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Precipitation Intensity-Duration-Frequency Curves Under Changing Climate - Aurangabad (Ms), India.

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Abstract: **-- Stormwater plays an important role in analysis, design and planning of storm water drains in case of rapidly growing urbanization. The change in rainfall pattern and intensity is becoming a great concern for hydrologic engineers and planners. The rainfall Intensity-Duration-Frequency (IDF) curves are commonly used in storm water management and other engineering design applications across the world and these curves are developed based on historical rainfall time series data by fitting a theoretical probability distribution to extreme rainfall series. In recent years, it has been widely reorganized that the extreme precipitation events are increasing due to global climate change. In addition, due to population and property concentration in relatively small areas, the flood damage potential in urban areas is high and the extreme rainfall events are the main cause of urban floods. Therefore, it is important to study the climate change impacts on rainfall IDF curves of an urban area. In this study, with the help of five Global Climate(GCMs) simulations and 'K' Nearest Neighbor(KNN) weather generator based downscaling method, the impacts of climate change on rainfall IDF curves of Shendra (DMIC) Aurangabad (MS), India are studied. Results of this study indicate that the climate change is increasing extreme rainfall events of Shendra (DMIC) Aurangabad. In addition, it is also observed that the return of period of an extreme rainfall of the Shendra (DMIC) Aurangabad is reducing.**

I. INTRODUCTION

The Study area is Shendra covering three villages namely Ladgaon, Kumbhephal, Karmad. Storm Water Management (SWM) is an inclusive concept and it refers to the policies, procedures, methods and options used to analyze and design, drainage systems that control the quantity of storm water runoff, reduce erodability, prevent flooding, preserve or enhance the quality of storm water runoff and ascertainment of preparedness with proposals of disaster management strategies in case of extreme events. To arrive at best management practices (BMP) in respect of SWM it is imperative to address major issues such as: accurate assessment of hydrological parameters such as rainfall pattern, runoff volume and its characteristics, delineation of flood prone area and hydraulic parameter such as routing of discharges through river/stream/nalla/culvert/channel, obtaining water profile, depth and velocity of flow, identification of sites for artificial storm water management system and emergency options. In the present era of vibrant economy and fast track development, these issues assume significant importance if the project area is undergoing rapid infrastructure growth and the associated financial stakes and interests are very high. The rainfall Intensity-Duration-Frequency (IDF) curves are commonly used in storm water management and other engineering design applications across the world (Endreny & Imbeah, 2009) and these curves are developed based on historical rainfall time series data by fitting a theoretical probability distribution of annual maximum rainfall series or partial duration series (Cheng & AghaKouchak, 2014). The increase in greenhouse gas concentrations is causing large-scale variations in atmospheric processes, which can then lead to changes in rainfall and temperature characteristics. Especially, recent studies show that the extreme rainfall events are intensifying due to global climate change (Allen & Ingram, 2002; Trenberth, et al., 2003; Emori & Brown, 2005; Tramblay, et al., 2012; Cavanaugh, et al., 2015; Xu, et al., 2015). Since the flood damage potential in urban areas is high due to population and property concentration in relatively small areas and the extreme rainfall events are the main cause for urban floods, it is essential to study the impacts of climate change on extreme rainfall characteristics of an urban area to reduce the flood damage of that city.Anticipating the potential effects of climate change on rainfall IDF curves and adapting to them is one way to reduce vulnerability to adverse impacts (Prodanovic & Simonovic, 2007). In particular, the changes in extreme rainfall events can lead to a revision of standards for urban infrastructures (ex. storm water drainage networks). Current design standards are based on historical climate information. For example, primary storm water drainage network is designed to control a 10-year flood event. But, if the intensity and duration of the 10-year flood event increase in future, it will provide a significantly lower level of protection. Therefore, to prepare for future climate changes, it is crucial to study the impacts of climate change on rainfall IDF curves of a city. Hence, in this study, the impact of climate change on rainfall IDF curves of the Shendra (DMIC) Aurangabad., India is studied.

