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Prediction of climate change scenarios in Varanasi District, U. P., India, using simulation models

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सार – जलवायु परिवर्तन से तात्पर्य लंबी अवधि में जलवायु में उतार-चढ़ाव से है, जो किसी क्षेत्र में जलवायु के प्रकार में बदलाव से संबंधित है। इसका प्रभाव विश्व और क्षेत्रीय दोनों स्तर पर निर्णायक हो सकता है। जलवायु परिवर्तन को समझने, प्रतिक्रिया रणनीतियों का चार्ट बनाने और जलवायु नीति तैयार करने का समर्थन करने के लिए जलवायु परिवर्तन एक शक्तिशाली माध्यम है। इस प्रकार, प्रेक्षित डेटा की तुलना में 5 CMIP3 GCMs के सिम्युलेटेड डेटा और भारित एंसेंबल विधि का उपयोग करके 2015-2054 के दौरान वर्तमान अनुसंधान वाराणसी जिले में जलवायु परिवर्तन परिदृश्यों के लिए आयोजित किया गया। सिम्युलेटेड परिणामों में अनिश्चितता को कम करने के लिए भारित एंसेंबल प्रणाली भी एक विधि है। उनके सिम्युलेटेड मासिक जलवायु प्राचल, जो कनाडा की CCCSN वेबसाइट से प्राप्त हुए हैं, द्विरेखीय अंतर्वेशन द्वारा डाउनस्केल किए गए थे। तब मौसमी और वार्षिक पैमाने में 4 डाउनस्केल जलवायविक प्राचलों के 4 परिणामों को सांख्यिकीय फॉर्मूला (R, D, MSD, SB, SDSD और LCS**)** का उपयोग करके प्रेक्षित डेटा के साथ मान्य किया गया था। एमएसडी, एसबी, एसडीएसडी, और एलसीएस)। परिणाम दर्शाते हैं कि, भारित एंसेंबल प्रणाली, आमतौर पर वांछनीय और उचित विधि है, जो सिम्युलेटेड परिणामों में अनिश्चितता को कम करती है। 2015 से 2054 की अवधि के लिए प्राप्त परिणामों के अनुसार, वाराणसी जिले की जलवायु में चार ऋतुओं में तापमान में वृद्धि होगी तथा दक्षिण पश्चिमी मॉनसून और मॉनसूनोत्तर ऋतु में वर्षा में कमी होगी। इसके अलावा, सर्दी, गर्मी और मॉनसून ऋतु में सापेक्ष आर्द्रता में कमी का अनुमान है। साथ ही, मॉनसूनोत्तर ऋतु, ग्रीष्म और दक्षिण पश्चिमी मॉनसून ऋतु में अनुमानित समुद्र तल दाब में वृद्धि प्रेक्षित की गई।

ABSTRACT. Climate change refers to climatic fluctuations over a long period of time such that shift in the type of climate may occur over an area. Its effect may be decisive both globally and regionally. Climate change scenarios are a powerful tool for understanding climate change, charting response strategies and supporting climate policy making. Thus, the present research was conducted to foretaste climate change scenarios in Varanasi district, during 2015-2054 using simulated data of 5 CMIP3 GCMs and weighted ensemble method in comparison with observed data. Weighted ensemble method is also method, for diminishing uncertainty in simulated results. Their simulated monthly climatic parameters, that have been received from the CCCSN website of Canada, were downscaled by bilinear interpolation. Then results of 4 downscaled climatic parameters in seasonal and annual scale were validated along with their observed data using statistical formula (R, D, MSD, SB, SDSD and LCS). Results showed that, weighted ensemble method, is generally desirable and proper method, in reducing uncertainty in simulated results. According to the results obtained for the period 2015 to 2054, climate of Varanasi district will experience increased temperature in four seasons and a decrease in rainfall for SW monsoon and post-monsoon seasons. In addition, a decrease is anticipated in relative humidity in winter and summer seasons. Furthermore, an increase was observed in predicted sea level pressure for post-monsoon season, summer and SW monsoon seasons.

Key words – Ensemble, GCMs, Climate change, Validation, Diminishing uncertainty, Weighted ensemble method.

