ASSESSMENT OF WATER RESOURCES UNDER CLIMATE CHANGE: DAMODAR RIVER BASIN, INDIA

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ABSTRACT

This study evaluates the impact of climate change on water resources of the Damodar river basin in eastern India. Future climate scenario has been framed based on climate projections of regional climate model PRECIS (Providing Regional Climates for Impacts Studies) of the Hadley Centre for A1B scenario [Special Report on Emissions Scenarios (SRES) prepared under the Intergovernmental Panel on Climate Change coordination (IPCC)]. A continuous daily hydrologic model HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) calibrated for the basin was used to simulate the daily hydrological condition for baseline period 1985-1990 and future period 2014-2025. The impact assessment has been carried out by comparing baseline and future precipitation, potential evapotranspiration (PET) and flow regimes and also performance of the Damodar Valley Corporation (DVC) system of reservoirs. Decrease of projected rainfall was noticed for months of July and August and increase of projected rainfall was observed for months of January and June for all sub-basins. The projected PET values for all sub-basins were found to be higher than corresponding baseline values during February to June and lower than corresponding baseline values for November to January. Increase of projected flow over the corresponding baseline flow was noted for months of January and June and decrease in projected flow was noted for the months of July and August for all sub-basins. Reliability of meeting municipal and industrial demands was found to be 100% during the months of June to December in projected years and in baseline years for all the reservoirs.

Keywords: climate change impact, damodar river, HEC-HMS, reliability, PRECIS model.

INTRODUCTION

Climate change is expected to create many challenges (including water availability) worldwide and projecting the impacts of climate change at regional scale allows communities to be proactive in planning for the future. South Asia in general and India in particular, are particularly vulnerable to climate change and its adverse socio-economic effects. Therefore, there is a need to evaluate the impact of climate change on water resources in India at regional and local level.

A lot of work on evaluation of impact of climate change in water sector has been done worldwide. It was predicted that the changes in global river flow under the IPCC SRES A1B and A2 scenarios found from HadGEM1-TRIP model [1]. Global climate models (GCM), CGCM2, CSIROMk2 and HadCM3 were applied [2] to estimate future water availability of Okanagan basin in England. Climatologic data bases (SICLIM and CLICOM) built by the Servicio Meteorológico Nacional (SMN) of Mexico [3] was fed to a hydrologic model to predict the annual volume of superficial available water in Mexico. The climate change impact was studied on the performance of Hirakund reservoir on the Mahanadi River in Orissa, India [4]. It was seen that hydropower generation [5, 6] and reliability with respect to hydropower and irrigation to be decreased in future in most scenarios.

The impacts of possible future climate change scenarios were evaluated on the hydrology of the catchment area of the Tungabhadra River, upstream of the Tungabhadra dam [7]. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) version 3.4 was used for the hydrological modeling of the study area. Linear regression-based Statistical Down Scaling Model (SDSM) version 4.2 was used to downscale the daily maximum and minimum temperatures and daily precipitation in the four sub-basins of the study area. The large-scale climate variables for the A2 and B2 scenarios obtained from the Hadley Centre Coupled Model version 3 were used. A regional climate model data was used from the Ensemble-Based Predictions of Climate Changes and their Impacts (ENSEMBLES) project to drive the Precipitation - Runoff - Evapotranspiration - Hydrotope (PREVAH) hydrological model in order to assess the impact of climate change on the hydrology in the Rhine basin in Europe [8].

An analysis was made on the potential hydro-climatic change in the Peace River basin in the province of British Columbia, Canada, based on two structurally different approaches: (i) statistically downscaled global climate models (GCMs) using the bias-corrected spatial disaggregation (BCSD) and (ii) dynamically downscaled GCM with the Canadian Regional Climate Model (CRCM) [9]. Additionally, simulated hydrologic changes from the GCM-BCSD-driven Variable Infiltration Capacity (VIC) model were compared to the CRCM integrated Canadian Land Surface Scheme (CLASS) output. Overall, the GCM-BCSD-VIC approach was reported to be the preferred approach for projecting basin-scale future hydrologic changes, provided that it explicitly accounted for the biases and included plausible snow and runoff parameterizations.

This paper addresses a study on the assessment of impact of climate change on water resources of the

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Damodar river basin (Eastern India) and also performance of the Damodar Valley Corporation (DVC) system of reservoirs developed on the River. The river Damodar and its three tributaries - the Bokaro, the Konar and the Barakar - form one important tributary of the Bhagirathi-Hugli (a distributory of the Ganga) in its lower reaches since India's first river development project was DVC [10]. The DVC system consists of four main multipurpose reservoirs [11] located at Tilaiya, Konar, Maithon and Panchet, a single purpose reservoir on the main stream of the Damodar at Tenughat (without provision of flood storage) and a barrage at Durgapur [12]. The demand in various sectors in the basin is met by regulating the flow through four dams namely (i) Maithon, (ii) Tilaiya on river Barakar, (iii) Panchet on river Damodar and (iv) Konar on the river Konar upstream of Panchet dam.