II. STUDY AREA AND DATA

Government of India is undertaking the development of Shendra Mega Industrial Park in district Aurangabad, Maharashtra in partnership with the State Government. The Maharashtra Industrial Development Corporation (MIDC) is the nodal agency responsible for implementation of Shendra Mega Industrial Park (MIP) in Maharashtra. The proposed Shendra MIP is spread over an area of 845.38 hectares (ha), covering three villages-of Ladgaon, Karmad and Kumbephal and primarily includes rural hinterland, comprising of agricultural lands and scrub lands. The land for the project is under possession with MIDC and was acquired under the Maharashtra Industrial Development Act 1961.The project has been accorded Environmental Clearance vide letter No. 21-1/2013-IA.III dated 18th June, 2015.About 50% of the total area has been demarcated for industrial land use, 8.4% for residential land use, 8.4% for transportation, 9.75% for commercial and 7.18% for public/semi-public uses, About 10.22% is earmarked for parks and open spaces. The annual rainfall over the study area varies from about 500mm to about 840mm.The climate of the area is characterized by a hot summer with dry conditions throughout the year except during the south-west monsoon season. The maximum and minimum temperature in the study area is 41.50c and a 28.50c.The major part of the district constitutes a sequence of basaltic lava flows (Deccan trap). The area extends within 19030’39.89” N - 19053’37.83” N Latitude and 75030’39.89” N - 75033’0.63” E Longitude. High drainage density in study area enables the region to be developed as a hub for future storm water management systems, is subjected to the same average climatic and geologic conditions. The area covered by survey of India toposheet map no. 47 M / 5 on scale 1:50000.The hourly observed rainfall data is procured from the India Meteorological Department (IMD) for the period of 01-01-1970 to 31-12-2016 (46 years). This data is a gauge observation and it is observed at the center of the Hyderabad city i.e. 78.46o E and 17.45o N. From the hourly observations, the 2-Hr, 3-Hr, 6-Hr, 12-Hr, 18-Hr and 24-Hr duration rainfall are calculated.

