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Climate change-induced variations in future extreme precipitation intensity-duration-frequency in flood-prone city of Adama, central Ethiopia

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Climate change-induced variations in future extreme precipitation intensity-duration-frequency in flood-prone city of Adama, central Ethiopia

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Abstract

The influences of climate change on the features of extreme rainfall events have become unprecedented that needs improved understanding at all levels for planning effective management strategies of the potential risks. This study aims to assess the potential influences of climate change on extreme rainfall characteristics in flood-vulnerable city of Adama. Daily precipitation records of 1967-2016 and projection of global circulation models (GCMs): CanESM2 and HadCM3 for 2021-2070 were disaggregated into shorter time resolutions using the Hyetos model. Gumbel Type I probability distribution and power-regression model ($i = aD^b$) were used for deducing intensity-duration-frequency (IDF) curves and for describing their functions, respectively. The extreme rainfall intensity of the historical and future periods for a range of storm durations and return periods were compared and contrasted. A close agreement is obtained between the observed and the modeled rainfall intensity with high values of coefficient of determination (> 0.996) and Nash-

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Sutcliffe efficiency (> 0.850). Besides, statistically significant ($p<0.05$) direct linear relationship is found between the return periods and the coefficient parameter of the IDF models. Moreover, the intensity of extreme precipitation over 2021-2070 in Adama city would increase up to 49.5%, depending on storm duration and return period considered. This could have consequences of the way the city's drainage infrastructures are designed, operated and sustained. Hence, flood-prone areas should be recognized in order to formulate effective strategies for mitigation and adaption of potential impacts. The standards for designing future drainage infrastructures should also be updated aiming to reflect the effects of climatic change.

Keywords: Climate change, Precipitation intensity, Climate extreme, Flood hazard

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The authors declare that they have no competing interests.

Availability of data and material

Not applicable.

Authors' contributions

Dejene Tesema Bulti: conceptualization, data curation, methodology, analysis, interpretation of the results, software, visualization and writing. **Birhanu Girma Abebe** and **Zelalem Biru**: supervised the study and reviewed the whole content. All authors read and approved the manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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1 Introduction

Weather and climate extremes have been considered as the underlying causes of environmental hazards, such as floods and landslides (Deb et al., 2018; Natarajan and Radhakrishnan, 2019; Stephenson et al., 2016; Zahiri et al., 2016; Zeder and Fischer, 2020). Studies have shown the potential rise in extreme precipitation events in the future period due to changes in global climate, with substantial impacts on lives and properties (Barbero et al., 2019; Dastagir, 2015; Hay et al., 2016; Lestari et al., 2019; Rao and Ramana, 2015; Shahid et al. 2015). Climate change influences the relationship between intensity, duration and frequency (IDF) of extremes (Buba et al., 2017; Fadhel et al., 2017; Yilmaz et al., 2014; Mirhosseini et al. 2012). The changes in IDF relationships would have key consequences of the way the current and future urban drainage system is designed, operated and sustained (Cook et al., 2020; Gebru, 2020; Moujahid et al., 2018; Sillmann et al., 2017). Therefore, an enhanced understanding of the potential changes in the relationship between the features of extreme rainfall events, under the changing climate has a primary importance of planning sustainable urban stormwater management strategies.

Establishing relationship between extreme precipitation IDF for applications for urban settings demands high temporal resolution of precipitation; e.g., sub-daily (Alam and Elshorbagy, 2015; Courty et al., 2019; Noor et al., 2021). In developing countries like Ethiopia, however the quantity and distribution of instruments capable of recording rainfall on shorter temporal scale is limited (Alem et al., 2019; Beyene et al., 2019; Engida and Esteves, 2011). In response to such limitations, various models, such as Hyetos, MuDRain, artificial neural network and cascade model have been developed to downscale daily precipitation to a finer temporal scale and have been applied for various studies (Garbrecht et al., 2017; Hanaish et al., 2011; Müller-Thomy et al., 2018; Noor et al., 2018; Pui et al., 2012; Saad et al., 2018; Shrestha et al., 2017).