The work comprises simulation of the hydrological condition that shall prevail under the projected climate condition in the study area with the help of a hydrologic model HEC-HMS [13] and ultimately projection of climate induced changes in the monthly and inter-annual precipitation, potential evapotranspiration (PET) and flow regimes and also performance of the DVC system of reservoirs in meeting various demands.

The projected climate scenario is based on simulated projections of climate over India by a high-resolution regional climate model (RCM) PRECIS (Providing Regional Climates for Impacts Studies) developed by the Hadley Centre and run at the Indian Institute of Tropical Meteorology (IITM), Pune, India at 50 km × 50 km horizontal resolution over the South Asian domain for A1B scenario [Special Report on Emissions Scenarios prepared under the Intergovernmental Panel on Climate Change (IPCC) coordination [14]].

MATERIALS AND METHODS

Study area

The Damodar rises in the Palamau Hills of the Chotanagpur Range (Jharkhand state) at an elevation of about 609.6 m above mean sea level. After flowing through the two important coalfields and the mineral rich areas of the region in the south-easterly direction in the states of Jharkhand and West Bengal, the river abruptly changes its course below Durgapur (lying in West Bengal) and bifurcates into two channels viz. the Damodar channel (also known as Amta channel) and the Kanka-Mundeshwari river. The main channel finally meets the Hooghly River which ultimately debouches into the Bay of Bengal. Mean annual rainfall in the basin is of the order of 1300 mm and about 80% of rain precipitates during the summer monsoon (June to September). The geology of the basin is spelt out by different types of rocks ranging from Archaean to recent age with deposits like coal and mica. The lower basin is characterized by alluvium soil. The slope of the basin ranges from 1.86m/km to 0.16 m/km [15].The upper part of the basin (up to Durgapur) is dominated by sandy loam soil and the remaining part is dominated by clayey loam soil. Agriculture is the main land-use or land-cover (38.5%) in the basin followed by forest (23.5%), grassland (12.4%) and water-body (14%). The basin of the river measuring 23527.8 km^2 and lying between the latitudes 22°19′N and 23°25′N and longitudes 84°45′E and 87°15′E forms the study area for the present work (Figure-1).

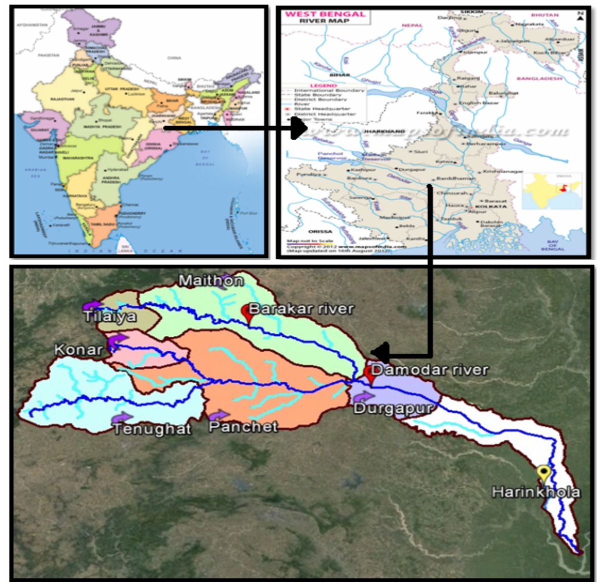

Figure-1. Location map of the Damodar river basin.

Data

Daily rainfall, temperature, relative humidity and wind speed data under A1B scenario of Regional Climate Model PRECIS (Providing Regional Climates for Impacts Studies) of the Hadley Centre, (the resolution being 0.44° × 0.44° latitude/longitude, giving a grid spacing of 50 km) was collected for 1985-1990 and 2014-2025 for the study area from Indian Institute of Tropical Meteorology (IITM), Government of India (GoI), Pune. Daily flow data spanning over the years 1985-1990 was collected from DVC, Maithon, India. The Thiessen polygon method has been used to determine the daily mean rainfall and mean temperature over each sub-basin and Penman’s method has been used to calculate the PET for the basin for the above noted years.

METHODOLOGY

Hydrologic model

The HEC-HMS model is designed to simulate the precipitation of dendritic watershed systems. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. The program has an extensive array of capabilities for conducting hydrologic simulation. Many of the most common methods in hydrologic engineering are included in such a way that they are easy to use [13]. It may be noted that HEC-HMS model has been successfully used for modeling hydrologic behavior of the Subarnarekha river basin in eastern India for proper assessment and management of its water resources [16].

For the present study, runoff depth was computed using Deficit and Constant Loss method, Clark unit hydrograph technique with the peak and time to peak computed by Snyder's unit hydrograph technique method was adopted to compute streamflow hydrograph. The constant monthly base flow (varying only monthly) method was used to account for the base flows. Muskingum method of channel routing was used to generate discharge hydrograph at relevant downstream points in channel. Modified Puls method was used for routing flow in the reservoirs.

The hydrologic model has been originally developed and applied to the Damodar river basin in eastern India for prediction of its hydrologic response in an earlier work [17]. The hydrologic model applied to the Damodar river basin has been calibrated and verified with sensitivity analyses. This calibrated hydrologic model has been used for the present study. For the sake of ready reference, sub-basins associated with reservoirs and barrage of the DVC system have been named after them whereas subbasin downstream Durgapur barrage up to outfall has been referred as sub-basin DS.

