ANALYSIS RAINFALL INTENSITY-DURATION-FREQUENCYRELATIONSHIPS UNDER CLIMATE CHANGE FOR MEKELE CITY, ETHIOPIA

Ekubay Tesfay Gebreigziabher
E-Mail Id: ekubay.tesfay@yahoo.com
Natural Resources Management Research Core Process
Shire-Maitsebri Agricultural Research Center (SMARC)

Abstract: Predicted future climate change impacts indicate that there will be increases in rainfall, leading to an intensification of the hydrologic cycle. One of the expected consequences of change is an increase in the magnitude and frequency of extreme events (e.g. high intensity rainfall, flash flooding, severe droughts, etc.). The main focus of this study is to see how intensity of rainfall changes in Mekele city under the conditions of the changed climate. To provide present and future Intensity-Duration-Frequency (IDF) information, historically daily and hourly rainfall data was collected and RCP2.6, RCP4.5 and RCP 8.5 climate scenarios was spatially downscaled using Statistical Downscaling Model (SDSM 4.2.9).Daily rainfall climate scenario data was generated and disaggregated in to hourly basis using regression models. Expected rainfall quantiles (X_T) for0.5Hr,1Hr,2Hr.4Hr,6Hr,8Hr,12Hr& 24Hr durations were computed at return periods of 2, 5, 10, 25, 50, and 100 years using frequency analysis. Intensity-Duration-Frequency (IDF) model parameters (A, B and C) were estimated and their performances evaluated. Mathematical relationships between Intensity-Duration-Frequency of rainfall were developed for all stations for the present and future climate conditions. Percentage differences in the intensity of rainfall between the current and future climate scenarios were quantified and general trends for the 21st century time line has established. In general, the outcomes of this study indicate that future rainfall Intensity patterns under the emerging climate change scenarios at Mekele city would vary. It is expected to decrease up to maximum range of 78.61% for longer frequencies while it tends to be higher up to 65.95% at shorter frequencies. These have major implications on ways in which current and future water management infrastructures are designed, operated, and maintained. Consequently, design standards and guidelines currently employed in the study area should be reviewed and/or revised with the reflection of the impacts of climate change.

Keywords: IDF relationships, Climate change, Downscaling, Disaggregation.

1. INTRODUCTION

One of the first steps in many hydrologic design projects, such as in urban drainage design, is the determination of the rainfall event or events to be used. The most common approach is to use a design storm or event that involves a relationship between rainfall intensity, duration and the frequency. In hydrologic term the relationship between rainfall intensity-duration–frequency is called IDF curves. IDF curves are graphical representations of the amount of rainfall that falls within a given period of time. It is usually represented as a graph with rainfall duration (D) plotted on horizontal axis, Intensity (I) on the vertical axis and a series of curves, one for each design return period [1].Current IDF curves are developed based on the concept of climate stationarity, which assumes that the occurrence probability of extreme precipitation events is not expected to change significantly over period of time.

However, climate change is expected to alter the intensity, duration and frequency of rainfall over time. The atmosphere of planet earth is undergoing changes unparalleled in human history. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change [2] "Warming of the climate system is unambiguous, and many of the observed changes are unprecedented over decades to millennia. This report also concluded with Very high confidence that the period from 1983 to 2012 was the warmest 30-year period of the last 1400 years. Furthermore, researches indicated that the rising temperatures and subsequent increases in atmospheric moisture content would be increase the probable maximum precipitation (PMP) or the expected extreme precipitation. Such changes in extreme climate events have enormous ecological, social and economic impacts and have great implications for municipalities and water resource management infrastructures [3]. With changing climate, it is necessary to thoroughly review and/or update the current design standards for urban Storm drainage and water management infrastructure in order to prevent the possibility of future infrastructure performing below its designed guideline. Changing hydro climatic conditions also require improvement, retrofitting and renovation. Therefore, one way of reducing vulnerability to adverse impacts of climate change is to anticipate their possible effects and developing adaptation mechanisms [3].Therefore, development of climate change adaptive design mechanisms is now becoming a major field of research in hydrology. Thus, the purpose of this research work was to construct climate change resilience rainfall IDF curves for urban drainage infrastructure design purposes for the 21st century for Mekelle City.

pg. 1
www.ijtrs.com
www.ijtrs.org

1.1 Statement of the Problem

This research work was initiated and executed due to two critical motives. The primary rationale is the concern of climate change. Climate change is the sever problem that the whole world facing today. It is now widely accepted that climate change is already happening and further change is inevitable. Among the different assessment that are carried out by the IPCC; the most recent which published in 2014 states that the projected global surface warming lies within the range of 0.3 to 4.8 ^{o}C at the end of this century relative to the 1986-2005[2]. Besides, the above mentioned global climate anomaly, some studies conducted in the study area show that Tigray Region is climate sensitive [4]. Therefore, without urgent and concerted action, it will damage fragile ecosystems, impede development efforts, frustrate poverty alleviation programs.

The second rationale is the non-availability of processed hydrologic data base. Before a hydraulic structure can be designed, the hydraulic engineer must prepare a hydraulic report indicating adequate opening size required to convey the water from a specific design basin. However, the dearth of processed hydrological data base is one of the major problems in Ethiopia as well as in the study area. This can be expressed by the non-availability of adequately processed and compiled standard information like IDF curves [5].

Some research works were done about rainfall IDF for some parts of Ethiopia like for Oromia region [5], Amhara & Tigray regions together [6] and Ethiopia Southern nations, nationalities and peoples region [7]. However, in addition to lack of geographical representativeness, all the earlier research works were based on the climate stationarity assumptions; which could not be a true premise under the current warning symptoms of climate change. Hence, in the absence of these climate change resilience IDF tools, water resource engineers are suffering in the planning and design of projects in the country as well as in the study area. In Ethiopia, until recently there were no comprehensive IDF relationships developed like families of curves and maps. Because of lack of this basic hydrological tool, the planning and design of urban flood drainage works and other water resource projects are often designed and implemented based on some assumptions and empirical data, even sometimes using data from other countries.