In most urban areas of Ethiopia, IDF curves provided by the Ethiopian Road Authority (ERA) are used as standards for designing stormwater management infrastructures. ERA categorized the country into eight rainfall regions and established IDF curves for the regions with storm length of 1-hr to 3-hr and six return periods (2, 5, 10, 25, 50 and 100-yr). The country is highly vulnerable to variability of extreme rainfall, especially in smaller spatial scales (Beyene et al., 2019; Dawit et al., 2019; Geremew et al., 2020; Mekonen and Berlie, 2019; Mohammed et al., 2018), and thus, the ERA's IDF curves could overestimate or underestimate the extreme hourly rainfall magnitude to some degree, when it comes to local applications. Moreover, the curves can only be used on the basis of time-invariant distribution (i.e., Stationary assumption). In other words, it assumes that significant changes in the extreme rainfall characteristics (e.g., Severity and frequency) overtime are less likely. Such assumption, however may not be valid under the conditions of potential global climate change that may result in changes in the frequency and intensity of extreme rainfall (Cheng et al., 2014; Katz, 2013; Tesfay and Quraishi, 2017).

In this regard, few studies (Gebreigziabher, 2020; Gebremedhin, 2017; Gebru, 2020; Tesfay and Quraishi, 2017) have been conducted to establish the relationships between rainfall IDF using the observed and projected daily precipitation of different areas of the country. They documented the IDF relationship of extreme rainfall in the present-day climate condition likely to change over the future period, with different magnitude and direction for analysis areas. However, research focusing on the impacts of climate change on the relationship of extreme precipitation for Adama City (Regional City) is scarce. It is the fast-growing city with the population growth rate of 9% from 2004 to 2016 (Bulti and Assefa, 2019). The city is highly vulnerable to urban flood (Bulti et al., 2017). Hence, the results of climate change impact study in Adama City can support the efforts being made to ensure sustainable development of the city.

106 The authors of the present study, recently published a research (Bulti et al., 2020) which
107 analyzed the trend of extreme rainfall in Adama city during 1965-2016 using 10 indices. By
108 downscaling daily precipitation from the Global Circulation Models (GCM) estimates for the
109 future 2021-2080, the study also assessed the potential changes in extreme precipitation events
110 based on the changes in annual percentage of wet-days, longest wet-spell, annual total
111 precipitation, and the ratio of 95th percentile and the total annual precipitation.

112 The study documented significant increasing trend of extreme precipitation in Adama city
113 over the last 52 years, and would continue to increase up to 2080. Despite the study provided a
114 valuable information about the climate change impacts on the historical and future extreme
115 precipitation events in Adama city, the relations between the features of extreme precipitation (i.e.,
116 IDF) are not well addressed. Improved understanding on the potential changes in extreme
117 precipitation characteristics due to climate change is useful for planning effective management
118 strategies of the potential risks and for designing climate-resilient urban drainage infrastructures.

119 Therefore, this study aims to expand the prior work (Bulti et al., 2020) by assessing the
120 potential influences of climate change on extreme precipitation intensity in Adama city.
121 Specifically, the study is conducted (a) to downscale daily precipitation observed during 1967-
122 2016 and GCMs projection for 2021-2070 into shorter time scales; (b) to establish rainfall IDF
123 relationships of the historical and future climate conditions; (c) to use the developed IDF models
124 and assess the possible changes in the future extreme rainfall intensity as compared to the historical
125 condition for a range of storm durations and return periods.

2 Materials and Methods

2.1 Study area

Adama city is located at 39° 16′ E longitude and 8° 33′ N latitude. The city is suited in the Rift Valley, with its flat terrain features, surrounded by mountains and rugged topography. Pluvial flood is almost a frequent feature of Adama City during the rainy season, causing a significant damage to life and property (Bulti et al., 2017). The floodplain area is densely populated and is marked by massive urban development. Fig. 1 shows the study area along with the nearby metrological stations. The findings of recent studies (e.g., Mohammed et al., 2018; Mekonen and Berlie, 2019; Geremew et al., 2020) indicate that the trend of long-term rainfall extreme is not uniform when it comes to smaller scale local scale and suggesting a small-scale analysis is essential to effectively address risks associated with climate. Hence, similar to Bulti et al. (2020), Adama meteorological station was considered as a representative station for the study area. The station is located at 8.55-degree latitude and 39.28-degree longitude with an altitude of 1622 m.

