in these cases the Sen's method can be applied. Hence, f(t) Eq.2 is equivalent as;

$f(t)=Qt+B$……………………………………………….(2)

Here Q represents the slope, t represents the time, and B represents a constant. For getting the Q slope estimation with the equation, first it is analyzed all the data value pair slopes using Eq.3;

$$Qi = \frac{x_j - x_k}{j-k} \quad \text{………………………..………...………………(3)}$$

Here j>k if in the time series, there are n values x_j then it gets as the slope estimates Qi and N= n(n-1)/2. These median of N values of Qi calculated using Sen's slope estimator.

3. RESULTS AND DISCUSSIONS

3.1. Trends Analysis of Maximum Temperature

The projected climate scenario is generated using SDSM. The plot of projected Tmax during 2017 to 2050 under RCP 2.6 scenario is shown in Figure 2.

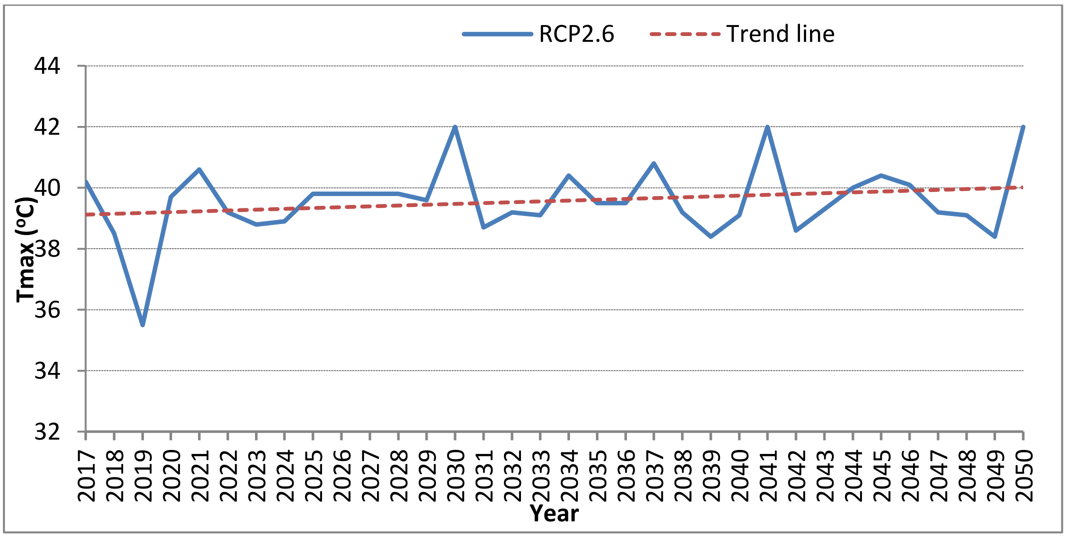

Figure 2: Projected annual mean Tmax during 2017 to 2050 under RCP 2.6 scenario

According to Figure 2, the projection showed the increasing trend of maximum temperature under RCP 2.6 scenarios. Maximum temperature shows the highest value of 42.0 ^{o}C in year 2030, 2041and 2050 and lowest value of 35.2 ^{o}C in year 2019. Maximum temperature shows the highest variation of -6.12 % in year 2019 with respect to trend line. The plot of projected annual mean Tmax during 2017 to 2050 under RCP 4.5 scenario is shown in Figure 3.