1.2 Objectives

- ➢ Develop mathematical relationships among Intensity-Duration-Frequency of rainfall for Mekele City under present and future climate change scenarios
- ➢ Evaluate the general temporal trends of the IDF curves under future climate change scenarios as compared to the present climate conditions

2. METHODS AND METHODOLOGIES

2.1 Study Area Description

The study area selected for this research is Mekele City, which is located in the Northern Tip of Ethiopia. Geographically the city is located at 13.52^{0} latitude and 39.49^{0} longitudes and 2100 meter above sea level (**Fig. 2.1**). The average annual rainfall ranges from 400 mm to 700 mm and about 84% of the rainfall is received in the Monsoon season (June-August).
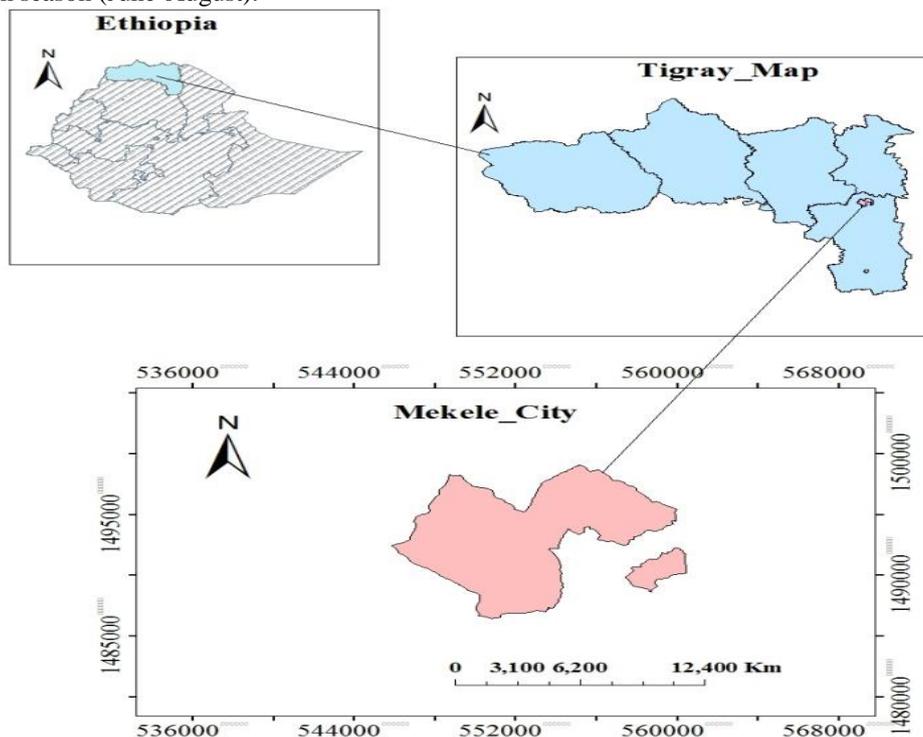

Fig.2.1 Map of Study Area

2.2 Historical Data Set

The historical precipitation data for the study city were collected from the Ethiopian National Meteorological service Agency (ENMSA).Another nearby meteorological stations was selected for missing rainfall value and consistency estimation purposes.

The missing rainfall values are estimated using inverse weighted distance method (IDW) between station in the city and nearby stations outside the city at comparable altitude and distances. Double mass curve method as used to check rainfall data consistency.

2.3 The Climate Change Scenario Data

Climate change scenarios data were obtained from Global Circulation Model (GCM/AOGCMs) simulation outputs. For this study, among the different GCM/AOGCM models, the second generation Canadian Earth System Model (CanESM2) for the African window was used.

The nearest grid boxes to the study area containing three emission pathways (RCP8.5, RCP4.5&RCP2.6) which is freely available at the Canadian Climate data and scenarios website (http://www.cccsn.ec.gc.ca/?page=download-intro) was obtained and downscaled to the site level. The CanESM2 is a global climate model of earth system category developed by Canadian Centre for Climate Modeling and Analysis. The resolution is uniform along the longitude with 2.8125° and nearly uniform along the latitude of roughly by 2.8125°.

2.4 Downscaling Daily Precipitation

In this study to bring the course resolution $(2.8125^0 \text{x} 2.8125^0)$ CanESM2/GCM outputs to a point scale resolution, Statistical downscaling model (SDSM 4.2.9) was employed using daily predictor-predictand relationships. SDSM has been used in different regions of the world and is widely accepted in climate change impact studies.

2.5 Disaggregation of Daily Rainfall

Downscaling results are daily bases and hence need to be divided/disaggregated to an hourly time scales to be convenient for IDF development. Different regression models relating the 24 hour(daily) observed rainfall records with the hourly rainfall records(0.5hr,1hr 2hr, 4hr,6hr, 8hr and 12hr)were first developed and then the developed models were used to disaggregate the future daily climate change scenario rainfall data in to 0.5hr,1hr 2hr, 4hr,6hr, 8hr and 12hr durations.

2.6 Rainfall Intensity-Duration-Frequency Analysis

Once the two stages downscaling-disaggregation rainfall modeling has carried out, annual maximum rainfall series data at required durations were collected for the base period and future climate change periods. The whole future simulation period was divided into three time horizons; the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100).

Different candidate Probability distribution functions were fitted to the annual maximum series data of the base period and those best fitted probability functions were used to estimate future rainfall quantiles under the climate change scenarios.

IDF model proposed by [8] were used to model the rainfall intensity-Duration-Frequency (IDF) relationships.

$$I = \frac{A}{(D + B)^c}$$

Where: I, is rainfall intensity (mm/hr), D is duration of rainfall (minutes), A is coefficient for a given return period with units of mm/hr, B is time constant in minutes and C is an exponent.