1. Introduction

Many studies conducted on amount of produced greenhouse gases have shown that, climate change phenomenon is serious challenge, as it increases global temperature and decreases global rainfall. This issue highlights the need for controlling and preventing more desirable performance of various human activities. There are multiple factors contributing in creation of climate change phenomenon. For instance, astronomical and extraterrestrial causes and those related to the use of fossil fuels have been identified responsible for warming the atmosphere and ocean, reduction of snow and ice global mean, rise of sea level and changes in some climatic and extreme incidents. It is strongly believed that, human influence has been dominant cause of observed warming since the mid-20th (IPCC, 2013). According to fourth report of IPCC, if countries cannot decrease emission of greenhouse gases, then mean temperature of the earth′s atmosphere will be increased between 1.1-6.4° by 2100 based on predictions of different climatic scenarios in comparison with previous 100 years (IPCC, 2007a). Nowadays, the information about future situation of climate change is received by applying Atmospheric-Ocean General Circulation Models (AOGCM). The GCMs are the most advanced tools currently available for simulation of global climate system. These models synthesize the current understanding of oceanic and atmospheric circulation, assimilated through "continuous interplay among theories and observations" (IPCC, 2007b). Thus, the models are constituted of mathematical equations derived from physical laws describing the dynamics of atmosphere and ocean using a three-dimensional grid over the globe, typically with a horizontal resolution of 250-300 km and about 20 vertical layers in the atmosphere and about 30 layers in the oceans. The amount of emission of greenhouse gases in future is the main input data of GCMs models. Their future evolution is highly uncertain. Hence, scenarios are alternative images demonstrating how the future might be unfold and are a proper tool with which one can analyze how driving forces may influence future emission outcomes and assess associated uncertainties (IPCC, 2000). These scenarios include physical, chemical, societal and economic elements in order to obtain closer output models to actual condition applied in them (IPCC, 1995). The most valuable climatic scenarios (confirmed by IPCC) include A1B, A2 and B1. Following rapid growth in economy and population, India's emissions of greenhouse gases is increasing. At the same time, potential climate effects in India are severe. They include sea level rise, changes in the monsoon, increased severe storms and floods and more droughts (Antoinettel *et al*., 2005). According to prediction of the IPCC, mean summer monsoon rainfall in India may decrease by 0.5 mm/day (IPCC, 2001). South Asia and particularly the Indo-Gangetic plains of India are most vulnerable to climate change. Maximum temperature is likely to increase between 0.6-3.0 ºC in Eastern U.P. while minimum temperature is likely to increase between 1.0- 4.5 ºC during ensuing decades by 2080 (Singh, 2017). At overall the world, so many studies, were done using simulated data of CMIP3 GCMs and weighted ensemble method. Fatich *et al*., 2012 checked, 12 CMIP3 GCM for temperature and precipitation using linear interpolation and weighted ensembles for Firenze Peretola station in Italy. The validation period since the uncertainty of the weighted ensemble is well within the 5 to 95 percentile bounds of the A1B scenario. The differences between the predicted climate and the stochastic ensemble of the A1B scenario are observed in the months of March, August and September. In these months several ensemble members exhibit a decrease in precipitation outside the 5-95th percentile range of the historical climate. The median predicted change is about 14% decrease of annual precipitation from the period of 2000-2009 to the period of 2081-2100. The expected change of temperature exhibits a high confidence of an increase of about 2.5 ℃ by the end of the century, as compared to the 2000-2009 period, with a higher increase during summer months. Perkins *et al*., 2012 have studied builds upon the IPCC projections by analysing and presenting projections of change from the CMIP3 GCMs and demonstrating spatial differences in projections across the west Pacific domain. They applied temperature, precipitation and wind speed and direction for the SRES A2 emission scenario for 2080-2099, where the projected change is relative to 1980-1999. All weighted ensemble were (19 models), the BEST ensemble (15 models) and the WORST ensemble (4 models). The BEST and WORST ensembles are based on model skill in simulating relevant climatic features, drivers and variables, which govern the interannual and annual climate of the study region. Projections presented for the study region under the SRES A2 scenario by 2090 show warming temperatures of around 3 °C, PR increases of at least 60% over the equator and 10 to 30% in the north and south, PR decreases of up to 20% in the far south and over East Timor during MJJASO. There have been so many studies with applying GCMs and using weighted ensemble method, for rainfall in India. It is the most studied number using GCMs in India. For instance; Acharya *et al*., 2014; Rajeevan *et al*., 2007; Acharya, 2011; Durai *et al*., 2014; Kulkarni *et al*., 2012; Nair *et al*., 2017. Sarthi *et al*., 2015 have applied simulated rainfall of summer monsoon over the Gangetic Plains with 3 CMIP3 and CMIP5 models and three scenarios A2, A1B and B1 for (1961-1999). The result clarified that the CCSM3 model shows the possibility of 5-15% excess of summer monsoon rainfall in A2 scenario. Also in CMIP3 and CMIP5, model performance in simulating rainfall (1961-1999) close to observations (IMD and GPCP) over the Gangetic Plain (GP), India, is evaluated. Acharya *et al*., 2014 in a research have attempted to the prediction of Indian summer monsoon rainfall using weighted multi-model ensemble and outputs from 8 CMIP3 GCMs in compression with observed data. The ensemble mean of all GCMs was miniaturized using bilinear interpolation. Results reveal that the ensemble method is able to show noticeable improvement in diminishing of uncertainty for north and north-east India. Also weighted ensemble was identified as an effective factor in the improvement of uncertainty. Jeganathan & Ramachandran *et al*., 2013 attempted to use 20 CMIP3 GCMs based on skill in predicting observed annual temperature and precipitation