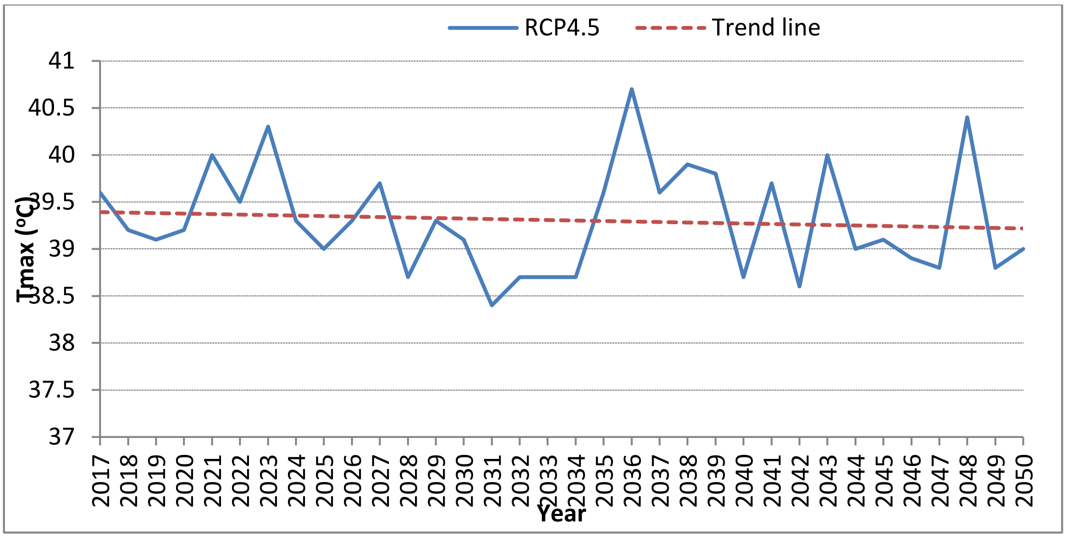

Figure 3: Projected annual mean Tmax during 2017 to 2050 under RCP 4.5 scenario

According to Figure 3 the projection showed the decreasing trend of maximum temperature under RCP 4.5 scenario. Maximum temperature shows the highest value of 40.7 ^{o}C in year 2036 and lowest value of 38.4 ^{o}C in year 2031. Maximum temperature shows the highest variation of 3.1 % in year 2036 with respect to trend line. The projected climate scenario is generated using SDSM. The plot of projected annual mean Tmax during 2017 to 2050 under RCP 8.5 scenario is shown in Figure 4.