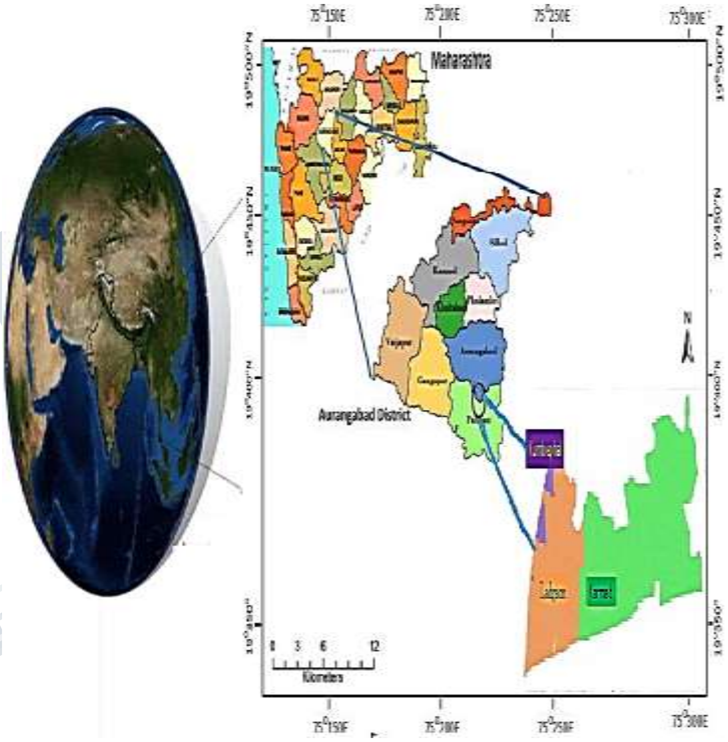
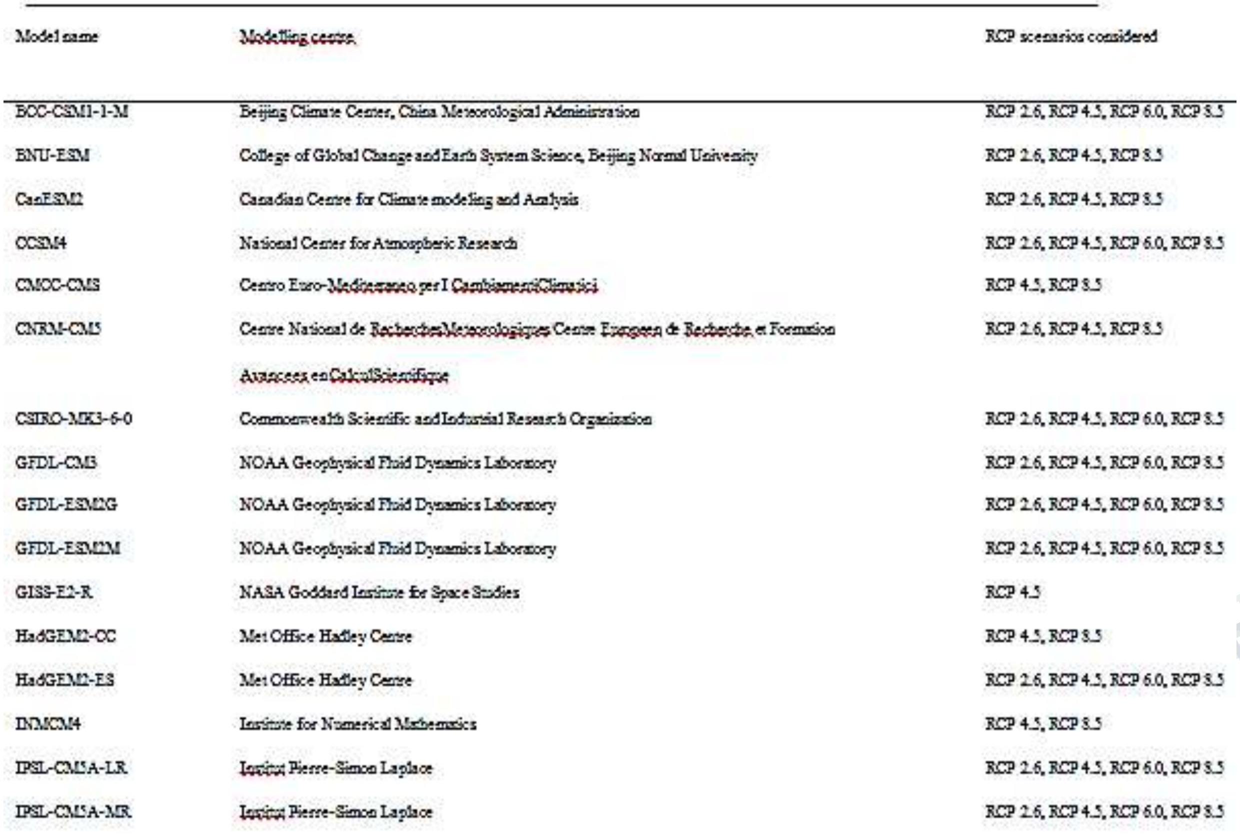


Figure 1: Location map of Shendra (DMIC) Aurangabad (Pathan & Waikar, 2016)

In addition, five GCM precipitation flux outputs (Table 1) for historical and future time periods are downloaded from CMIP5 website http://www.ipcc-data.org/sim/gcm_monthly/AR5/Reference-Archive.html (accessed during September anSd October 2017).

Table 1: List of GCMs used and the future climate scenarios considered for the study area.



Model name	Modelling centre	RCP scenarios considered
BCC-CSM1-1-M	Beijing Climate Center, China Meteorological Administration	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	RCP 2.6, RCP 4.5, RCP 8.5
CanESM2	Canadian Centre for Climate modeling and Analysis	RCP 2.6, RCP 4.5, RCP 8.5
CCSM4	National Center for Atmospheric Research	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
CMCC-CMS	Centro Euro-Mediterraneo per I CambiamentiClimatici	RCP 4.5, RCP 8.5
CNRM-CM5	Centre National de RecherchesMeteorologiques/Centre Europeen de Recherche et Formation Avancees enCalculScientifique	RCP 2.6, RCP 4.5, RCP 8.5
CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organization	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
GISS-E2-R	NASA Goddard Institute for Space Studies	RCP 4.5
HadGEM2-CC	Met Office Hadley Centre	RCP 4.5, RCP 8.5
HadGEM2-ES	Met Office Hadley Centre	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
INMCM4	Institute for Numerical Mathematics	RCP 4.5, RCP 8.5
IPSL-CM5A-LR	Institut Pierre-Simon Laplace	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5
IPSL-CM5A-MR	Institut Pierre-Simon Laplace	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5

III. METHODOLOGY

The aim of this study is to study the impacts of climate change on rainfall IDF curves of the Shendra (DMIC) Aurangabad, India. The methodology adopted to achieve the aim of this study comprises of following three parts,

1. To obtain historical observed rainfall IDF curves using extreme value analysis.
2. Assessment of future rainfall IDF curves with the help of Global Climate Model (GCM) simulations.
3. Identifying the impacts of climate change on rainfall IDF curves by comparing these two IDF curves in terms of return levels.