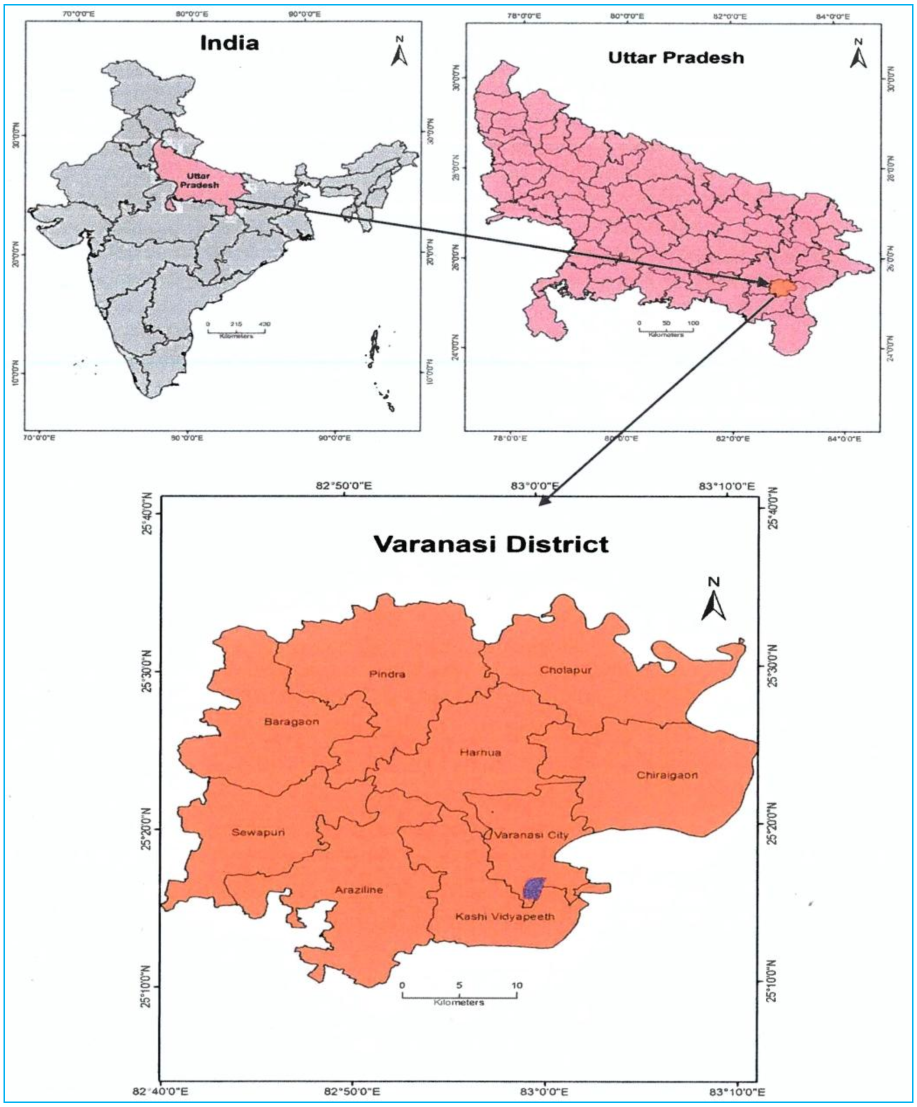

Fig. 1. Location of Varanasi district

conditions in Tamil Nadu, India. The ensemble of these four models shows superiority over the individual model scores. These models were subjected to increases in future anthropogenic radiative forcing for constructing climate change scenarios. Model results show both temperature and precipitation increases under increased greenhouse gas scenarios. Northeast and north-west parts of Tamil Nadu show a greater increase in temperature and precipitation. Seasonally, the greatest rise in temperature occurred during the MAM season, followed by DJF, JJA and SON. Decreasing trends of precipitation were observed during DJF and MAM. The number of research done, with the performance of GCMs, for other climatic parameters in India, was lesser. Panjwani *et al*., 2020 have been compared to the performance of selected six global climate models in simulating temperature extreme events over the Indian region for the 1976-2005 periods. For this, performance statistics such as root-mean-square error, correlation coefficient and agreement index were compared spatially and spatio-temporally. The study reveals that all six models overestimate minimum and maximum temperature extremes for most parts of Central India, which resulted in hot bias. However, these models show a cold bias in simulating low-temperature extremes over the Himalayan region.

2. The study area

Varanasi district, extending between the latitudes of 25°10′30″ and 25°35′15″ N and longitudes of 82°40′50″ and 83°12′18″ E lies in the eastern part of Uttar Pradesh and is a part of the Indo-Gangetic alluvial plain (Fig. 1).

The study area is bounded by the districts Jaunpur in north and north-west, Ghazipur in the north and north-east, Chandauli in the east, Mirzapur in the south and Bhadohi in the west. The Ganga River forms its natural boundary in the east and south-east while northern boundary is marked by the Gomati River. Total area of Varanasi district is 1,535 km² including 1,371.22 km² rural area and 163.78 km² urban area. The total area of Varanasi district has reduced from 5092.00 sq. km in 1991 to 1535 sq. km. in 2001 due to carving out of new districts. Although, there are 8 development blocks in Varanasi district.