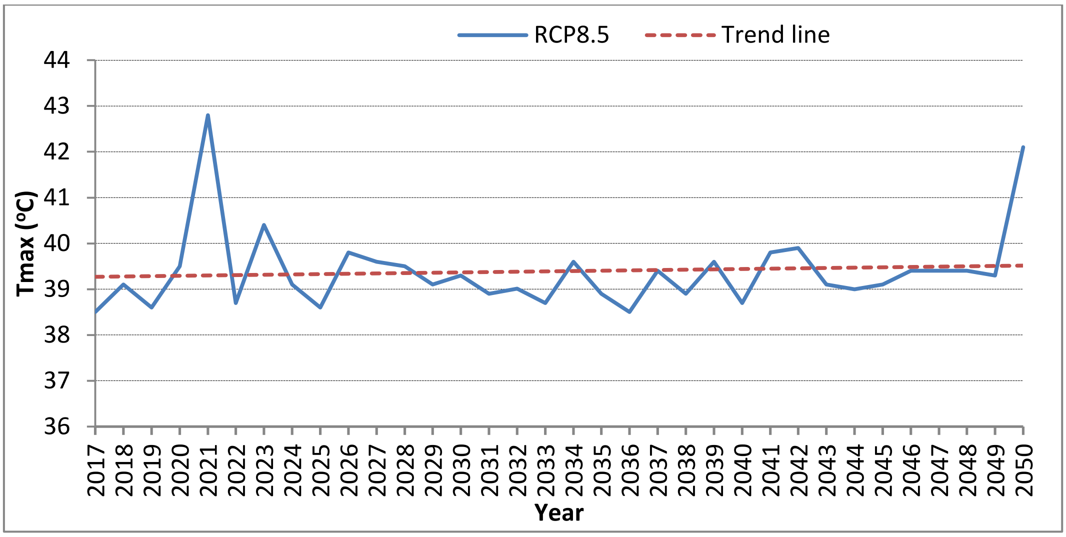

Figure 4: Projected annual mean Tmax from 2017 to 2050 under RCP 8.5 scenario

According to Figure 4 the projection showed the increasing trend of maximum temperature under RCP 4.5 scenarios. Maximum temperature shows the highest value of 42.9 ^{o}C in year 2021 and lowest value of 38.5 ^{o}C in year 2017. Maximum temperature shows the highest variation of 7.6 % in year 2021 with respect to trend line. The details of statistical results of MK test and SS test at significance level for the different time series are given in Table 1.

Table 1: The Mann-Kendall's and Sen's slope test results for projected maximum temperature (2017-2050).

Variables	Maximum Temperature (°C)											
Scenarios	RCP2.6				RCP4.5				RCP8.5			
Test	Mann Kendalls		Sen's Slope		Mann Kendalls		Sen's Slope		Mann Kendalls		Sen's Slope	
Time Series	Z_{cal}	Trend	Q_{med}	Trend	Z_{cal}	Trend	Q_{med}	Trend	Z_{cal}	Trend	Q_{med}	Trend
January	0.00	o	0.00	o	4.04	↑	0.56	↑	0.00	o	0.00	o
February	1.63	↑	1.19	↑	0.67	↑	0.03	↑	0.61	↑	0.35	o
March	1.52	↑	0.23	↑	-1.15	↓	-0.35	↓	3.09	↑	0.92	↑
April	1.42	↑	1.26	↑	-1.74	↓	-0.92	↓	-3.37	↓	-0.79	↓
May	-1.19	↓	-0.34	↓	-1.43	↓	-1.48	↓	0.00	o	0.00	o
June	-1.90	↓	-0.08	↓	-4.46	↓	-1.14	↓	2.22	↑	1.24	↑
July	-2.65	↓	-0.01	↓	-2.96	↓	-0.21	↓	-1.45	↓	-0.12	↓
August	1.43	↑	0.34	↑	-4.98	↓	-0.41	↓	0.00	o	0.00	o
September	-0.73	↓	-0.14	↓	0.77	↑	0.39	↑	1.24	↑	1.18	↑
October	-9.03	↓	-0.84	↓	-5.65	↓	-0.07	↓	2.39	↑	1.01	↑
November	0.85	↑	1.04	↑	-0.82	↓	-0.03	↓	-1.21	↓	-1.69	↓
December	-0.53	↓	-2.15	↓	-1.15	↓	-0.81	↓	0.43	↑	0.69	↑
Symbols: ↑ = Increasing Trend, ↓ = Decreasing Trend, o = No Trend												

According to Table 1, the Mann-Kendall's and Sen's slope test are showing different results for the projected maximum temperature. According to the obtained trend of projections which showed the increasing trend of maximum temperature during February to April, August and November month in RCP 2.6 scenarios. According to RCP 2.6, the Z_{cal} value is higher 1.63 in February month and lowest -9.03 in October month and Q_{med} value is higher 1.26 in April month and lowest -2.15 in December. According to RCP 4.5 the Z_{cal} value is higher in 4.04 in January month and lowest -5.65 in October month and Q_{med} value is higher in 0.56 in January month and lowest -1.48 in may month. According to RCP 8.5 the Z_{cal} value is higher in 3.09 in March month and lowest -3.37 in April month and Q_{med} value is higher in 1.24 in June month and lowest -1.69 in November month.