Climate change scenario

This work uses future climate change scenario (corresponding to IPCC-SRES A1B emission scenario and comprising daily precipitation and temperature data) provided by IITM Pune, India [18]. A high-resolution regional climate model, PRECIS, developed by the Hadley Centre was run at the IITM Pune, at 50 km × 50 km horizontal resolution over the south Asian domain in order to develop high resolution climate change scenario for the period 1961-1990, 2011-2040, 2041-2070 and 2071-2098 for impact assessment studies.

The method as suggested in [19] has been followed to reduce the uncertainty normally associated with future climate predictions. Thus, the hydrological model was validated for the baseline period 1985-1990 with the precipitation and temperature data as provided by PRECIS. A comparison of mean and standard deviation values of estimated daily flows, with inputs from PRECIS, with those of observed flows revealed a reasonably good agreement (deviations being 18.4% to 22.5% and -16.2% to 12.1% respectively). The validated hydrological model was used to generate the streamflows and for the sub-basins of the study area for baseline and future periods by using the temperature and precipitation data provided by PRECIS and also to assess the performance of the reservoir system during both time periods.

The performance of the DVC system in meeting various demands for baseline and future periods was evaluated in terms of time based reliability (RI1) index. RI1 is the ratio of number of stages during the simulation for which demands could be met and the total number of stages in the simulation.

RESULTS

Analysis of impact of climate change

Figures (2-10) show Box plots of monthly and annual rainfall, PET for Maithon and Panchet sub-basins, streamflow for Maithon and Panchet subbasins and at outfall (though analysis has been carried out for the other subbasins) and also *reservoir reliability of meeting various demands individually and also as a system* for baseline and future periods. The line in the middle of the boxes denotes the median values and the upper and lower boundaries show the 25^{th} (quartile 1) and 75^{th} percentiles (quartile 3), respectively. The ticks outside of the boxes denote the maximum and minimum values of the data.

Rainfall

Increase of projected rainfall (median values) by 2.33% to 1231.4% was noted for months of December, January, April, May and June for all sub-basins (Figure-2). However, for Maithon sub-basin projected rainfall was found to decrease by 17.1%, 30.6% and 8.39% in April, May and December, respectively. A decrease of projected rainfall by 5% to 94.4% (median values) was noted for months of July, August, September and October for all sub-basins excepting for Tilaiya and Durgapur. The projected rainfall was found to increase by 10% in September and October for Tilaiya subbasin and by 24.8% in October in Durgapur sub-basin.

The projected rainfall was found to increase for Konar sub-basin in May and April by 740.7% and 1231.4% respectively and for Panchet subbasin by 1001.7% during the month of December. A relatively small increase in projected rainfall (by 7.5% to 88.77%) in months of May and December for Tilaiya sub-basin in January and June for Tenughat sub-basin, for the month of June for Konar, Maithon, Panchet, Durgapur sub-basins, for the month of December for Durgapur sub-basin was noted. However, no change in rainfall for the month of June for subbasin DS was noted.