3. Database and methodology

Observed climatic data like rainfall, temperature, relative humidity and sea level pressure were collected, from the India Meteorological Department (IMD), Pune, India. These data for seasonal and annual scale were extracted, for the periods of 1974-75 to 2013-14 and 1975-2014 respectively. There are different sources and causes of uncertainty at different stages of simulating climatic parameters by paired (AOGCM) model. There is uncertainty in results of climatic elements simulated in climate change projects. Hence, lack of decrease of uncertainty in results of climatic elements simulated in climate change projects leads to reduction of validity of results in submission of unrealistic results to the users. A number of uncertainties exist in climate simulation because the results of climate models are influenced by factors such as their dynamic framework, physical processes, initial and driving fields and horizontal and vertical resolution. The uncertainties of the model results may be reduced and the credibility can be improved by employing multi-model ensembles (Jinming *et al*., 2011). Therefore, a collection or ensemble of models is preferably used to characterize the uncertainty in projections, while credibility of projected trends increases when multiple models are determined in the same direction (Gain *et al*., 2011). Moreover, the average of a multi-model ensemble often outperforms single models when compared with observations (Gleckler *et al*., 2008). It is often true that, the quality of the forecast increases with respect to number of ensemble members. In the present research, simulated outputs of four major climatic parameters, *i.e*., temperature, rainfall, relative humidity and sea level pressure from CMIP3 GCMs, were used using, weighted ensemble method for the period of 40 years. Nowadays, different research centers, make and produce output data of GCMs based on monthly measurements. Canadian Climate Change Scenarios Network (CCCSN) site, belonging to the Canadian Environmental Assessment Agency, is one of the most valid centers, for production of these kinds of data. This site, provides monthly simulated data with 24 paired models of general circulation of atmospheric-oceanic for most climatic parameters (like temperature, rainfall, humidity, wind speed, sea level pressure etc.), using 3 different emission scenarios (A1B, A2 and B1) considering geographic longitude and latitude of study area. The Special Report on Emissions Scenarios (SRES) of the IPCC, includes various driving forces of climate change, such as population growth and socio-economic development. These drivers encompass various future scenarios that might influence Greenhouse Gas (GHG), sources and sinks such as the energy system and land use change. The A1B scenario, describe a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technologies, with a balanced emphasis on all energy sources. Major underlying themes are convergence among the region, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A2 scenario, describes a very heterogeneous world. Its underlying theme is self-reliance and preservation of local indentities. Fertility patterns across regions converge very slowly, resulting in high population growth. Primarily, economic development is, regionally oriented and per capita economic growth and technological change, are more fragmented and slower than other storylines. The B1 scenario, describes a convergent world with the low population growth, but with rapid changes in economic structures toward a service and information economy, along with reductions in material intensity and introduction of clean and resource-efficient technologies. Generally, emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives. From used scenarios in present research, two scenarios, are very important ratio to other scenarios. Scenarios A2 and B1 are the most widely simulated global emission scenarios in all GCMs (Tazebe *et al*., 2010). Large scale of gridded data network in comparison with the study area, is the major problem in using output of GCMs as, they have smaller spatial resolution-Power of spatial resolution for different GCMs is distinct; therefore, their grid cells are not coincident with each other. In fact, geographic longitude and latitude of a grid cell, where meteorological station is located on it, is distinct in different models. As a results, simulated output data in models from different areas extracted for comparison, will not be correct. To analyze the data of grid cells of large scale in GCMs models before use and those of selected models with increased number of pixels, inside them, they should be miniaturized to the same measurement level. Therefore, in selection of GCMs, adaptation size of grid cell of GCMs should be considered with the same size, in terms of their geographic longitude and latitude and necessary data should be provided, for 3 emission scenarios. Finally, on the basis of Coupled Model Intercomparison Project CMIP3, 5 models of BCM2 (Bergen Climate Model - Version 2) designed in BCCR center of Norway, CGCM3 model (Coupled Global Climate Model - Version 3) designed in CCCM of Canada, CNRMCM3 model (Center National de Recherché Meteorologiques-Climate Model - Version 3) designed in CNRM center of France, MRICGCM2.3 model (Meteorological Research Institute-Coupled General Circulation Model - Version 2.3) designed in MRI center of Japan, MIROC3.2 model (Model for Interdisciplinary Research Center on Climate - Version 3.2) designed in IRCC center of Japan were selected. Five used GCMs had spatial resolution of less than 5 degrees of geographic longitude and latitude. Thus, grid cell that was in image format and Varanasi station was located on it for every month, along with increasing number of its pixels with coordinates of 0.5 × 0.5 degrees of geographic longitude and latitude for every grid cell, was miniaturized using bilinear interpolation. Thus, with miniaturizing one grid cell of large scale to pixels with coordinates of 0.5 × 0.5 degrees of geographic longitude and latitude, absolute error of simulated data reduced. Altogether, process of downscaling was made by code-writing in MATLAB software, using bilinear interpolation method for 3 scenarios (A1B, A2 and B1), to generate of forecasted data, for the period of 2015-2054. Finally, downscaled data of two climatic parameters, *i.e.*, temperature and relative humidity, along with percentage of their changes ratio to observed data, without any other changes on them, were verified. On the other hand, due to existence of large uncertainty in downscaled data of two climatic parameters, *i.e.*, rainfall and sea level pressure in GCMs, using weighted ensemble method, their uncertainty, was reduced.

4. Analysis and discussion

Lack of decrease of uncertainty in climate change investigations, leads to reduction of validity of results in submission of unrealistic results to the users. Weighted ensemble method, is one of the methods used for reducing uncertainty in predictions, in which a weighted combination of several models is applied together. Thus, weighted ensemble method is used, to diminish uncertainty in forecasted results of GCMs. Because, weighted ensemble method is preferred as it can remove the systematic biases and improve the prediction capability since higher weights are assigned to better GCMs (Krishnamurti *et al.*, 1999, 2000). According to which, considering amount of deviation of simulated climatic parameters from mean observed data, weight is assigned to them as obtained using Equation 1. In fact, based on this method, each model that, has less deviation consequently has high weight in last modeling of area, which is naturally expected in the future modeling of the same weight, thus it will be selected as reliable model.

$$W_i = \frac{(1/\Delta F_i)^2}{\sum_{i=1}^{n}(1/\Delta F_i)^2} \tag{1}$$

In this equation, W_i is weight of each model in desired month, ΔF_i is deviation of mean for longtime in simulated parameters by each models in comparison with observed data and n is number of models. After calculation of weight for each model by Equation 1 for two simulated parameters *i.e.*, precipitation and sea level pressure, weight of each model should be multiplied in simulated amount of selected month M_i based on 3 scenarios, then yield amounts are summed with simulated amount of selected month as given in Equation 2.

$$\text{Ensemble} = \sum_{i=1}^{n} W_i M_i \tag{2}$$

Using Equations 1 and 2, weight of models for two climatic parameters of rainfall and sea level pressure is separately computed, for simulated data of 5 models used for 3 scenarios. Because, their downscaled results in all GCMs, had uncertainty especially for rainfall and sea level pressure, so weighted ensemble method, was used to diminish of uncertainty in them. Figs. 3 and 5 present the results obtained regarding weight of these two climatic parameters, *i.e.*, rainfall and sea level pressure, along with percentage of their changes in relation to observed data. The highest weight belonged to the models that had least error and the highest correlation of agreement coefficients. Hence, the least uncertainty belonged to the model that had higher weight. To submit the final result of two other climatic parameters, *i.e.*, temperature and relative humidity, percentage of increase or decrease in downscaled data to basic data was computed. Figs. 2 and 4 present percentages obtained regarding increase or decrease in two climatic parameters listed in presence of different scenarios. Thus, predicted values of climatic parameters for the period of 2015-2054 in different scenarios are based on average of 5 used models. It was necessary to verify downscaled data obtained using above models, with respect to their basic data. Therefore, to compare downscaled climatic data of 5 selected models with observed actual data, correlation amount, was calculated by Equation 3. Considering that amount of R^2 alone cannot be appropriate criterion for estimating the ability of a model, hence amount of agreement index or D, was computed using Equation 4. The amount of agreement index close to 1, shows more agreement of