3.2 Trend of Annual Rainfall and Reservoir Storage

There is always relationship between rainfall, runoff and reservoir storage (Yanlong Kong et al). Dam storage is calculated using factors like runoff, infiltration, and evaporation etc. of catchment area, but in this study it is tried to correlate the rainfall and storage with each other. In case of Gangapur dam the relation between the rainfall and storage is found using the data since 1971 to 2010 by using regression analysis (Gupta S.G., 1981) for which R square value is 0.83. The relationship obtained between rainfall and percent storage of Gangapur dam is shown in Eq. (4).

$$S=0.070R+26.66 \quad \ldots\ldots(4)$$

Where, S is storage of dam (%) and R is Rainfall (mm). The projected climate scenario for rainfall is found using SDSM and dam storage using Eq. (4). The plot of projected annual rainfall and dam storage from 2017 to 2050 under RCP 2.6 scenario is shown in Figure 5.

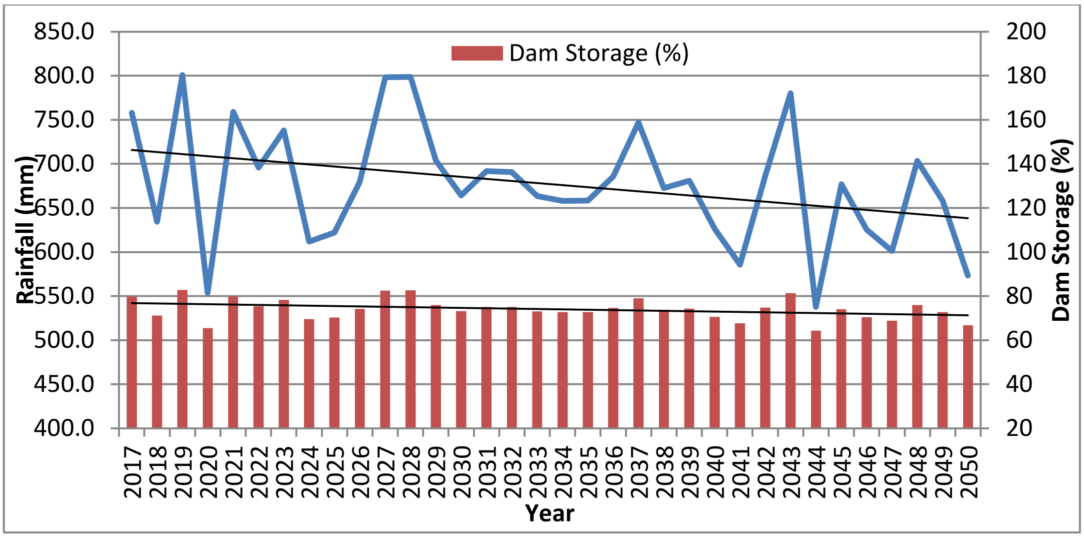

Figure 5: Projected annual cumulative rainfall and reservoir storage from 2017 to 2050 under RCP 2.6

According to Figure 5 the projection showed the decreasing trend of annual rainfall under RCP 2.6. Annual rainfall shows the highest value of 800 mm in year 2019, 2027 and 2028 and storage also more than 80 % in those years and lowest value of 535 mm and dam storage is 65% in year 2044. Annual rainfall shows the highest variation of 21 % in year 2020 with respect to trend line. The plot of projected annual rainfall during 2017 to 2050 under RCP 4.5 is shown in Figure 6.