The value of the model parameters were solved by least square optimization algorithm for return periods of 2, 5, 10, 25, 50 and 100 years.

3. RESULT AND DISCCUSION

3.1 Homogeneity and Consistency of Rainfall Data Series

Double Mass curve, which is the plot of the cumulative annual rainfall of the test station against the cumulative annual average rainfall of the group of reference stations, was used to check the consistency of the rainfall data series. Accordingly, as shown below from Fig. 3.1, the graph of the double mass curve plot was found to be almost linear for Mekele station with coefficient of determination (R^2) =0.998.

This implies that the rainfall data was consistent over the considered period of time. To determine the homogeneity of the rainfall data series, a trend analysis was made by a nonparametric Mann-Kendall rank test method and Mann-Whitney parametric test methods at 5% significance level.

The result of the statistics associated with those tests is summarized in Table-3.1.

Based on the hypothesis made, the computed test statistics at Mekele station was found to be greater than the Critical statistic value (at alpha = 0.05) as shown in Table-3.1 above.

Thus, one can generalize that there is no trend in the rainfall data series at Mekele station. This depicts that the data is homogenous and identically distributed.
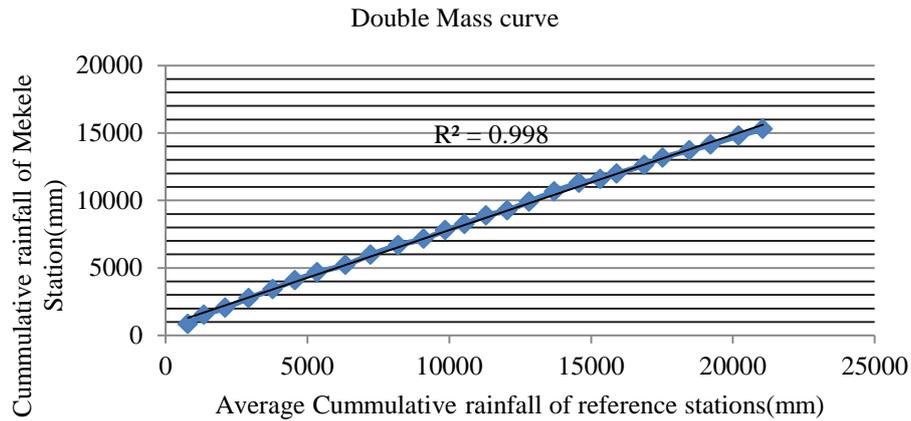
Fig. 3.1 Double Mass Curve Plot for Mekele Station

Table-3.1 Summery Statistics of the Mann-Kendal and Mann-Whitney trend test for Mekele Station

	Computed Test statistic		Critical Statistic (Two tailed),α=5%	Remark
	Mann Kendall (Z)	Mann-Whitney(μ)		
	1.15	1.13	1.96	No Trend

3.2 Downscaled Future Climate Rainfall Data

Daily synthetic rainfall time series were generated for the whole 21[st]Century (2006-2100) for RCP2.6, RCP4.5 and RCP8.5 Climate change scenarios. The outcome of the 20 ensembles of future climate change was averaged and divided into three time horizons, which are the near term 2020s (2011-2040), midterm 2050s (2041-2070) and the long-term 2080s(2071-2100) for further analysis of climate change impact on IDF. A reference base period that represents the current climate conditions was considered from 1986-2015. The percentage difference (change fields) between the present and future climate forcing scenario was constructed in reference to this period. The percentage change (change field) in monthly mean precipitation, for the three future time horizons was established as indicated in Fig. 3.2-Fig. 3.4. As shown from Fig. 3.2-Fig. 3.4,there would be a decrease in mean monthly precipitation at Mekelle station under RCP2.6 emission scenario for the 2020s(2011-2040) in the months of January by 41.88%, February (0.17%), April (23.15%), May(24.78%), September (12.34%), October(56.07%), November(5.69%) and December (55.56%) while there would be an increase in the months of March by 22.20%, Jun (29.81%), July (4.39%) and August (11.88%).In the case of RCP4.5 scenario, the months of March, Jun, July, August and September would be increased by 57.94%, 23.43%, 19.14%, 11.14%, and 7.12% respectively. However, the months of January, February, April, May, October, November, and December would be expected to decrease by 60.9%, 0.73%, and 43.73%, 27.97%, 47.46%, 31.15% and 75% respectively. In the case of high emission scenario RCP 8.5,a mean monthly precipitation increase in the months February by 1.32%, March(36.13%), Jun(48.16%), July(18.32%), August(13.49%),September (13.66%) and November(24.05%) while in the months of January, April, May, October and December would be expected to decrease by 60.27%,44.36%,36.23%,58.54% and 50.85% respectively.

By 2050s (2041-2070) time horizon, the mean monthly precipitation is projected to increase in the months of March (39.75%), Jun (48.49%), July (8.86%) and August (19.36%) with a percentage decrease in January by 73.5%, February (3.14%), April (25.73%), May (41.91%), September (16.87%), October (59.17%), November (13.77%) and December(51.85%) under the RCP2.6 emission scenario. Whereas, under the RCP4.5 scenario, it is likely to decrease continuously for the months of January, February, April, May, October, November, and December by a percentage of 56.84, 15.38, 61.89, 62.2, 55.80, 16.49 and 47.73 respectively with an increment in March, Jun, July, August and September by 54.75%,53.48%,33.26%,22.99% and 16.35% respectively. Similarly for RCP8.5,an increase in monthly mean precipitation would be expected in the months March, Jun, July, August, November by a percentage of 32.26,55.62,35.89,34.5 and 1.45 respectively while a decrease in the months of January by 43.15%,February(20.19%), April(36.78%), May(73.80%), September(6.07%), October(56.45%) and December (47.46%) would be expected.