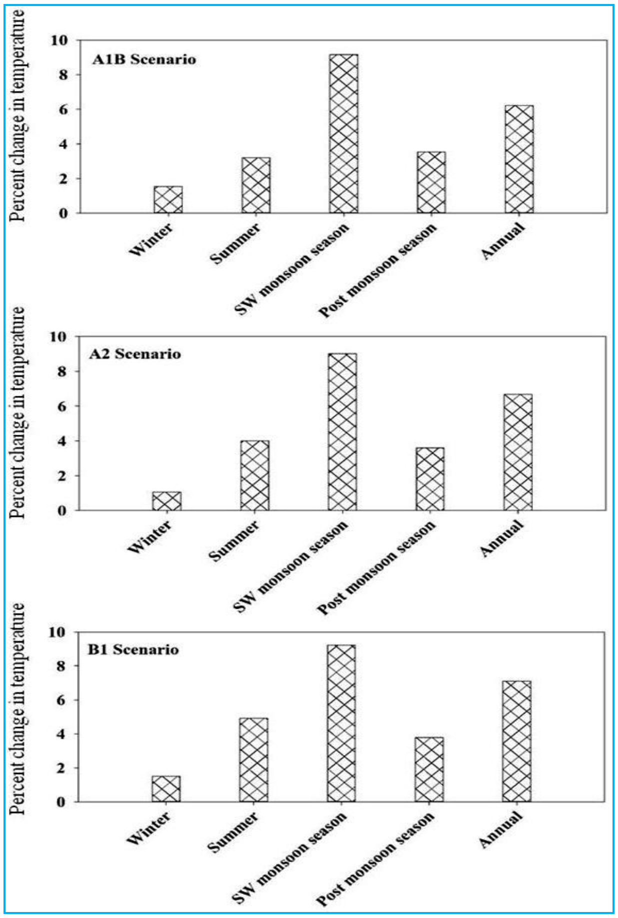

Fig. 2. Predicted change in mean temperature at Varanasi station during 2015-2054 relative to both seasonal and annual periods of 1974-75 to 2013-14 and 1975-2014, respectively, based on weighted ensemble of 5 GCMs and 3 scenarios

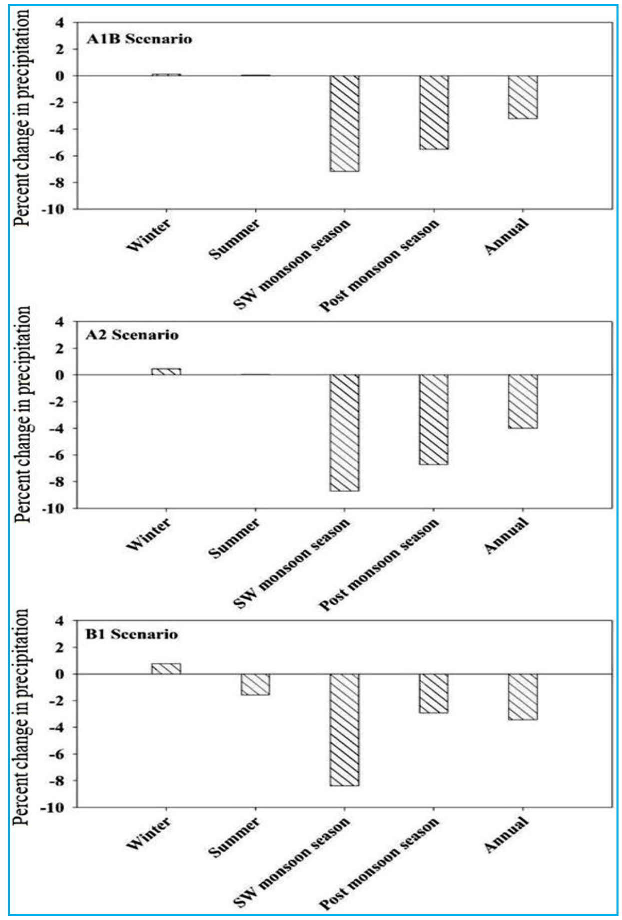

Fig. 3. Percentage of changes in predicted precipitation at Varanasi station during 2015-2054 relative to both seasonal and annual periods of 1974-75 to 2013-14 and 1975-2014, respectively, based on weighted ensemble of 5 GCMs and 3 scenarios

simulated amounts with observed amounts. Furthermore, to check and estimate error amount of model, Mean Squared Deviations or MSD was computed using Equation 5. This index, shows general deviations of predicted amounts in comparison with observed amounts. Equation 6 is the sum of 3 indices, *i.e.*, Squared Bias or SB (Equation 7), Squared Differences of Standard Deviations or SDSD (Equation 8) and Lack of Correlation or (LCS Equation 9). Index of SB, indicates the degree of bias in simulated amounts and observed amounts. The index of (SDSD), elucidates on the difference in scattering between predicted amounts with observed amounts. In addition, (LCS) indicates time pattern of oscillation between observed and simulated data. In Equations 3-9, S_i, O_i are i^{th} simulated and observed data, respectively $\bar{S}, \bar{O}$, are total average of data S_i, O_i, in statistical society $S_i' = S_i - \bar{S}, O_i' = O_i - \bar{O}, N$ is total number of estimated samples, SD_s and SD_o are standard deviations of data S_i , O_i and r is correlation coefficient.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(S_i - \bar{S})(O_i - \bar{O})\right]^2}{\sum_{i=1}^{n}(S_i - \bar{S})^2 \sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (3)$$

$$D = 1 - \left[\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(|S_i'| + |O_i'|)^2}\right] \quad (4)$$

$$\mathrm{MSD} = \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n} \quad (5)$$

$$\mathrm{MSD} = \mathrm{SB} + \mathrm{SDSD} + \mathrm{LCS} \quad (6)$$

TABLE 1

Error validation of downscaled climatic parameters with observed data by different scenarios and models at Varanasi station