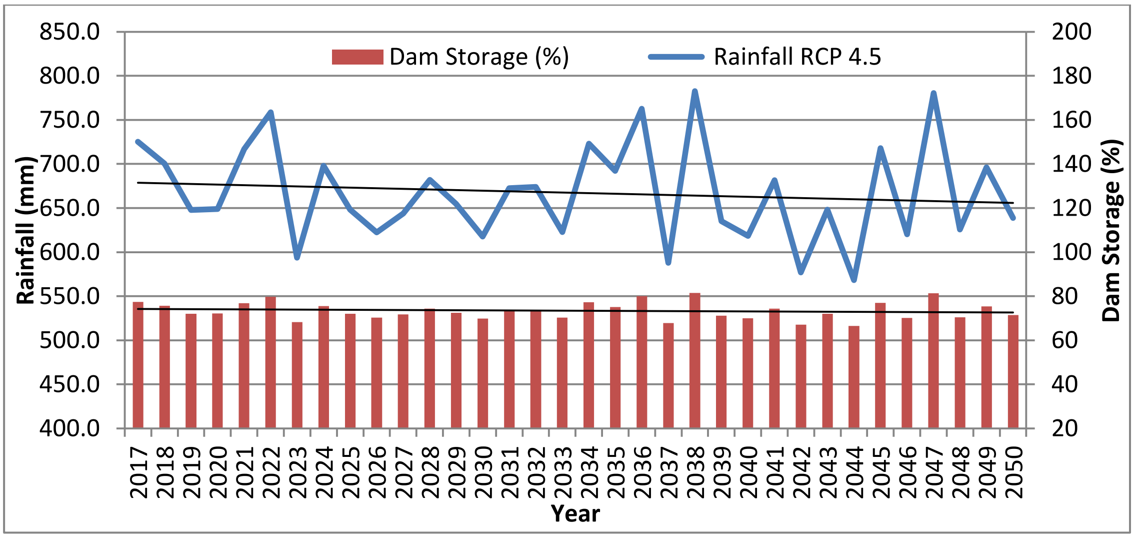

Figure 6: Projected annual cumulative rainfall and reservoir storage from 2017 to 2050 under RCP 4.5 scenario

According to Figure 6 the projection showed the decreasing trend of annual rainfall under RCP 4.5 scenarios. Annual rainfall shows the highest value of 780 mm in year 2038, and 2047, hence dam storage more than 80 % in those years and lowest value of 555 mm in year 2044; hence dam storage is 66 %. Annual rainfall shows the highest variation of 26 % in year 2038 with respect to trend line. The graph of projected annual rainfall from 2017 to 2050 under RCP 8.5 scenario is shown in Figure 7.

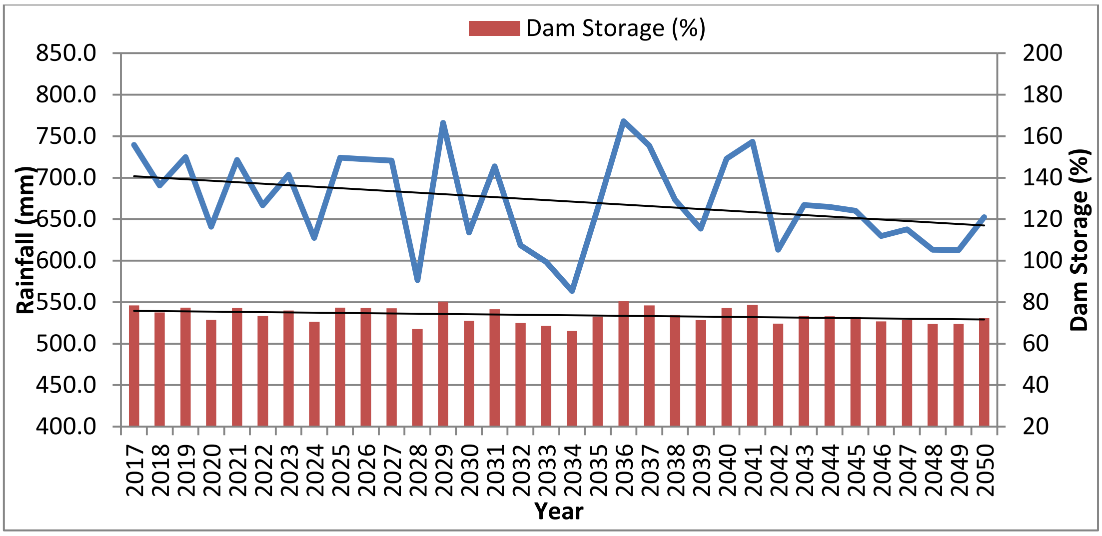

Figure 7: Projected annual cumulative rainfall and reservoir storage from 2017 to 2050 in RCP 8.5 scenario

According to Figure 7 the projection showed the decreasing trend of annual rainfall under RCP 8.5 scenarios. Annual rainfall shows the highest value of 760 mm in year 2029, and 2036, hence dam storage near to 80 % in those years and lowest value of 560 mm in year 2034 hence dam storage is 66 %. Annual rainfall shows the highest variation of -18 % in year 2034 with respect to trend line. The details of statistical results of MK test and SS test at significance level for the different time series are given in Table 2.