By 2080s (2071-2100) the mean monthly precipitation is expected to increase in the month of March by 26.72%, Jun (39.80%), July (3.43%) and August (16.95%) while it decreases in January by 49.57%, February (6.79%), April (17.21%), May (46.04%), September (13.49%), October (59.69%), November (6.46%) and December (44.44%) under RCP2.6 emission scenario. On the other hand, the mean monthly precipitation would increase in the months of March, Jun, July, August and September by 62.78 %,66.29%,42.93%,28.73% and 0.57% respectively while it decrease in January (57.05%), February (8.79%), April (45.21%),

International Journal of Technical Research & Science

May(60.96%),October(64.86%), November(18.85%) and December (52.27%)under RCP4.5 scenario. For RCP 8.5 a percentage decrease of 58.8, 36.79, 43.36, 63.16, 30.75, 45.30, 18.08 and 100 would be expected for the moths January, February, April, May, September, October, November and December respectively. On the other hand, a percentage increase of 50.60 for March, 62.42 for June, 68.63 for July and 54.85 for August would be expected to occur.
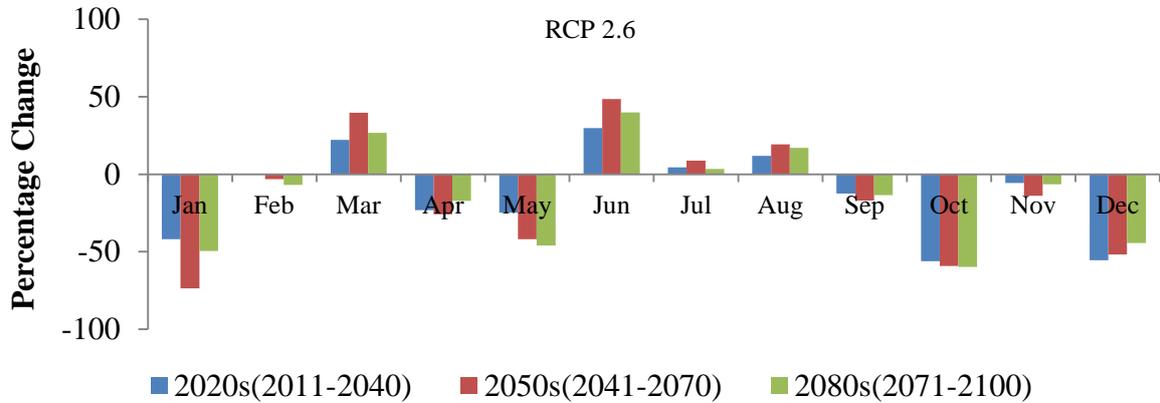

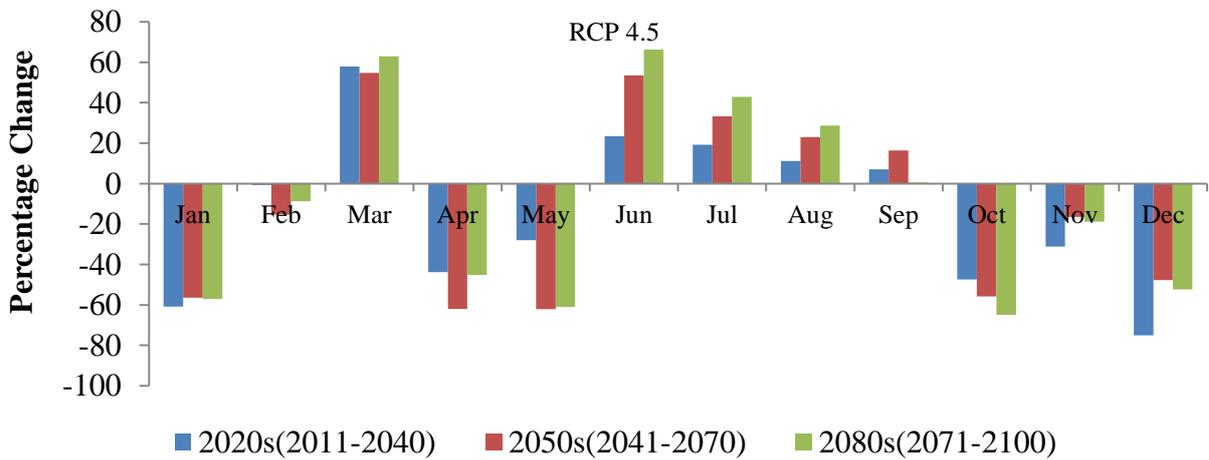**Fig. 3.2 Mean Monthly Percentage Change in Precipitation for RCP 2.6 at Mekele Station**

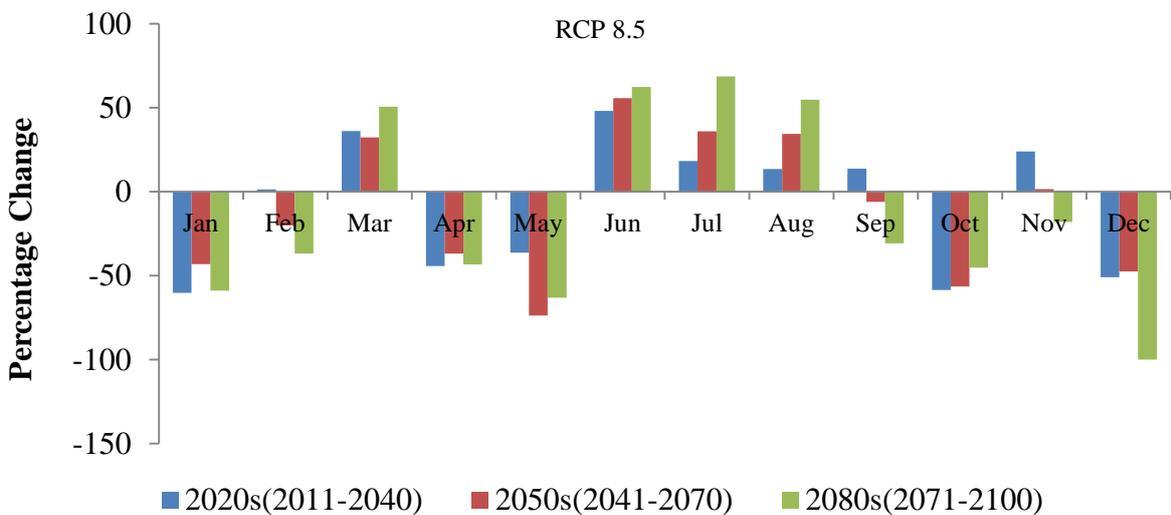**Fig. 3.3 Mean Monthly Percentage Change in Precipitation for RCP 4.5 at Mekele Station**