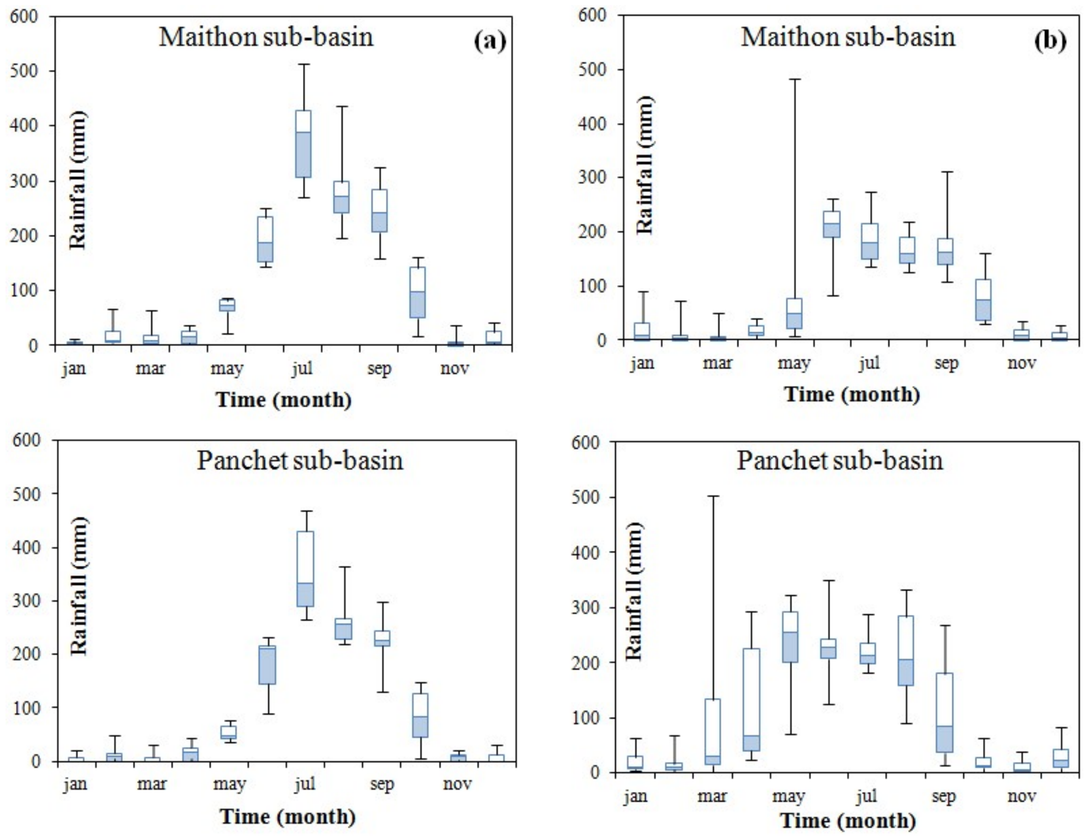

Figure-2. Monthly box plots of rainfall for the (a) baseline and (b) projected periods.

Analysis of quartile 1, quartile 3 and median rainfall values indicates an increasing trend for rainfall for the month of April and decreasing trend for rainfall in July for all subbsins. Figure-5 show an increase of (5.4% to 38.2%) in annual rainfall (median) in the future for all the sub-basins except a decrease of 3.2% and 23% in annual rainfall (median) for sub-basins DS and Maithon respectively.

Potential evapotranspiration

The projected PET values (median) for all sub basins were found to be higher (1.3% to 19.6%) than corresponding baseline values during February, March, April, May and June. The PET values were found to be lower for November, December and January (2.9% to 21.1%) than corresponding baseline values for all sub-basins except for Tenughat sub-basin for which the PET value was found to be higher by 0.4% than baseline value for January (Figure-3). During July, August, September and October the median values of projected PET for all the sub-basins were found to be lower than corresponding baseline PET values (by 0.2% to 7.2%) except for Tenughat sub basin where the projected PET values for August, September, October were found to be higher by 4.3%, 1.9% and 1.8%, respectively, for Panchet sub-basin where during July the PET was higher by 0.15%, for Durgapur where during July, August, September the PET was higher by 1.9%, 1.2% and 0.6%, respectively and for sub-basin DS where during July, August, September the PET was higher by 2.6%, 1.7% and 1.5%, respectively.

Analysis of quartile 1, quartile 3 and median PET values indicate a decreasing trend for projected PET for the months of November and December for all sub-basins in comparison to baseline values. Figure-6 shows an increase of 3.3%, 4.1% and 5.9% in annual PET (median) in the future for the sub-basins Panchet, Durgapur and DS, respectively and a decrease of 0.8% to 2.2% in annual PET (median) for the other sub-basins. The range of monthly PET values (difference of maximum and minimum values) was found to be increased in future period in comparison to baseline period for all subbasins.

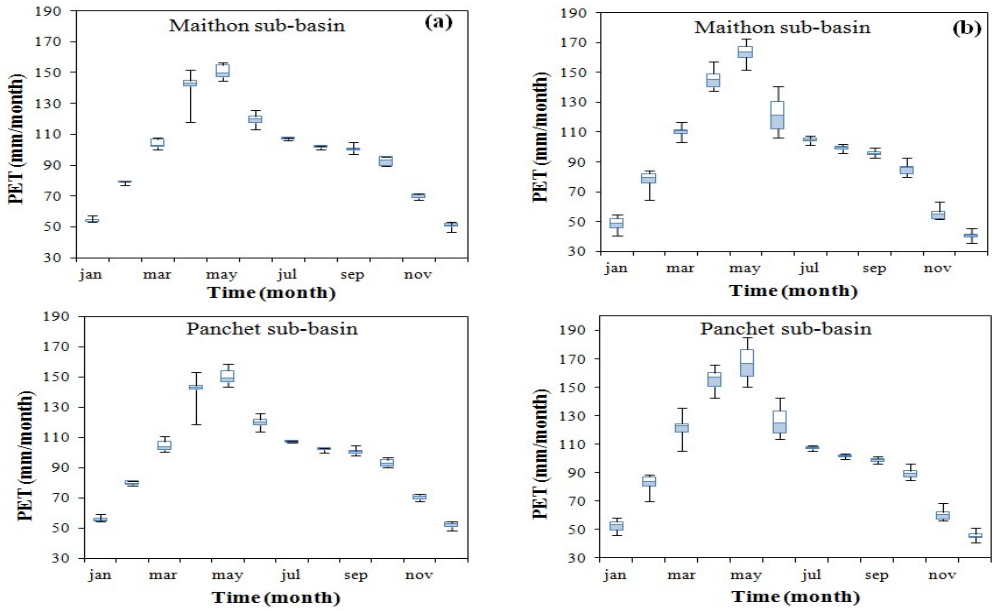

Figure-3. Monthly box plots of PET for the (a) baseline and (b) projected periods.