Parameter	Scenario	Model	R^2	D	MSD	SB	SDSD	LCS
Temperature	A1B	BCM2	0.9973	0.9931	2.694	0.3451	2.1737	0.1752
		CGCM3	0.9938	0.9664	2.9541	2.0378	0.587	0.3293
		CNRMCM3	0.9963	0.9861	2.0573	0.3087	0.9445	0.8041
		MRICGCM2.3	0.9991	0.9964	0.8064	0.0825	0.2393	0.4846
		MIROC3.2	0.9912	0.9418	2.0847	0.4014	0.7241	0.9592
	A2	BCM2	0.9973	0.9928	2.6702	0.183	2.3024	0.1848
		CGCM3	0.9937	0.9662	0.9315	0.0261	0.6871	0.2183
		CNRMCM3	0.9952	0.9861	2.0543	0.2828	0.996	0.7755
		MRICGCM2.3	0.9994	0.9965	0.7787	0.0759	0.2263	0.4765
		MIROC3.2	0.9901	0.9425	1.7435	0.0911	0.703	0.9494
	B1	BCM2	0.9974	0.9929	0.6158	0.2259	0.2058	0.1841
		CGCM3	0.9951	0.9663	1.8556	0.905	0.6333	0.3173
		CNRMCM3	0.9962	0.9854	2.0534	0.283	0.9952	0.7752
		MRICGCM2.3	0.9994	0.9962	0.7648	0.0744	0.2143	0.4761
		MIROC3.2	0.9939	0.9132	1.7663	0.089	0.7452	0.9321
Precipitation	A1B	BCM2	0.9934	0.9459	1.3029	0.7234	0.2385	0.341
		CGCM3	0.9912	0.9074	1.9352	0.5328	0.7449	0.6575
		CNRMCM3	0.9937	0.9813	2.0873	0.7748	0.5999	0.7126
		MRICGCM2.3	0.9948	0.9538	0.7298	0.0851	0.0138	0.6309
		MIROC3.2	0.9971	0.9903	0.4116	0.2322	0.024	0.1554
	A2	BCM2	0.9923	0.9461	1.2226	0.6582	0.2214	0.343
		CGCM3	0.9901	0.9162	1.3731	0.4521	0.3226	0.5984
		CNRMCM3	0.9957	0.9815	2.0812	0.7717	0.5974	0.7121
		MRICGCM2.3	0.9938	0.9532	0.7301	0.0842	0.0145	0.6314
		MIROC3.2	0.9971	0.9923	1.4089	0.2316	0.0221	1.1552
	B1	BCM2	0.9926	0.9459	2.2249	0.6318	1.2421	0.351
		CGCM3	0.9912	0.9063	3.7782	0.4851	1.6546	1.6385
		CNRMCM3	0.9941	0.9817	3.0806	0.776	1.6008	0.7038
		MRICGCM2.3	0.9933	0.9539	1.7696	1.124	0.0142	0.6314
		MIROC3.2	0.9967	0.9913	2.3656	1.2112	0.022	1.1324
Relative humidity	A1B	BCM2	0.8379	0.7124	4.4439	1.8936	0.747	1.8033
		CGCM3	0.8854	0.8144	4.111	0.063	2.919	1.129
		CNRMCM3	0.8268	0.6981	2.4888	0.1942	0.8372	1.4574
		MRICGCM2.3	0.854	0.7226	4.3955	1.4958	1.3706	1.5291
		MIROC3.2	0.9104	0.8348	4.2209	1.2497	1.0014	1.9698
	A2	BCM2	0.8514	0.8098	1.3669	0.1571	0.119	1.0908
		CGCM3	0.9174	0.8323	4.1613	2.0049	1.0754	1.081
		CNRMCM3	0.8558	0.8039	1.9244	0.5387	0.7199	0.6658
		MRICGCM2.3	0.8707	0.8297	4.324	2.1812	1.1447	0.9981
		MIROC3.2	0.9321	0.8435	4.4826	2.5282	1.7251	0.2293
	B1	BCM2	0.8623	0.7969	2.1985	1.0623	0.4975	0.6387
		CGCM3	0.8891	0.8214	2.3862	1.1019	1.1564	0.1279
		CNRMCM3	0.8558	0.7757	3.139	1.7952	0.3471	0.9967
		MRICGCM2.3	0.8707	0.8152	4.4545	1.1538	1.4598	1.8409
		MIROC3.2	0.9116	0.9188	3.6338	1.5587	0.7096	1.3655
Sea level pressure	A1B	BCM2	0.9971	0.9849	2.8521	1.1456	1.5228	0.1837
		CGCM3	0.9938	0.9554	3.9439	1.6692	0.9873	1.2874
		CNRMCM3	0.9957	0.9816	3.0881	0.443	1.8101	0.835
		MRICGCM2.3	0.9985	0.9921	2.2376	0.2222	1.3778	0.6376
		MIROC3.2	0.9916	0.9112	1.847	0.3144	0.4494	1.0832
	A2	BCM2	0.9972	0.9928	1.0886	0.8949	0.0457	0.148
		CGCM3	0.9937	0.9215	2.0195	0.6317	0.3108	1.077
		CNRMCM3	0.9966	0.9858	0.8739	0.304	0.0135	0.5564
		MRICGCM2.3	0.9989	0.995	1.0119	0.0004	0.3112	0.7003
		MIROC3.2	0.9926	0.9175	2.6987	0.8847	0.8675	0.9465
	B1	BCM2	0.9958	0.9823	4.7617	1.2221	2.7385	0.8011
		CGCM3	0.9935	0.9544	4.1099	0.9408	1.8411	1.328
		CNRMCM3	0.999	0.9848	2.8588	1.2266	1.4407	0.1915
		MRICGCM2.3	0.9966	0.9923	2.1724	0.2172	1.3259	0.6293
		MIROC3.2	0.9944	0.913	3.0852	0.5651	1.4397	1.0804