Fig. 3.5 Mean Monthly Percentage Change in Precipitation for RCP 8.5 at Mekele Station

3.3 Rainfall Disaggregation Model Development

Downscaled climate data results are on a daily basis time resolution and need to be divided and/or disaggregated to smaller time resolutions as most of hydrologic models require finer time resolution data input for design purposes as in the case of IDF Curves. In this study, the disaggregation scheme was performed by developing regression models from sixteen years observed daily and hourly rainfall records. Table-3.2 and Table-3.3shows the developed disaggregation Models and their performance respectively for Mekelle station.Table-3.2 illustrates that the developed disaggregation equations relating the 24hr duration observed rainfall(X) with the indicated observed hourly durations(Y) are the better models with their coefficient of Determination (R^2) ranging from 0.67-0.99.

Similarly, as indicated in Table-3.3 model performance evaluation measures such as Nash-Sutcliffe coefficient of Efficiency (NSE) [9],Root Mean Square Error (RMSE), percent of bias (PBAIS) and RMSE-observations standard deviation ratio (RSR) were used to assess the models efficiency. As per the minimum criteria set by [10]>0.5 for NSE and R^2, ≤ 0.7 for PSR, ±0.25 for PBIAS the minimum criteria was satisfied at Mekele station for all durations. Hence the developed disaggregation models perform to a high accuracy in explaining the relationship between 24hr rainfall duration with the hourly durations.

Table-2 Disaggregation Equations Relating Daily Rainfall(X) with hourly durations(Y) at Mekele Station

Rainfall Durations(hr)	Regression Equations	(R^2)	Sum of squared errors(SSE)
0.5	$Y = 489.9 * X/(1025.6 + X)$	0.95	27.50
1	$Y = 0.604 * X^{(1.01)}$	0.67	318.59
2	$Y = 0.64 * X^{(1.05)}$	0.81	180.22
4	$Y = 14.0 * e^{(0.021839 * X)}$	0.91	112.27
6	$Y = 0.99 * X^{(0.98)}$	0.93	56.86
8	$Y = 1.36 + 0.89 * X$	0.97	52.19
12	$Y = 1.04 * X^{(0.97)}$	0.99	20.81

Table-3.3 Disaggregation Model Performance for Mekele Station

Duration(hrs)	Regression Equations	Model Performance Evaluation Measures				
		R^2	NSE	RMSE	PSR	PBIAS
0.5	$Y = 489.9 * X/(1025.6 + X)$	0.95	0.95	1.31	0.22	-0.004
1	$Y = 0.604 * X^{(1.01)}$	0.64	0.62	5.70	0.59	-0.02
2	$Y = 0.64 * X^{(1.05)}$	0.79	0.78	5.13	0.46	-0.021
4	$Y = 14.0 * e^{(0.021839 * X)}$	0.91	0.90	3.67	0.30	-0.004
6	$Y = 0.99 * X^{(0.98)}$	0.98	0.97	1.89	0.16	0.00003
8	$Y = 1.36 + 0.89 * X$	0.98	0.98	1.81	0.15	0.0020
12	$Y = 1.04 * X^{(0.97)}$	0.99	0.99	0.70	0.06	-0.00081

(NSE) =Nash-Sutcliffe coefficient of Efficiency, (RMSE) = Root Mean Square Error, PBAIS= Percent of bias, (RSR) =observations standard deviation ratio

3.4 Selection and Comparison of Probability Distribution Functions

More than 50 candidate continuous probability distribution functions have been tested and evaluated for their suitability to the sample rainfall data. The suitability of the distribution to the sample rainfall data of different durations was evaluated based on graphical and chi-squared goodness of fit test (χ^2). **Table-4**and**Table-5**show best fitted probability distribution functions and the result of chi-squared goodness of fit test for Mekelle rainfall station respectively. According to**Table-5**, the hypothesis made; the calculated chi-square statistic ((χ^2) values for all indicated durations were found to be less than the tabulated chi-square at the all significance levels. Thus, the indicated probability distribution functions were accepted to be theoretically best fitting probability distribution functions for the indicated durations in this particular study.

Table-3.4 Best Fitted Probability distributions and their parameter values at Mekele station

Durations(hr)	Distributions	Parameters Value
0.5	Chi-squared	ν=20
1	Weibull	α= 2.956, β= 30.345
2	Weibull	α= 3.0882, β= 31.236
4	Weibull	α= 3.8995, β= 41.055
6	Weibull	α= 3.9652, β= 43.57
8	Weibull	α= 4.0239, β= 43.602
12	Weibull	α= 3.9826, β= 44.596

Table-3.5 Result of Chi-square Goodness of Fit test of Selected Probability Functions at Mekele Station

Durations(hr)	P-Value	Test statistic(χ^2)	Critical value(Tabulated)					Degree freedom	Rank
			α=20%	α=10%	α=5%	α=2%	α=1%		
0.5	0.88952	0.0193	1.6424	2.7055	3.8415	5.4119	6.6349	1	1
1	0.89535	0.0173	1.6424	2.7055	3.8415	5.4119	6.6349	1	1
2	0.84228	0.03959	1.6424	2.7055	3.8415	5.4119	6.6349	1	1
4	0.00442	0.94699	1.6424	2.7055	3.8415	5.4119	6.6349	1	1
6	0.44217	1.6321	3.2189	4.6052	5.9915	7.824	9.2103	2	1
8	0.44592	1.6153	3.2189	4.6052	5.9915	7.824	9.2103	2	1
12	0.96183	0.00229	1.6424	2.7055	3.8415	5.4119	6.6349	1	1

