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ASSESSMENT OF WATER AVAILABILITY IN A RIVER BASIN OF INDIA FOR CHANGING CLIMATE

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ABSTRACT

This study narrates impact of changing climate on hydrologic behavior of a sub basin of Subarnarekha river (in eastern region of India) using hydrologic model HEC-HMS, HEC, USA and future climate projection. The climate projections are based on the data corresponding to IPCC - SRES A1B emission scenario (for 2022-2031, 2040, 2050) generated at IITM, Pune, using PRECIS (a Regional Climate Model) for the Indian region with lateral boundary conditions of three QUMP (Quantifying Uncertainty in Model Projections) simulations (Q0, Q1 and Q14) as available from Hadley Centre, UK. The work revealed increase of annual rainfall and corresponding increase of annual streamflow, increase of potential evapotranspiration for months viz., March to June and September to November for all the simulations. Increase of annual maximum 24-h rainfall and corresponding increase in annual maximum flow and occurrence of peak flow shifting from monsoon months to April or May or June or end of October or November were also noted.

KEYWORDS

Climate change, Hydrology, Streamflow, Precipitation, Evapotranspiration.

1. INTRODUCTION

Anthropogenic interventions triggering climate change may alter hydrological characteristics on region basis by changing hydrological cycle and quantum and frequency of extreme events (both drought and flood) (IPCC, 2007, 2013). South-east Asia (inclusive of India), which is abode of socio-economically under-privileged population, turns out to be vulnerable to changing climate and resulting detrimental socio-economic impact. In this background this work reports impact of changed climate on water arena of a sub basin of Subarnarekha river (flowing through eastern region of India) using HEC-HMS model (HEC-HMS 3.4, developed by HEC, USA (HEC 2000) and future climate scenario, as provided by IITM, Pune.

A high-resolution regional climate model PRECIS, developed by the Hadley Centre, UK was run at the IITM, Pune, at 50 km × 50 km resolution over south Asia for A1B scenario in order to develop climate change scenario for a period of 1961–2098 for impact assessment studies. An ensemble of future scenario was generated by running the regional climate model (RCM) using lateral boundary conditions (LBC's) of three QUMP (quantifying uncertainty in model projections) simulations (Q0, Q1 and Q14) as available from Hadley Centre, UK. A part of the above noted data for our study area for the baseline (1985-1990) and future period (2022-2031, 2040, 2050) was used for this study. The changes in rainfall, evapotranspiration, and stream flows for future period compared to baseline period have been investigated.

Works related to our study topic which have been executed by various workers are narrated here. Mittal et al. (2013) assessed impact of extreme climate over Kangsabati River basin (India) using data from four Regional Climate Models for future period of (2021–2050) and reported intensification of most of the extreme events. Using data from four Regional Climate Models (driven by a number of General Circulation Models) for 2021–2100, Arampatzis et al. (2018) reported significant decrease of availability of water in Pinios River Basin in Greece. Peraza-Castro et al. (2018) evaluated single and dual effects of changing a climate and deforestation on seasonal and annual streamflow, suspended particulate matter and particulate organic carbon for Oka river basin in Basque country. The results showed a reduction in rainfall, discharge, suspended particulate matter and particulate organic carbon load and increase of mean temperature under RCP 4.5 and RCP 8.5 scenarios in comparison with baseline scenario.

Oliveira et al. (2019) assessed climate change impact in upper basin of Paranaíba river (Brazil) using SWAT model, ensemble climate model and four Regional Climate Models streamflow and sediment loads and concluded that monthly streamflow to be reduced and change in sediment loads following pattern of streamflow projections. Pokhrel et al. (2019) concluded increase in precipitation, surface flow and actual evapotranspiration for upper catchment of Kase River basin using (data of Regional Climate Model for 2081–2100. They have further reported decrease of surface flow and increase of actual ET for scenario comprising

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increased mean monthly air temperature by 3 °C with unchanged precipitation at the end of twenty-first century.

2. STUDY AREA

The Subarnarekha River, an east flowing inter-state river, originates in Ranchi district (23°18'N, 85°11'E, elevation 740 m) of Jharkhand. The river is about 450 km long. The principal tributaries of the river are Raru, Kanchi, Kharkai and Karkari and Dulung. The basin lies between latitudes 21°33'N to 23°32'N and longitudes 85°09'E to 87°27'E. It is surrounded by Chhotanagpur Plateau (in North-West), Brahmani basin (in South-West), in Burhabalang basin (in South) and Bay of Bengal (in South-East). The average annual rainfall for the basin is around 1400 mm. The area of basin is 19,296 km², covering 0.6% of geographical area of the country. The annual yield of water within the basin constitutes about 0.4% of total surface water resources of India. Utilizable water resources (annual) of the basin have been reported to be 9.66 km³ (CWC, 1988). The basin of the river from point of genesis to Jamshedpur and measuring 10,197.83 km² and lying between latitudes 23°18'N and 22°53'N and longitudes 85°11'E and 86°02'E forms the study area for the present work (Fig. 1).