$$\mathrm{SB} = \left(\overline{S} - \overline{O}\right)^2 \quad (7)$$

$$\mathrm{SDSD} = \left(SD_s - SD_o\right)^2 \quad (8)$$

$$\mathrm{LCS} = 2SD_sSD_o\left(1 - r\right) \quad (9)$$

Table 1, shows the results obtained for error validation of data for the period of 2015 - 2054 for 5 used models and 4 selected climatic parameters. The model with the highest coefficient R^2 and agreement index and the least amount of indices of error verification, it will be more trustworthy model and its results will be more close to reality of climate change condition in that region. The results given in Table 1, indicate high amount of correlation coefficient and agreement index with low amount of error verification demonstrating relative adaptation of simulated data of 5 selected models with observed data. It allows the user to apply these models, in order to predict the future scenarios. Amongst all selected parameters, generally, the most error assessment model or MSD, was relevant to simulate sea level pressure and relative humidity. Because, according to obtained results, error coefficients were higher between these two used parameters. In all the 5 used models, the cases of rainfall and temperature are much reliable, because of existence of high correlation coefficient and agreement and MSD or less model error coefficient between simulated and observed data. Atmospheric-oceanic model of MRICGCM2.3 in scenario A2 with correlation coefficient of 0.9994 and agreement coefficient of 0.9965 and less error coefficient in MSD, SB, SDSD and LCS, had more accuracy in simulating mean seasonal temperature at Varanasi station. On the other hand, model of MIROC3.2 for seasonal rainfall parameter with scenario A2, had correlation coefficient of 0.9971 and agreement coefficient of 0.9923 and less error validation coefficient in SB, SDSD between simulated and observed data. Hence, this model was found, to have suitable and reliable operation in simulating rainfall parameter among the 5 used models. Also, in simulating seasonal relative humidity, model of MIROC3.2 with scenario B1, had correlation coefficient of 0.9116 and agreement coefficient of 0.9188, which is rather high, between simulated and observed data. Therefore, this model is more suitable among 5 used models in simulating seasonal relative humidity. Finally, model of MRICGCM2.3 with scenario A2, had high correlation coefficient of 0.9989 and agreement coefficient of 0.995 and less coefficient of SB for sea level pressure parameter. Therefore, this model showed, better precision in simulation of sea level pressure parameter among 5 used models.

The results obtained showed, an increase in predicted seasonal temperature in all the 3 scenarios and also, in mean annual temperature for the period of 2015-2054. The highest increase in predicted seasonal temperature, was about 9.3% according to scenario B1 for SW monsoon season compared to its observed period (Fig. 2). After SW monsoon season, higher increase in temperature, was related to mean annual temperature and summer season. These predicted increases in seasonal summer temperature and annual temperature, were equal to 5% and 7%, respectively in scenario B1. Also, it is clear that, the increase in mean seasonal winter temperature will be equal to 1.7%, 1% and 1.7% for the period of 2015-2054, which is higher than the base period in 3 scenarios of A1B,A2 and B1, respectively. But, for the post-monsoon season, 5 used models showed, an increase of about 3.7%, 3.7% and 3.8% in 3 scenarios of A1B, A2 and B1, respectively for predicted period. Fig. 3 shows, a considerable decrease in rainfall amount in the future compared to base period at Varanasi station. The most significant decrease, was predicted in rainfall with scenario A2 as -8.8 %, -6.8 % and - 4 % in

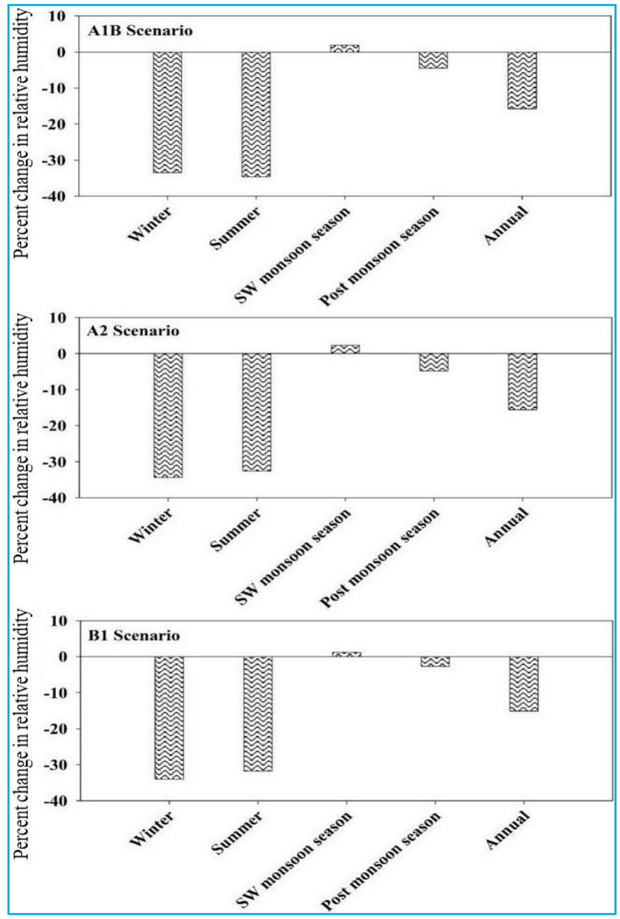

Fig. 4. Percentage of changes in predicted relative humidity at Varanasi station during 2015-2054 relative to both seasonal and annual periods of 1974-75 to 2013-14 and 1975 -2014, respectively, based on weighted ensemble of 5 GCMs and 3 scenarios