3.5 Rainfall Intensity-Duration-Frequency Relationships (IDF)

Mathematical IDF expression was developed for Mekelle station using the estimated IDF parameters for a given duration and frequency taking the IDF model proposed by [8] and [11] as:

$$I = exp[(\ln A - C \ln(B + D))]$$

Where, I is rainfall intensity (mm/hr), A, B and C are the estimated IDF parameters and D is rainfall duration in minutes

Table-3.6 and Table-3.7 shows the mathematical relationships of rainfall intensity, duration and frequency for the current and future climate change time horizons respectively.

Table-3.6 Mathematical IDF Equations for the Stations at different Return Periods for the Current Period (2000-2015)

Return Periods(years)	Mathematical IDF Expressions
2	I=exp[7.92- ln (38.74+D)]
5	I=exp[8.0- 0.98*ln (32.28+D)]
10	I=exp[8.04- 0.97*ln (28.95+D)]
25	I=exp[7.77- 0.91*ln (19.79+D)]
50	I=exp[7.83-0.92* ln (18.43+D)]
100	I=exp[7.82- 0.90*ln (16.57+D)]

International Journal of Technical Research & Science

Table-3.7 Mathematical IDF Equations for the Future Climate Change Scenario at Mekele Station

Return period	IDF Equations for the indicated return periods, T (years)		
	RCP2.6 2020s	RCP2.6 2050s	RCP2.6 2080s
2	I=exp[7.96-0.97*ln (29.43+D)]	I=exp[8.08-0.98* ln (32.33+D)]	I=exp[7.96-0.97* ln (30.01+D)]
5	I=exp[7.95-0.96* ln (27.12+D)]	I=exp[8.23-0.99* ln (36.74+D)]	I=exp[8.22-0.99* ln (35.89+D)]
10	I=exp[8.27- ln (35.89+D)]	I=exp[8.35- ln (38.74+D)]	I=exp[8.12-0.97* ln (31.03+D)]
25	I=exp[8.37- ln (39.12+D)]	I=exp[8.30-0.99* ln (36.23+D)]	I=exp[8.25-0.98* ln (34.51+D)]
50	I=exp[8.46- 1.01*ln (41.12+D)]	I=exp[8.8.42-ln (39.92+D)]	I=exp[7.88- 0.92*ln (19.33+D)]
100	I=exp[8.58-1.02* ln (44.48+D)]	I=exp[8.48- ln (41.09+D)]	I=exp[8.15-0.94* ln (28.04+D)]
	RCP4.5 2020s	RCP4.5 2050s	RCP4.5 2080s
2	I=exp[8.14-0.99* ln (35.89+D)]	I=exp[8.22- ln (36.27+D)]	I=exp[8.21-0.99* ln (36.27+D)]
5	I=exp[8.28- ln (37.36+D)]	I=exp[8.32-ln (37.37+D)]	I=exp[8.34-ln (38.74+D)]
10	I=exp[8.37-1.01* ln (38.74+D)]	I=exp[8.49-1.02* ln (41.22+D)]	I=exp[8.40-ln (41.11+D)]
25	I=exp[8.54-1.03* ln (42.51+D)]	I=exp[8.37-0.98* ln (32.28+D)]	I=exp[8.46- ln (38.74+D)]
50	I=exp[8.47- 1.01*ln (41.10+D)]	I=exp[8.96- 1.02*ln (44.74+D)]	I=exp[8.48- ln (35.88+D)]
100	I=exp[8.55-1.02* ln (42.51+D)]	I=exp[9.08-0.99* ln (36.27+D)]	I=exp[8.52- ln (35.89+D)]
	RCP8.5 2020s	RCP8.5 2050s	RCP8.5 2080s
2	I=exp[8.17-0.99* ln (35.89+D)]	I=exp[8.25- ln (36.88+D)]	I=exp[8.42-1.01* ln (41.12+D)]
5	I=exp[8.30-ln (37.52+D)]	I=exp[8.42-1.01* ln (39.88+D)]	I=exp[8.41- ln (38.55+D)]
10	I=exp[8.40-1.01* ln (39.05+D)]	I=exp[8.32-0.99* ln (36.27+D)]	I=exp[8.44- ln (38.71+D)]
25	I=exp[8.27-0.98* ln (32.73+D)]	I=exp[8.50-1.01* ln (40.13+D)]	I=exp[8.43-0.99* ln (36.88+D)]
50	I=exp[8.36- 0.99*ln (34.51+D)]	I=exp[8.71- 1.02*ln (47.98+D)]	I=exp[8.79- 1.03*ln (47.98+D)]
100	I=exp[8.48- ln (37.52+D)]	I=exp[8.73-1.02* ln (47.98+D)]	I=exp[8.87-1.04* ln (50.07+D)]

D, Rainfall duration (Minutes), ln, Natural logarithm, exp, exponent of a number

3.6 Comparison of Current and Future IDF Results

IDF results from the historic climate conditions were compared with IDF curves developed under the emerging climate change scenarios for Mekele city to quantify the change in rainfall intensities. Comparison of changes in rainfall intensities were made in terms of the relative difference given by [12] between the present and future rainfall intensities.

$$RD = \left(\frac{(X1 - X2)}{\left(\frac{X1+X2}{2}\right)} \right) * 100$$

Where: RD is relative difference (%), x_1 is intensity of rainfall under future climate change (mm/hr) and x_2 is intensity of rainfall under the present climate condition (mm/hr).Tables(3.8-3.10) illustrates the relative difference in rainfall intensity of the future climate change periods as compared to the present time.