Figure 1: Subarnarekha basin

3. MATERIALS AND METHOD

Hydrologic model was developed for the study subbasin using HEC-HMS model. This was reported in the work (Jana et al., 2018). This calibrated hydrologic model was used for this study. HEC-HMS model simulates precipitation-runoff process of watershed by disintegrating hydrologic cycle in pieces (Chatterjee et al., 2104). Many common methods of hydrology have been considered in the model (Jana et al., 2015). Input to model comprises rainfall, temperature, soil and land use data. Daily rainfall, temperature, relative humidity, actual sunshine hours and wind speed data for Q0, Q1 and Q14 simulations for the study area were collected for 2022-2031, 2040 and 2050 from IITM Pune.

4. RESULT AND DISCUSSIONS

4.1 Rainfall

Figure 2 shows the annual rainfall for baseline and projected (2022-2031) years under Q0 simulation. The annual rainfall values for the years 2022, 2024, 2025, 2029 and 2030 are found to be higher than the baseline value with the highest value amounting 1723 mm in 2022 followed by 1580.11 mm in 2030.

Figure 3 shows the annual rainfall for baseline and future years of 2022 (mean of 2022-2031 has been considered for Q0 simulation only), 2030, 2040 and 2050 under Q0, Q1 and Q14 simulations. The annual rainfall for Q0 simulation is found to be higher than the other two simulations in 2022 and 2030 and it is higher than Q1 simulation and lower than Q14 simulation in 2040 and 2050.

Figure 2: Annual rainfall for baseline and 2022 - 2031 under Q0 simulation

Figure 3: Annual rainfall for baseline and future years under Q0, Q1 and Q14 simulations

As per Q1 simulation the highest annual rainfall year is 2030 followed by 2022. For Q14 simulation the highest rainfall year is 2050 followed by 2040. The Q1 simulation projection for annual rainfall is lesser than baseline quantum for the future years. The highest annual rainfall was noted to be 1605 mm in 2050 under Q14 simulation and the lowest was noted to be 661.3 mm in 2040 under Q1 simulation among the three simulations. Figures (4-6) illustrate the deviation (%) in average monthly rainfall for Q0, (for 2030 (mean of 2022-2030), 2040 and 2050), Q1 (2030, 2040 and 2050) and Q14 (2030, 2040 and 2050) simulations with respect to baseline monthly rainfall. It is found from the Fig. 4 (Q0 simulation) that there is very small deviation (positive or negative from the historical value) of rainfall values for February, March, April, June, for all the projected years. The highest increase (388%) in rainfall is found for the month of October of 2040 followed by the second highest increase (271%) in the month of May of 2030. For Q1 simulation, a noticeable increase has been found for August and September of 2030 and 2040 and October of 2030 with the highest deviation (97%) in September followed by that in August (95%) in 2040.

For Q14 simulation, the deviation of monthly rainfall of all the projected years for the monsoonal period (December-May) has been found to be very small. A noticeable increase in monthly rainfall has been found in October (1258%) in 2040 and June (1211%) of 2050 under Q14 simulation. The quantum of 24-hr maximum rainfall for the years (2022-2031, excepting 2030) for Q0 simulation, are found to lie between the corresponding historical highest and lowest values. For the year 2030, the annual 24-h maximum rainfall is projected to be the highest among the projected year (2022-2031) for Q0 simulation (Fig. 7).

Figure 4: Deviation in average monthly rainfall for Q0 simulation with respect to baseline average monthly rainfall (Jamshedpur)

Figure 5: Deviation in average monthly rainfall for Q1 simulation with respect to baseline average monthly rainfall (Jamshedpur)

Figure 6: Deviation in average monthly rainfall for Q14 simulation with respect to baseline average monthly rainfall (Jamshedpur)

Figure 7: Annual 24-h maximum rainfall for baseline and 2022-2031 under Q0 Simulation

Figure 8: Annual 24-h maximum rainfall for baseline and projected years under Q0, Q1 and Q14 simulations

4.2 Potential Evapotranspiration

Figure 9 shows box-whisker plots of annual Potential Evapotranspiration (PET) values during 2022-2031 and the baseline period. It is observed that median monthly PET values for future years are lower than the baseline value in all projected years under Q0 simulation. The monthly distribution

of projected Potential evapotranspiration values for the basin for three scenarios (Q0, Q1 and Q14) for the years 2030, 2040 and 2050 are shown against baseline average (Figs. 10-12). The distribution of projected monthly PET values is found to follow the pattern of baseline PET values. However, as per Q0 simulation, the monthly PET value for 2030 is found to be the highest (increased by 23%) in the month of April (rather than that in the month of May). Larger increase in quantum of monthly PET (over the baseline average) is found for the month of March, April, May and June in projected years for both the simulations Q1 and Q14.