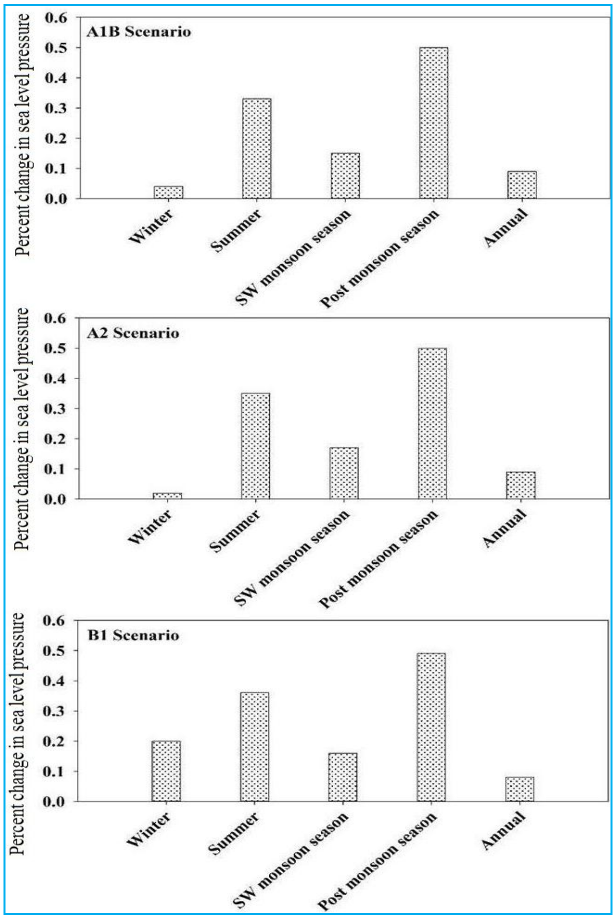

Fig. 5. Percentage of changes in predicted sea level pressure at Varanasi station during 2015-2054 relative to both seasonal and annual periods of 1974-75 to 2013-14 and 1975-2014, respectively, based on weighted ensemble of 5 GCMs and 3 scenario

SW monsoon season, post-monsoon season and on annual scale, respectively. Furthermore, significant decrease in predicted rainfall, was also associated with scenarios A1B, A2 and B1 that resulted in -7% , -9% and -8.3% in SW monsoon season for the future period of 2015-2054 compared to base period. As shown in Fig. 3, it is clear that, there is an increase in seasonal rainfall amount in winter season in all the scenarios of A1B, A2 and B1. As depicted in Fig. 4, relative humidity will be decreased in winter, summer , post-monsoon seasons and annual mean with varying amounts and an increase will occur, in SW monsoon season for the future period of 2015-2054 compared to base period in all the 3 scenarios. Maximum increase of 2% in relative humidity is obtained in SW monsoon season in both scenarios of A1B and A2. In winter season, the maximum amount of predicted relative humidity will be decreased by -35% in scenarios A2 for future period of 2015-2054. For summer season, a decline will happen, in relative humidity amounts to -35%, -33% and -32% with scenarios of A1B, A2 and B1, respectively. It seems that, decreasing trend in seasonal relative humidity for predicted future period in post-monsoon season, is lesser than the two winter and summer seasons. These decreasing amounts, are equal to -4%, -5% and -2.5% for scenarios of A1B, A2 and B1 respectively. At the annual scale, decline in amounts of relative humidity for assessed period of 2015-2054, are equal to -17%, -17% and -15% in 3 scenarios of A1B, A2 and B1, respectively. Sea level pressure at seasonal and annual scale, will be increased in 3 scenarios during assessed period of 2015-2054. However, the highest amount of increase in sea level pressure is predicted as 0.5%, 0.49% and 0.48% for scenarios of A1B, A2 and B1, respectively in post-monsoon season. As demonstrated in Fig. 5, sea level pressure at Varanasi station will be increased, about 0.34%, 0.36% and 0.37% in scenarios of A1B, A2 and B1, respectively in summer season. However, the increase in sea level pressure is very low in other seasons and on at annual scale. Thus, considering predicted results obtained from all the 3 scenarios of A1B, A2 and B1 for Varanasi district, it can be concluded that, Varanasi will experience an increase in temperature of SW monsoon season, decrease in rainfall of SW monsoon season, decrease in relative humidity of summer and winter seasons and partial increase in sea level pressure of post-monsoon season during period of 2015-2054 compared to observed period.

5. Conclusions

Among selected climatic parameters, higher error was obtained in simulating sea level pressure and relative humidity, but in case of temperature and rainfall, the 5 used models, were very reliable. Obtained results indicated, high correlation coefficient and agreement index with low amount of indices of error validation demonstrating, relative adaptation of simulated data of 5 selected models with their observed data. GCMs of MRICGCM2.3 with scenario A2 showed, better correlation and agreement coefficients and less error indices, in simulating two climatic parameters, *i.e*., mean seasonal temperature and mean seasonal sea level pressure. Hence, this model with scenario A2 was identified as, reliable model showing more accuracy in simulation of the two climatic parameters. Obtained results also showed that, SW monsoon season is a season with the highest increase in temperature for predicted period of 2015-2054 followed by annual increase in it. SW monsoon season was also recognized as, a season with the highest decrease in precipitation. Considering the results of 4 simulated climatic parameters for 40 next (years 2015-2054), Varanasi district will experience, a climate somewhat dry in winter and summer seasons due to forestalled decline in relative humidity. The study region will also be confronted with, reduction in precipitation and an increase in the temperature in SW monsoon season. In post-monsoon season, Varanasi district, will be faced with partial augmentation in sea level pressure, very partial reduction in relative humidity and sensible decline in precipitation.

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