International Journal of Technical Research & Science

Table-3.8 Relative Difference (RD) in Intensity of Rainfall from the Current Period for RCP 2.6 2020s, 2050s and 2080s Time Lines for Different Return Periods at Mekelle Station

Duration(hr)	RD(%) for RCP2.6 2020s						RD(%) for RCP2.6 2050s					
	2	5	10	25	50	100	2	5	10	25	50	100
0.5	30.84	12.17	-0.76	-7.94	-10.89	-18.25	33.53	12.3	2.66	-6.54	-9.48	-15.03
1	27.48	10.17	1.61	-1.1	-2.1	-8.07	31.3	14.07	6.33	-0.64	-0.84	-5.51
2	25.18	8.98	3.04	2.62	3.13	-2.27	29.74	15.38	8.85	2.43	4.41	-0.03
4	24.32	8.69	3.3	2.76	4.3	-1.37	29.12	16.03	9.93	2.37	5.8	1.06
6	24.46	8.72	2.99	1.59	3.48	-2.8	29.24	16.13	9.93	1.21	5.27	0.00
8	24.65	9	2.68	0.36	2.49	-4.39	29.31	16.2	9.68	0.12	4.35	-1.19
12	25.33	9.7	1.76	-2.09	0.17	-7.29	29.85	16.11	9.04	-2.09	2.55	-3.74
24	26.57	10.53	0.00	-6.62	-4.28	-13.57	30.52	15.75	7.65	-6.28	-1.63	-8.85
	RD(%) for RCP2.6 2080s											
0.5	30.06	13.06	4.15	-4.65	2.82	-3.11						
1	27.03	14.46	5.25	0.81	3.45	2.48						
2	24.96	15.42	6.15	3.68	3.92	5.7						
4	24.32	15.89	6.77	3.72	4.18	6.7						
6	24.46	15.83	7.06	2.78	4.29	6.39						
8	24.65	15.82	7.19	1.80	4.35	6.04						
12	25.33	15.73	7.22	-0.17	4.38	5.07						
24	26.57	15.02	7.3	-3.92	4.42	3.06						

Table-3.9 Relative Difference (RD) in Intensity of Rainfall from the Current Period for RCP 4.5 2020s, 2050s and 2080s Time Lines for Different Return Periods at Mekelle Station

Duration(hr)	RD(%) for RCP4.5 2020s						RD(%) for RCP4.5 2050s					
	2	5	10	25	50	100	2	5	10	25	50	100
0.5	30.14	12.56	0.48	-8.47	-10.25	-18.34	33.55	15.9	5.16	10.97	29.58	54.81
1	29.23	14.24	3.8	-1.23	-1.48	-8.96	32.44	17.6	9.17	15.32	39.2	61.92
2	28.6	15.31	5.84	2.36	3.74	-3.9	31.48	18.68	11.71	17.26	45.02	65.61
4	28.45	15.62	6.3	1.78	4.93	-3.49	30.87	18.96	12.27	16.71	46.55	65.95
6	28.5	15.33	5.98	-0.19	4.11	-5.06	30.61	18.66	11.8	15.44	45.81	64.9
8	28.48	15.17	5.54	-1.95	3.08	-6.77	30.4	18.48	11.27	14.35	44.7	63.74
12	28.84	14.78	4.44	-5.31	0.86	-9.95	30.44	18.15	10.11	12.3	42.5	61.59
24	29.36	13.55	2.25	-11.88	-3.61	-16.18	30.14	16.83	7.3	8.59	37.7	57.26
	RD(%) for RCP4.5 2080s											
0.5	36.22	15.7	5.09	2.04	2.42	-3.55						
1	35.49	18	9.76	8.72	9.22	3.68						
2	35.01	19.59	13.19	12.26	12.9	7.15						
4	34.91	20.23	14.81	12.36	13.24	6.86						
6	35.07	20.19	15.07	11.1	12.26	5.21						
8	35.15	20.1	15.06	9.87	11.12	3.69						
12	35.45	19.78	14.63	7.47	9.05	0.91						
24	35.76	18.6	13.1	2.84	4.72	-4.62						

pg. 9
www.ijtrs.com
www.ijtrs.org
Paper Id: IJTRS-V4-I12-005   Volume V Issue II, February 2020

Table-3.10 Relative Difference (RD) in Intensity of Rainfall from the Current Period for RCP 8.5 2020s, 2050s and 2080s Time Lines for Different Return Periods at Mekelle Station

Duration(hr)	RD(%) for RCP8.5 2020s						RD(%) for RCP8.5 2050s					
	2	5	10	25	50	100	2	5	10	25	50	100
0.5	32.77	13.41	3.02	-0.24	-2.58	-9.74	35.45	17.71	8.41	-1.09	0.11	-7.09
1	31.86	15.19	6.45	4.36	3.95	-1.77	34.63	20.13	11.33	5.85	11.24	4.46
2	31.23	16.33	8.63	6.48	7.54	2.35	33.9	21.71	13.37	9.45	18.4	11.45
4	31.09	16.65	9.2	6.06	8.07	2.51	33.45	22.13	14.31	9.32	20.82	13.22
6	31.13	16.43	8.89	4.86	7.28	1.08	33.27	21.78	14.35	7.86	20.36	12.24
8	31.21	16.2	8.45	3.79	6.29	-0.32	33.07	21.44	14.36	6.43	19.42	10.86
12	31.43	15.92	7.41	1.71	4.55	-3.11	33.18	20.85	13.94	3.72	17.32	8.07
24	31.67	14.65	5.17	-1.94	0.96	-8.54	32.81	19.31	13.1	-1.62	12.41	1.96
	RD(%) for RCP8.5 2080s											
0.5	41.86	65.3	12.47	5.13	3.65	-5.31						
1	42.49	45.42	16.12	11.34	14.44	6.33						
2	42.9	28.23	18.63	14.63	21.16	13.14						
4	42.99	16.07	19.63	14.79	23.01	14.4						
6	42.96	11.23	19.6	13.66	22.22	12.91						
8	42.73	8.63	19.47	12.56	21.08	11.14						
12	42.61	5.9	18.77	10.46	18.61	7.79						
24	42.04	3.03	17.3	6.21	13.25	0.56						

As illustrated above in **Tables** (3.8-3.10) the intensity of the rainfall at Mekele city showed an increasing/decreasing trend under the future climate change scenarios for the near term (2020s), midterm (2050s) and long term (2080s) time horizons. The general climate change trends were quantified from the percentage difference between the present and future climate conditions.