Stream flow

Increase of projected flow (median values) by 0.44% to 259.7% over the corresponding baseline flow was noted for months of November, December, January and June for all sub-basins (Figure-4) except for the Tenughat sub basin during the months of June and November, for the Maithon sub-basin for December and for Panchet subbasin for November. A marked increase in the projected monthly flow was observed during April (by 1789.7%) and May (by 746.4%) in Konar sub-basin, during May (by 2207.5%) in Tenughat sub-basin and during March (by 706.4%) in Panchet sub-basin.

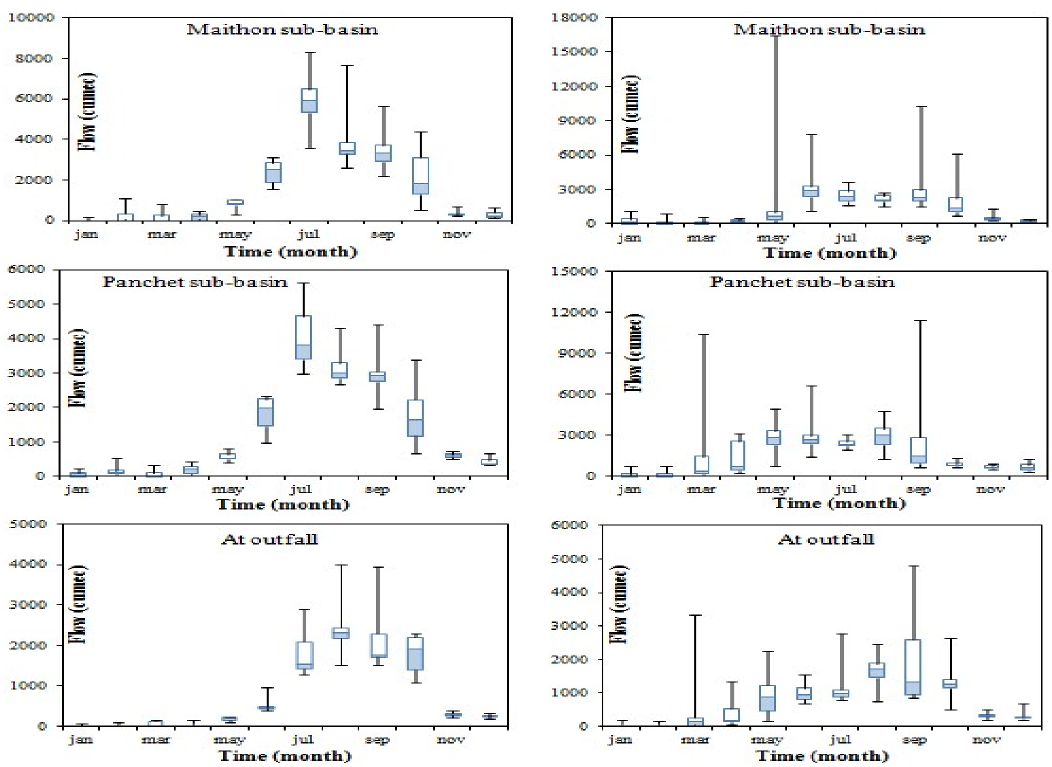

Figure-4. Monthly box plots of stream flow for the (a) baseline and (b) projected periods.

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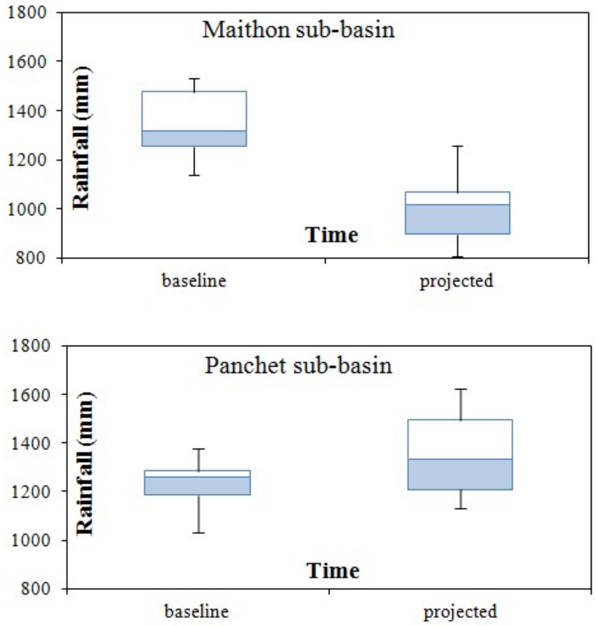

Figure-5. Annual box plots of rainfall for the baseline and projected periods.