Figure 9: Box plot showing projected monthly PET values in Jamshedpur sub-basin during 2022-2031 under the Q0 simulation

Figure 10: Monthly variation of Potential Evapotranspiration under Q0 simulation

Figure 11: Monthly variation of Potential Evapotranspiration under Q1 simulation

Figure 12: Monthly variation of Potential Evapotranspiration under Q14 simulation

4.3 Stream Flow

The stream-flow for 2022-2025, 2030, 2040 and 2050 under Q0 simulation and for 2022, 2030, 2040 and 2050 under Q1 and Q14 simulations have been computed using the calibrated model and projected rainfall and other meteorological data and have been shown in Figs. 13 -16.

For Q0 simulation, annual highest flow has been found to occur in end of October in 2022 and in 2023, contrary to historical stream flow pattern. Additionally, high flow has been found to occur in April in 2022. 2050 has been observed as low flow year compared to 2030 and 2040. For the year 2040 peak flow has been found to occur in October.

As per Q1 simulation the flow pattern for projected years has been found to be the same as historical one. Peak discharge has been simulated to occur in September for all projected year 2022, 2030, 2040 and 2050.

Figure 13: Stream flow hydrographs for 2022, 2023, 2024 and 2025 under Q0 simulation

Figure 14: Stream Flow Hydrographs for Q0 simulation for 2030, 2040, 2050

Figure 15: Stream Flow Hydrographs for Q1 simulation

Figure 16: Stream Flow Hydrographs for Q14 simulation

for Jamshedpur Sub-basin

for Jamshedpur Sub-basin

As per Q14 simulation the flow pattern (Fig. 16) for all the projected years has been found to be the same as historical flow pattern. However, the annual peak flow has been found to occur in month of June in 2050 and in October in 2040.

The annual peak flows (1st, 2nd and 3rd highest) for Q0 simulation have been found to be higher (significantly higher for 1st peak for 2022 and 2030) than the corresponding baseline peak flow (averaged) for 2022, 2030 and 2040 (Fig. 17). The lowest values of peak flow (1st highest) have been found for the year 2050, which are less than the baseline averaged peak flow.

Figure 17: Annual peak flow for Q0 simulation

As per Q1 simulation (Fig. 18), the annual peak flows (1st, 2nd and 3rd highest) have been found to be less than the corresponding baseline averaged peak flows for all the projected years except the year 2030. Annual peak flows (1st, 2nd and 3rd highest) in 2030 have been found to be higher than the corresponding peak flows in 2022, 2040 and 2050 for Q1 simulation. Highest annual peak flow was found in 2040 for Q14 simulation in conformity with 24 –hr maximum rainfall. Other peak flows for all the years have been found to lie close to the baseline averaged peak flows as per Q14 simulation (Fig. 19).

The annual pattern of average monthly projected flow of 2022-2031 under Q0 simulation has been found to be similar to the corresponding baseline averaged flow pattern (Figs. 20-21).

Figure 18: Annual peak flow for Q1 simulation

Figure 19: Annual peak flow for Q14 simulation

Figure 20: Maximum, average and minimum monthly flow for baseline years at Jamshedpur

Figure 21: Maximum average minimum monthly flow during 2022-2031 at Jamshedpur

The magnitudes of maximum monthly projected flow and minimum monthly projected flow have been found to be respectively higher than the corresponding baseline flows. The maximum and minimum baseline flow has been found to reach the highest value in July and August respectively. Maximum and minimum projected flow has been found to reach its highest value in the month of October and September respectively.

Figure 22 illustrates the percentage deviation in annual stream-flow volume (MCM) for 2030, 2040 and 2050 under Q0, Q1 and Q14 simulations. For Q0 and Q14 simulations, annual stream-flow volumes for all projected years have been found to be higher.

Figure 22: Deviation in annual stream-flow volume (MCM) from baseline stream-flow volume for projected years under Q0, Q1 and Q14 simulations (Jamshedpur)

(range 26% to 84%) than the baseline value and lower than baseline value for Q1 simulation. For 2040 under Q14 simulation the annual stream-flow volume is significantly higher (84%) than the observed historical basin average as well as the other projected years under all the simulations (in conformity with rainfall).

5. CONCLUSION

This study narrates impact of changing climate on hydrologic behavior of a sub basin of Subarnarekha river (in eastern region of India) using hydrologic model HEC- HMS and future climate scenario (Regional Climate model, PRECIS for A1B scenario, IITM, Pune) for baseline (1985-1990) and projected (2022-2031, 2040 and 2050) period. An ensemble of future scenario was generated by running PRECIS model with lateral boundary conditions of three QUMP simulations (Q0, Q1 and Q14) as available from Hadley Centre, UK. The work revealed increase of annual rainfall and corresponding increase of annual streamflow, increased potential evapotranspiration for summer months and also for September to November for all the simulations. Increase of annual maximum 24-h rainfall and corresponding increase in annual maximum flow and occurrence of peak flow shifting from monsoon months to other months were also noted.

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