Rainfall intensity in the near-term (2020s) for the RCP2.6 climate scenario would be shown an increasing trend ranging from 0.17% to 30.84% for all rainfall durations at 2 and 10 years return periods with slight decrease at the shorter durations(0.5 and 1hr) for 25 and 50 years return periods. But for the 100 years return period a completely decrease up to 18.25% was observed for all durations. Concomitantly, the rainfall intensity by 2050s would likely to increase for all durations by a percentage ranging from 2.66 to 33.53 for the shorter return periods (2, 5 and 10) along with a completely decrease by (0.03-15.03%) for the 100 years return period for all durations except the 4hr and 6hr durations. In association to this, the rainfall intensity by 2080s will increase up to 30.06% almost for all durations and rainfall frequencies with a slight decrease by (0.17-4.65%) for the 25 year return periods at 0.5hr, 12hr and 24hr durations. Generally rainfall intensity in Mekele city would be expected to intensify with varying ranges up a maximum intensity of 65.95% for RCP4.5 climate change scenario in the mid-term period (2050s) for 100years return period of 4 hour duration (**Table-9**).

CONCLUSION

The study briefly presents the relationship between extreme rainfall characteristics with other climate variables (temperature, humidity, wind) in order to develop rainfall IDF models that could be used for evaluating the impact of climate change and variability on the magnitude and frequency of occurrence of extreme rainfall events. The analysis of the annual maximum rainfall series for developing intensity -duration-frequency plots for Mekele city under changing climate has resulted in important findings. First, an extensive investigation of the possible realizations of future climate from recently developed climate change scenarios are performed using downscaling based disaggregation approach. Statistical downscaling method was employed using Statistical downscaling Model (SDSM) to produce long sequence of future rainfall data. The downscaled daily rainfall outputs were disaggregated in to finer time resolution values appropriate for IDF development by regression based equations developed from daily and hourly historical rainfall for each station. Based on the findings of this work the following conclusions are forwarded.

> ➢ The General temporal rainfall pattern in Mekele City will most certainly change in future due to climate change.

> ➢ Generation of future IDF information based on single GCM is limited. Incorporating multiple GCMs/RCMs to produce sequence of future rainfall enable to quantify GCMs/RCMs inherent uncertainties.
> ➢ Adoption of single downscaling approach for developing IDF information may suffer from over/underestimation of rainfall extremes; application of other downscaling approach can provide more realistic information about the future climate.
> ➢ Although, the IDF information developed from RCP2.6, RCP4.5 and RCP8.5 climate change scenarios contain uncertainties due to the global climate model; all of them indicate a general increase in intensity of future rainfall for Mekele City.

ACKNOWLEDGEMENTS

REFERENCES

[1] Chow,V,T. Midment, D.R., and Mays,L.W,(1988). Applied hydrology: NewYork: McGraw-Hill. Book Company.

[2] R.K. Pachauri and L.A. Meyer (2014). Climate Change 2014 Synthesis Report:Contribution of Working Groups I,II and III to the Fifth Assessment Report of the Intergovernmental Panel on ClimateIPCC(pp 151). Geneva, Switzerland.

[3] Mehdi B., Mrena C., and Douglas A. (2006).Adapting to climate change: An introduction for Canadian Municipalities. Canadian Climate Impacts and Adaptation Research Network (CCIARN). Accessed at http://www.cciarn.ca/ on October 16/2016.

[4] TagelGebrehiwot and Anne van der Veen (2013).Assessing the evidence of climate variability in the northern part of Ethiopia.Journal of Development and Agricultural Economics.

[5] Chali, E. (2007) Establishment of Intensity-Duration-Frequency Relationships for Oromiya National Regional State, Arbaminch University, Arbaminch, Ethiopia.

[6] Cherkos Tefera(2002). Development of Intensity-duration –frequency curves for Tigray & Amhara regions,MSc. thesis,Addis Ababa University,Ethiopia.

[7] Feleke Gerbi (2006).Development of Intensity-duration –frequency relationships for SNNP,Ethiopia. MSc. thesis , Arbaminch University,Ethiopia.

[8] Wenzel H.G (1982) Rainfall for Urban Storm Design. Washington DC: American Geological Union.

[9] Nash, J.E. and J.V. Sutcliffe (1970). River flow forecasting through conceptual models, Part I: A discussion of principles. J. Hydrol., 10: 282-290. DOI: 10.1016/0022-1694(70)90255-6.

[10] Moriasi D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner and R.D. Harmel et al., (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans.ASABE. 50, 885-900.

[11] Exact (2006). Middle East Water Data Banks Project. Application of Methods for Analysis of Rainfall Intensity in Areas of Israeli,Jordanian, and Palestinian Interest. Water resources of Palestinian, Jordanian, and Israeli Interest.

[12] Slobodan P. Simonovic and Angela Peck (2010). Updated Rainfall Intensity Duration Frequency curves for the City of London under the changing climate. Department of Civil and Environmental Engineering. University of Western Ontario London, Ontario, Canada.

[13] Mehla, M. K. and Singh, K. (2019). Optimizing Drip Irrigation System Design for Onion Crop Using DIDAS Software. Bull. Env. Pharmacol. Life Sci., 8(2),64-69.