Past year rainfall data (1970-2016) from IMD, Pune (Shivajinagar) were collected for rain gauge station of chikalthana situated at Aurangabad city to analyze rainfall pattern and to develop IDF curve relationship:

Table.2 Annual mean Rainfall Data (mm) of Aurangabad City (1970-2016)

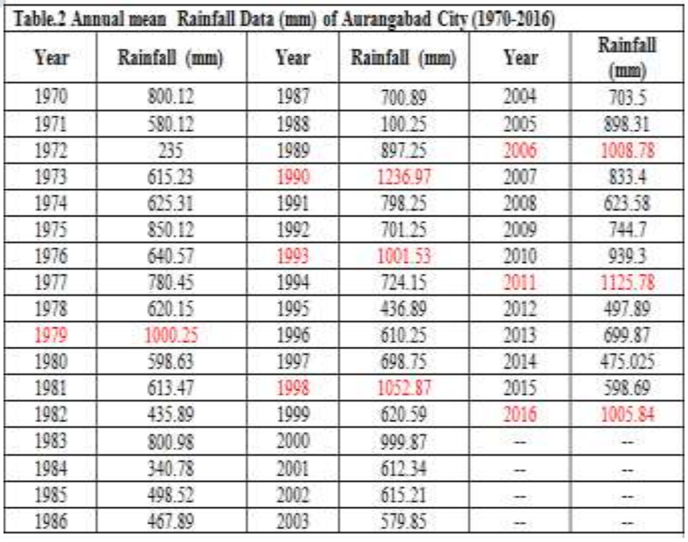
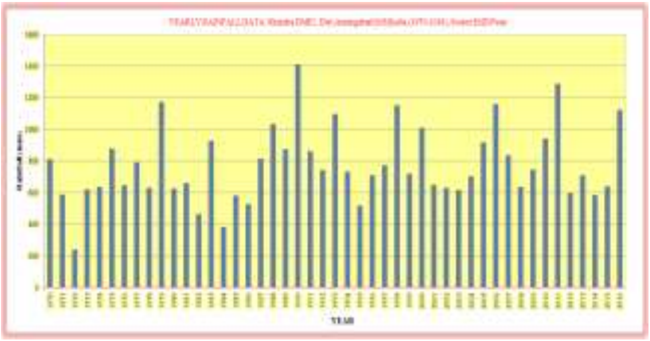


Table.2 Annual mean Rainfall Data (mm) of Aurangabad City (1970-2016)

Year	Rainfall (mm)	Year	Rainfall (mm)	Year	Rainfall (mm)
1970	800.12	1987	700.89	2004	703.5
1971	580.12	1988	100.25	2005	898.31
1972	235	1989	897.25	2006	1008.78
1973	615.23	1990	1236.97	2007	833.4
1974	625.31	1991	798.25	2008	623.58
1975	850.12	1992	701.25	2009	744.7
1976	640.57	1993	1001.53	2010	939.3
1977	780.45	1994	724.15	2011	1125.78
1978	620.15	1995	436.89	2012	497.89
1979	1000.25	1996	610.25	2013	699.87
1980	598.63	1997	698.75	2014	475.025
1981	613.47	1998	1052.87	2015	598.69
1982	435.89	1999	620.59	2016	1005.84
1983	800.98	2000	999.87	--	--
1984	340.78	2001	612.34	--	--
1985	498.52	2002	615.21	--	--
1986	467.89	2003	579.85	--	--



3.1. Gumbel's Method

Gumbel's distribution type-I is the most widely distribution for IDF analysis owing to its suitability for modeling peak rainfall depth for different duration. In this method, the frequency precipitation depth X_T (in mm) for any rainfall duration t_d (in hour) with specified return period T_r (in year) is computed.The Gumbel method calculates the 2, 5, 10, 15, 25, 50, and 100-year return intervals for each duration period.