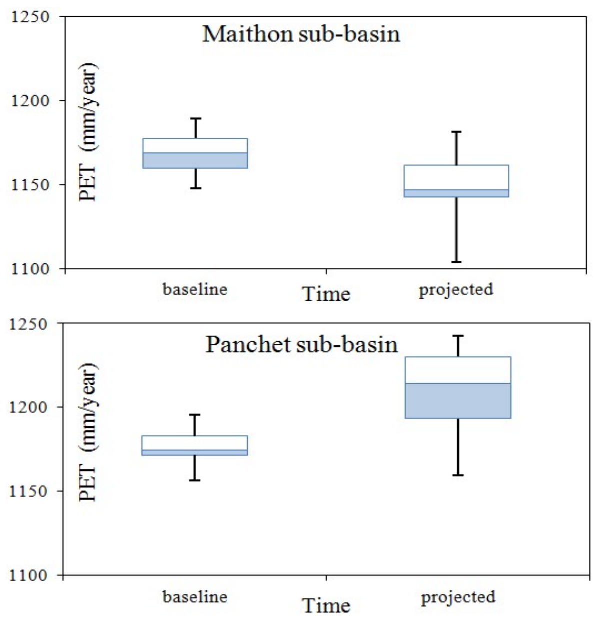

Figure-6. Annual box plots of PET for baseline and projected periods.

Decrease in projected flow by 0.35 to 68.8% was noted for the months of July, August, September, October and February for all sub-basins, exception being the Tilaiya sub-basin wherein the projected flow was found to increase by 7.25% and 16% in the months of September and October respectively, the Panchet sub-basin wherein the projected flow was found to increase by 12.9% in February and the Durgapur sub-basin wherein the projected flow was found to increase by 19.8% in October.

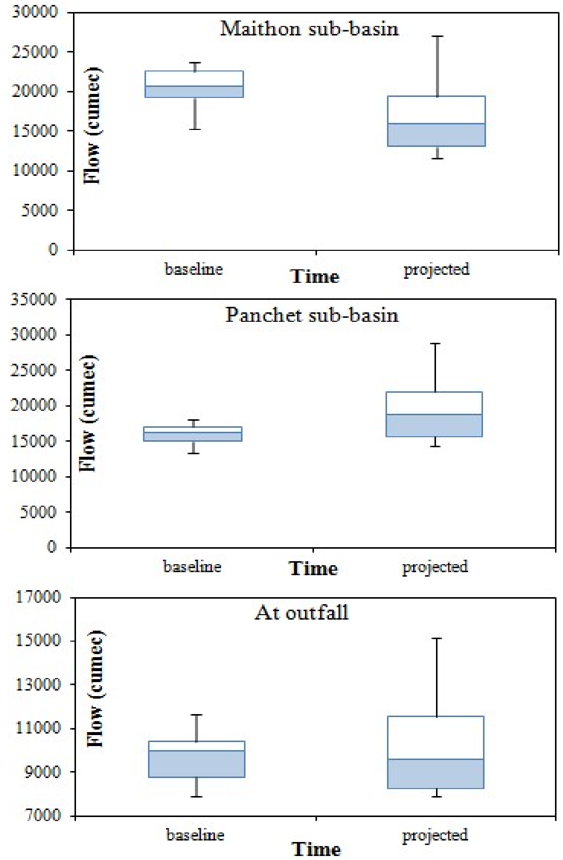

Figure-7. Annual box plots of streamflow for baseline and projected periods.

Analysis of quartile 1, quartile 3 and median discharge values indicate an increasing trend for projected discharges for the months of April and decreasing trend for discharge in July for all the sub-basins. Figure-7 shows an increase of 2.5% to 9.3% in annual flow (median) in the future for the sub-basins Durgapur and Konar and 15% for Panchet with respect to the baseline flows. A decrease of 3.5% to 23.33% in annual flow (median) in the future for the sub basins Tilaiya, Maithon Tenughat and at outfall with respect to the baseline flows was noted.

Reservoir reliability for meeting municipal and industrial demand

The period of meeting municipal and industrial demands with 100% reliability was found to extend from June to December for the five reservoirs, also during January for Tilaiya and Konar reservoirs and during February for Tilaiya reservoir in both baseline and future periods (Figures 8 and 9). In general this reliability for the five reservoirs in March to May (exception being Maithon for May and Panchet for March to May) was found to be lower in future period than in baseline period - the values were found to range from 61% to 99% and 31% to 99% in baseline and future periods respectively. The high reliability of Maithon reservoir in May in future year may

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be correlated with high inflow projected for the month of May in future period.

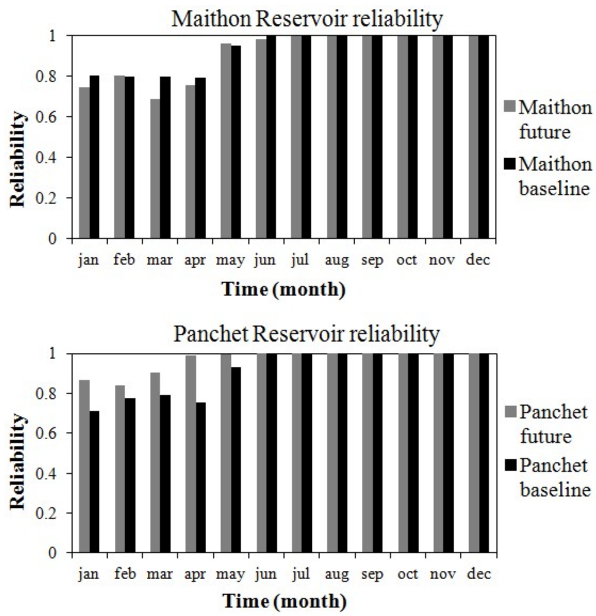

Figure-8. Reservoir reliability for municipal and industrial use.