Table 2: The Mann-Kendall's and Sen's slope test results for the different series of time for projected Rainfall

Variables	Rainfall (mm)											
Scenarios	RCP2.6				RCP4.5				RCP8.5			
Test	Mann Kendalls		Sen's Slope		Mann Kendalls		Sen's Slope		Mann Kendalls		Sen's Slope	
Time Series	Z_{cal}	Trend	Q_{med}	Trend	Z_{cal}	Trend	Q_{med}	Trend	Z_{cal}	Trend	Q_{med}	Trend
January	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o
February	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o
March	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o
April	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o
May	2.06	↑	2.44	↑	0.00	o	1.44	↑	1.11	↑	0.84	↑
June	-0.80	↓	-2.98	↑	0.39	↑	6.74	↑	-0.26	↓	-9.67	↓
July	-0.56	↓	-0.46	↓	0.00	o	-0.46	↓	-0.52	↓	-0.73	↓
August	-1.55	↓	-0.24	↓	-2.71	↓	-0.37	↓	0.00	o	0.00	o
September	0.39	↑	1.53	↑	-0.26	↓	-1.82	↓	-0.30	↓	-0.19	↓
October	-2.58	↓	-0.87	↓	1.86	↑	1.47	↑	0.00	o	0.94	↑
November	-1.39	↓	-0.10	↓	0.88	↑	0.20	↑	2.47	↑	0.07	↑
December	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o	0.00	o
Symbols: ↑ = Increasing Trend, ↓ = Decreasing Trend, o = No Trend												

According to Table 2 the Mann-Kendall's and Sen's slope test are shows unequal results with the projected annual rainfall. According to RCP 2.6 the Z_{cal} value is higher 2.06 in May month and lowest -2.58 in October month and Q_{med} value is higher in 2.44 in May month and lowest -2.98 in June. According to RCP 4.5 the Z_{cal} value is higher in 1.86 in October month and lowest -2.71 in August month and Q_{med} value is higher in 6.74 in June month and lowest -1.82 in September month. According to RCP 8.5 the Z_{cal} value is higher in 2.47 in March month and lowest -0.52 in April month and Q_{med} value is higher in 0.94 in October month and lowest -9.67 in June month.

4. CONCLUSION

The Statistical Downscaling Model (SDSM) is found suitable tool to predict the future climate. Performance of the SDSM model is found to be satisfactory. The set of recent scenarios like RCP 2.6, RCP 4.5, and RCP 8.5 are available and used in this study to generate the future climatic scenarios. Non-parametric tests like M-K test and S-S test have been used suitably for the trend detection of the future time series data. The projection showed the increasing trend of maximum temperature under RCP2.6and RCP 8.5 and decrease in RCP 4.5 scenarios. The projection under RCP2.6 RCP 4.5 and RCP 8.5 showed the decreasing trend of annual precipitation and accordingly, decreasing trend of Gangapur dam storages. As compare to the year 2017, under RCP 2.6, rainfall showed the decrease of 9.86 % up to the year 2050 whereas dam storage decreases up to 7.69 %. Under RCP 4.5 rainfall showed decrease up to 1.39 % and dam storage decrease up to 1.32 %. Whereas under RCP 8.5 rainfall showed decrease up to 8.57 %, and dam storage decrease up to 6.49 %. It can be concluded from the present study that, in future, storage in the Gangapur dam is about 83%.

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