Procedure for IDF curve

Estimation of short duration rainfall-from daily rainfall data to hourly data, Indian meteorological department (IMD) use an empirical reduction formula for estimation of short duration rainfall like 5 min, 15 min, 30 min, 1-hr, 5-hr, 6-hr, 12-hr and 24-hr and so on Chowdhury et.al.(2007),

$$P_t = P_{24}\left(\frac{t}{24}\right)^{1/3} \qquad 1$$

P_t = required rainfall depth in mm at t − hr duration
P_{24} = daily rainfall (mm)
t = the duration of rainfall for which the rainfall depth is required in (hrs)

Climate change analysis:

In this study, the average rainfall was determined at every 2, 3,5,10,15,25,50 and 100-year interval, which gives IDF and change in rainfall depth with climate change effect.

Probability analysis for one day annual maximum rainfall:

The purpose behind frequency analysis of an annual series is to obtain a relation between the magnitude of the event and its probability of exceedance. The probability P of an event equated to or exceeded is given by the Weibull formula.

$$P = \frac{m}{N+1} \qquad 2$$

The recurrence interval or return period,

$$T = \frac{1}{P} \qquad 3$$

Rainfall Intensity: The intensity of rainfall is the rate of precipitation i.e. depth of precipitation per unit time and is given by,

$$i = \frac{P_t}{D} \qquad 4$$

In this method, the frequency precipitation depth X_T (in mm) for any rainfall duration t_d (in hour) with specihe Gumbel method calculates the 2, 5, 10, 15, 25, 50, and 100-year return intervals for eacfied return period T_r (in year) is computed.Th duration period.

$$X_T = \bar{X} + K_T S \qquad 5$$

$$\bar{X} = \text{mean} = \frac{1}{m}\sum x_i$$

$$S = \text{standard deviation} = \sqrt{\frac{\Sigma(X_i - \bar{X})^2}{N-1}}$$

$$K_T = -[0.5772 + \ln\left[\ln\left[\frac{T}{T-1}\right]\right]] \qquad 6$$

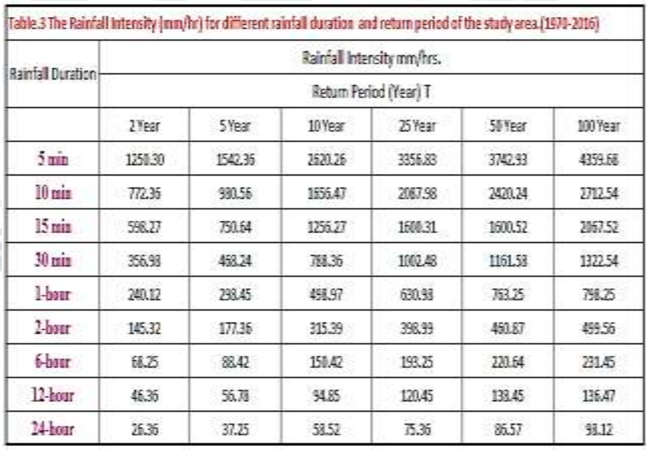


Table.3 The Rainfall Intensity (mm/hr) for different rainfall duration and return period of the study area.(1970-2016)

Rainfall Duration	Rainfall Intensity mm/hrs.					
	Return Period (Year) T					
	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
5 min	1250.30	1542.36	2620.26	3356.83	3742.93	4359.68
10 min	772.36	980.56	1656.47	2067.98	2420.24	2712.54
15 min	598.27	750.64	1256.27	1600.31	1600.52	2067.52
30 min	356.98	468.24	788.36	1002.48	1161.58	1322.54
1-hour	240.12	298.45	498.97	630.98	763.25	798.25
2-hour	145.32	177.36	315.39	398.99	460.87	499.56
6-hour	68.25	88.42	150.42	193.25	220.64	231.45
12-hour	46.36	56.78	94.85	120.45	138.45	136.47
24-hour	26.36	37.25	58.52	75.36	86.57	98.12

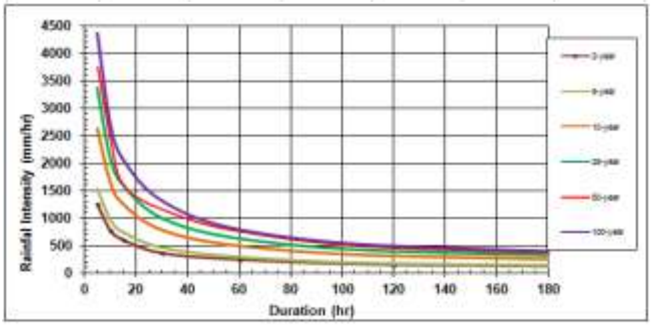


Figure 2: Rainfall IDF curves of the Shendra (DMIC), Aurangabad from observed rainfall.