Reservoir reliability for instream flow requirement

The reliability of meeting in-stream flow requirement turned out to be 100% for all the reservoirs at Konar, Tenughat, Maithon and Panchet during June to December for both baseline and future years, exception being the Konar reservoir during June and July in baseline period and during June to December in future years (with reliability value of 92%) and Maithon reservoir in June in future period (Figures 9 and 10). This reliability is about (50% to 93%) and (21% to 93%) for the remaining months of the year for Maithon and Panchet reservoirs during baseline and future years respectively. However, the reliability for Konar reservoir during January, February and March is very low during future years (5% to 9%).

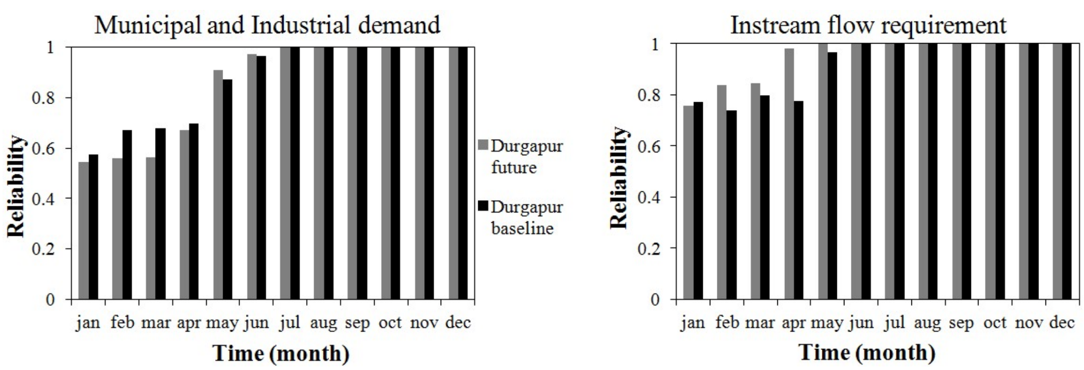

Figure-9. Reliability of meeting Durgapur demands by Maithon and Panchet reservoirs.

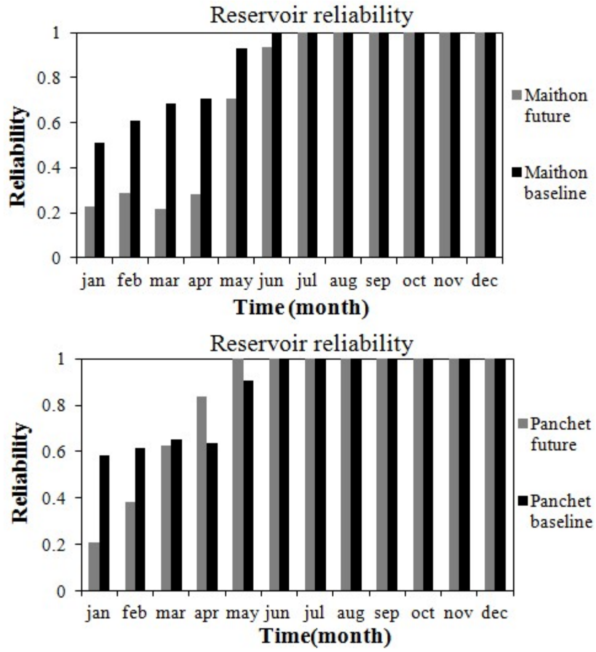

Figure-10. Reservoir reliability for instream flow requirement.

DISCUSSIONS

The study uses a continuous hydrologic model HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) to simulate the daily hydrological condition for baseline period 1985-1990 and future period 2014-2025. Future climate scenario has been framed based on climate projections of Regional Climate Model PRECIS (Providing Regional Climates for Impacts Studies) of the Hadley Centre, UK for A1B scenario prepared under IPCC coordination [14]. The impact assessment has been carried out by comparing baseline and future precipitation, potential evapotranspiration (PET) and flow regimes and also performance of the DVC system of reservoirs in meeting demands.

Quantum of rainfall during the monsoon period was found to decrease for most of the sub-basins during the projected period and subsequently flow was also found to decrease during these months for almost all the sub-basins. Increase of projected rainfall was noted for months of December, January, April, May and June for all sub-basins - excepting for Maithon sub-basin. The projected rainfall was found to increase substantially in May and April (by 740.7% and 1231.4%, respectively) for Konar subbasin and by 1001.7% during December for Panchet subbasin. Increase of annual rainfall in the future for all the sub-basins was noted except a decrease for Maithon and DS subbasins.

The projected PET values for all sub-basins were found to be higher than corresponding baseline values during February, March, April, May and June. The PET values were found to be lower for November, December and January than corresponding baseline values except for Tenughat sub-basin. Increase of annual PET in the future for the sub basins Panchet, Durgapur and DS and a decrease in annual PET (median) for the other sub-basins were noted.