IV. FUTURE SIMULATED RAINFALL IDF CURVE

GCM simulations offer possibilities of what might happen if the future development follows a certain course of action i.e. scenarios (Prodanovic & Simonovic, 2007) and it can be used to develop rainfall IDF curves for future rainfall conditions (Mailhot, et al., 2007; Prodanovic & Simonovic, 2007; Willems, 2013; Rodriguez, et al., 2014; Rupa, et al., 2015). In this study, five GCM outputs of different Representative Concentration Pathways (RCPs) scenario are considered. The list of GCMs and scenarios used in this study are given in Table 1. For each climate model, the grid point which is nearest to Hyderabad city rain gauge station is considered. Rainfall data from GCMs are only available at the low spatial resolution and cannot be applied directly to studies of climate impacts at the smaller scale (Willems, et al., 2012; Bi, et al., 2015). Downscaling of climate variable (in this case rainfall) is a technique that consists of deriving high-resolution climate data from low-resolution GCM data. In this study, in order to obtain future downscaled rainfall time series, the observed for-the-day maximum rainfall series are first altered using change factor method.

2016-2057 average change factors calculated using daily scaling method for RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios are shown in Figure 3 and Figure 4 shows the same for the 2058-2099 time periods. These change factors are then applied to the observed for-the-day maximum rainfall time series of different rainfall durations and the altered time series are further resample using KNN algorithm. Towards developing future rainfall IDF curves, the annual maximum rainfall series is extracted from the KNN resample datasets and these annual maximum rainfall series are fitted with GEV distribution (Eq. (1)). Further, return levels are calculated for different return periods with GEV distribution parameters which are obtained from the future extreme rainfall time series of different RCP scenarios. The return levels calculated with future downscaled rainfall data for different durations and return periods are given in Table 2 for both 2016-2057 and 2058-2099 time periods.

		2016-2057				2058-2099			
	Observed	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP4.5	RCP6.0	RCP8.5
2-Year									
1-Hr	43.86	44.14	41.61	42.04	43.61	40.28	49.21	47.86	49.28
2-Hr	27.63	29.26	26.01	27.54	28.44	27.57	30.89	30.39	31.42
3-Hr	20.15	21.43	18.83	18.97	20.67	20.87	22.42	22.75	22.67
6-Hr	11.60	12.21	10.84	11.34	11.69	11.15	12.60	12.94	12.58
12-Hr	5.27	5.32	6.12	6.67	7.01	6.25	7.14	7.07	7.22
18-Hr	5.12	5.98	4.87	4.80	4.66	4.61	4.98	4.48	5.62
24-Hr	3.50	3.72	3.92	3.75	3.89	3.87	3.28	3.96	4.28
5-Year									
1-Hr	52.27	53.87	50.55	52.33	54.31	52.59	60.76	63.48	59.64
2-Hr	32.89	34.86	31.45	32.99	34.81	33.51	39.15	40.65	39.31
3-Hr	24.29	25.59	23.70	24.89	24.88	24.94	28.57	30.15	28.63
6-Hr	14.03	14.72	14.00	14.51	15.10	14.60	16.76	17.62	16.59
12-Hr	8.44	8.72	8.16	8.65	9.01	8.33	9.98	9.93	10.02
18-Hr	6.38	6.84	6.23	6.55	6.57	6.42	7.23	6.85	7.59
24-Hr	5.21	5.34	5.12	5.26	5.41	5.38	5.74	6.04	5.90
10-Year									
1-Hr	55.26	54.52	51.24	53.25	54.64	53.60	61.28	64.49	61.32
2-Hr	33.15	35.05	32.54	33.62	34.95	33.53	40.18	41.64	40.25
3-Hr	23.36	26.63	25.41	26.25	24.76	24.95	29.36	32.16	28.39
6-Hr	15.10	15.03	16.01	16.09	15.18	14.68	17.81	18.67	17.85
12-Hr	9.27	9.86	8.16	9.41	10.58	8.74	10.27	10.87	11.15
18-Hr	7.82	6.84	7.20	7.52	7.82	6.78	7.29	7.15	8.15
24-Hr	6.31	6.32	6.21	6.29	6.14	5.47	5.98	7.52	6.25
25-Year									
1-Hr	59.64	62.83	58.34	62.60	64.96	62.47	77.88	86.30	70.39
2-Hr	39.01	41.74	36.51	37.64	41.12	40.50	48.76	55.50	46.94
3-Hr	31.68	33.35	30.46	32.10	32.79	31.96	37.15	41.14	36.49
6-Hr	19.37	20.30	18.95	19.12	20.22	20.37	23.33	25.03	22.98
12-Hr	12.16	12.55	12.27	11.03	11.43	12.41	15.35	15.77	14.78
18-Hr	9.59	9.74	8.67	9.06	10.19	9.75	11.88	13.38	10.24
24-Hr	8.30	8.00	7.36	8.30	7.94	8.34	10.48	12.26	9.46

Table 4: Return levels in mm/hr.

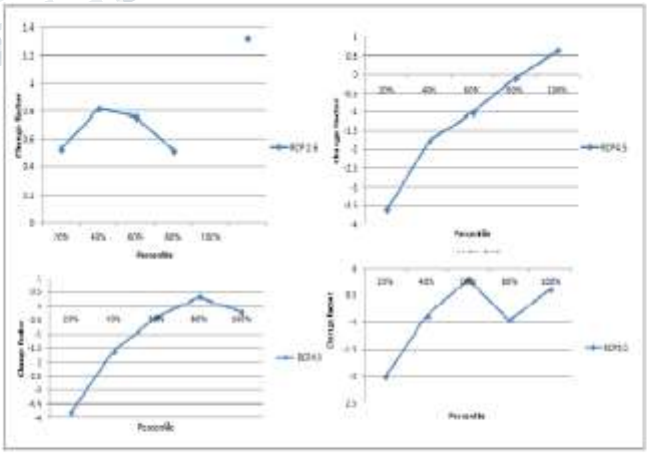


Figure 4: 2015-2056 average change factors for (a) RCP 2.6, (b) RCP 4.5, (c) RCP 6.0 and (d) RCP 8.5 scenario.

COMPARISON OF TWO METHODS

Overall, from the Table 4, it is observed that the return of period of an extreme rainfall of the Shendra (DMIC), Aurangabad is reducing. In particular, during 2016-2057 and under RCP 8.5 scenario, the 10 year return period future extreme rainfall of 1-hour duration is 61.32 mm/hr and it is nearly equal (61.32 mm/hr) to the 25 year return period observed extreme rainfall. Similarly, during 2058-2099 and under RCP 8.5 scenario, the 5 year return period future extreme rainfall of 1-hour duration is 61.32 mm/hr and it is equal (61.32 mm/hr) to the 25 year return period observed extreme rainfall. Therefore, from the results, it is observed that the return of period of an extreme rainfall of the Shendra (DMIC), Aurangabad is reducing and the Shendra (DMIC), Aurangabad drainage networks will fail more frequently than its actual design.

V. CONCLUSION

In order to study the impacts of climate change on rainfall IDF curves of the Shendra (DMIC) Aurangabad , rainfall IDF curves of two future time periods are developed with the help of five GCM (Table 1) simulations and KNN weather generator based downscaling method. The KNN weather generator is coded in the R programming language. Further, these IDF curves are compared with the IDF curves which are developed with observed rainfall of the Hyderabad city. Since the study area is an urban catchment and most of the urban infrastructure is designed for return level of 25 year or less, the observed and future IDF curves are compared in terms of 2, 5, 10 and 25 year return levels. From the comparison results, it is observed that the return period of an extreme rainfall of the Shendra (DMIC), Aurangabad is reducing. In other words, if the IDF curve developed from the observed data is used for an infrastructure design of the Shendra (DMIC), Aurangabad, the drainage networks will fail more frequently than its actual design.

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