Increase of projected flow (median values) by 0.44% to 259.7% over the corresponding baseline flow was noted for months of December, January and June for all sub-basins (Figure-4.4c) except for the Tenughat sub-basin during the months of June and for the Maithon sub-basin for December. A marked increase in the projected monthly flow was observed during April (by 1789.7%) and May (by 746.4%) in Konar sub-basin, during May (by 2207.5%) in Tenughat sub-basin and during March (by 706.4%) in Panchet sub-basin. Decrease in projected flow by 0.35% to 68.8% was noted for the months of July, August, September, October and February for the sub-basins with some exceptions.

Increase by 2.5% to 9.3 % in annual flow in the future for the sub-basins Durgapur and Konar and 15% for Panchet with respect to the baseline flows was noted. A decrease of 3.5% to 23.33% in annual flow in the future for the sub-basins Tilaiya, Maithon Tenughat and at outfall with respect to the baseline flows was noted. The reliability of meeting municipal and industrial demands was found to be 100% during the months of June to December in projected years and in baseline years for all the reservoirs.

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REFERENCES

[1] Hotchkiss RH, Jorgensen SF, Stone MC and Fontaine TA. 2000. Regulated River modeling for climate change impact assessment: The Missouri River. Journal of the American Water Resources Association. 36(2): 375-386.

[2] Merritt WS, Alila Y, Barton M, Taylor B and Cohen S. 2006. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin. British Journal of Hydrology. 326: 79-108.

[3] Mendoza VM, Villanueva EE, Garduño R, Nava Y, Santisteban G, Mendoza AS, Oda B and Adem J. 2009. Thermo-hydrological modelling of the climate change effect on water availability in two hydrologic regions of Mexico. International Journal of Climatology. 29(8): 1131-1153.

[4] Raje D and Mujumdar PP. 2010. Reservoir performance under uncertainty in hydrologic impacts of climate change. Advances in Water Resources. 33(3): 312-326.

[5] Chowdhury S. 2010. Feasibility Analysis of Mini Hydel Power Plant on the Tiljuga Dhar River at Nirmali, Bihar. ME Thesis. School of Water Resources Engineering, Jadavapur University. India.

[6] Das S, Roy D, Mazumdar A, Chowdhury S and Majumder M. 2012. Hydrological feasibility of a mini hydropower plant on Tiljuga River, Bihar, India. Water and Energy International. 69(12): 30-37.

[7] Meenu R, Rehana S and Mujumdar PP. 2012. Assessment of hydrologic impacts of climate change in Tungabhadra river basin, India with HEC-HMS and SDSM. Hydrological Processes. 27: 1572-1589.

[8] Bosshard T, Kotlarski S, Zappa M and Schär C. 2014. Hydrological Climate-Impact Projections for the Rhine River: GCM-RCM Uncertainty and Separate Temperature and Precipitation Effects. Journal of Hydrometeorology. 15(2): 697-713.

[9] Shrestha RR, Markus AS, Arelia TW and Francis WZ. 2014. Evaluating Hydroclimatic Change Signals from Statistically and Dynamically Downscaled GCMs and Hydrologic Models. Journal of Hydrometeorology. 15(2): 844-860.

[10] Roy D, Mukherjee S and Bose B. 1995. Regulation of a multipurpose reservoir system: Damodar Valley, India. IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences.

[11] Roy D and Bose B. 2001. Management of multi-reservoir system. 1st Asian Regional Conference of ICID: Seoul, Korea Republic.

[12] Mukherjee B, Das S and Mazumdar A. 2013. Mathematical Analysis for the Loss of Future Storage Capacity at Maithon Reservoir, India. ARPN Journal of Engineering and Applied Sciences. 8(10): 841-845.

[13] HEC. 2000. Hydrologic Modeling System HEC-HMS. Technical Reference Manual. US Army Corps of Engineers. Hydrologic Engineering Center: CA, USA.

[14] IPCC. 2007. Climate Change Synthesis Report. Contribution of Working Group I, II and III to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge.

[15] WMO. 2003. The associated programme on flood management. Integrated Flood Management, Case Study. India: Flood Management - Damodar River Basin. World Meteorological Organization.

[16] Roy D, Begam S, Ghosh S and Jana S. 2013. Calibration and Validation of HEC-HMS Model for a River Basin in Eastern India. ARPN Journal of Engineering and Applied Sciences. 8(1): 33-49.

[17] Chatterjee M., De R, Roy D, Das S and Mazumdar A. 2014. Hydrological Modeling Studies with HEC-HMS for Damodar Basin, India. World Applied Sciences Journal. 31(12): 2148-2154.

[18] Kumar KK, Patwardhan SK, Kulkarni A, Kamala K, Rao KK and Jones R. 2011. Simulated projections for summer monsoon climate over India by a high-resolution regional climate model (PRECIS). Current Science. 101(3): 312-326.

[19] Dibike YB and Coulibaly P. 2007. Validation of hydrological models for climate Scenario simulation: the case of Saguenay watershed in Quebec. Hydrological Processes. 21: 3123-3135.