Fig. 1 Location map of the study area, a) Regions of Ethiopia; b) Oromia Region; and c) Adama City with surrounding weather observation stations

2.2 Data used

Two rainfall datasets were used in this study. Daily precipitation records of 1967-2016 were used for establishing IDF relationship of the historical extreme rainfall. Future daily rainfall data which have been spatially downscaled from the outputs of HadCM3 and CanESM2 in previous research (Bulti et al., 2020) were used for establishing IDF relationship of the future period. In this regard, an average of the daily rainfall data projected under the scenarios of CanESM2 (RCP2.6,

148 RCP4.5 and RCP8.5) and HadCM3 (A2a and B2a) were considered. Future 50 years (2021-2070)
149 spanned time-series were used to ensure the consistency of time-series lengths between the base
150 period and future period.

151 ## 2.3 Methods

152 ### 2.3.1 Derivation of sub-daily precipitation and annual maximum series

153 Precipitation data of both the present and future periods were limited to a daily time resolution.
154 In order to extract annual maximum precipitation at sub-daily resolution, the daily rainfall depths
155 were disaggregated into hourly values using a Hyetos computer program. It is an easy temporal
156 downscaling software, and freely available at http://www.itia.ntua.gr/e/softinfo/3/. Hyetos has
157 been used in a number of studies in different regions of the world (Beyene et al., 2019; Engida and
158 Esteves, 2011; Kossieris and Efstratiadis, 2015; Shrestha et al., 2017). Hyetos uses the Bartlett–
159 Lewis model (BLM) and the adjustment procedures for the disaggregation process. The description
160 of the model and the meaning of its parameters can be found elsewhere (Sun et al., 2019).

161 In response to the existing limited hourly rainfall records to be used for the disaggregation
162 model calibration, validated BLM parameter values (Table 1) for the Addis Ababa station were
163 adopted from (Beyene et al., 2019). It is the nearest station to the study area, among the stations
164 with validated values available. In addition, both Addis Ababa and Adama stations are located
165 within the upper Awash basin (Shawul and Chakma, 2020), and rainfall Regime-A which covers
166 the central part of the country with the bimodal rainfall system (Berhanu et al., 2014). Using hourly
167 data, thus obtained, rainfall depths for larger time-windows (3-hr, 6-hr and 12-hr) was generated.
168 Finally, the sets of annual maximum (AMAX) corresponding to five storm durations (1-hr, 3-hr,
169 6-hr, 12-hr and 24-hr) for the analysis periods, 1967-2016 and 2021-2070, were extracted.

Table 1 Values of BLM parameters used in disaggregation process, adopted from (Beyene et al., 2019)

Using the AMAX datasets, descriptive statistical analysis was conducted on the basis of skewness. The skewness index describes the shape of the distribution. It takes the value zero for a symmetrical distribution. However, a skewness of exactly zero is quite unlikely to real-world data. In this study, the skewness values between -2 and +2 were considered for normal distribution (Muzaffar, 2016). Values less than -2 and greater than +2 indicate negatively skewed and positively skewed distribution, respectively. This helped to provide an overview of the data series used in the study.

2.3.2 Developing IDF relationship

The modeling of the rainfall IDF relationships involves a series of steps that can be categorized as determining probable maximum rainfall; estimating rainfall intensity; determining the fitting model parameters; and assessing the model performance of the fitting model (validation). In addition, correlation between return periods and model fitting parameters was assessed.

Estimation of probable maximum precipitation (PMP): It is the extreme rainfall depth for a defined period, which is meteorologically possible for a given watershed at a given time of year, without taking into account long-term climate trends. PMP is usually determined by fitting annual maximum rainfall series to a suitable theoretical probability distribution. Gumbel's extreme value distribution type I (EVI) was employed to fit each set of annual maximum rainfall series corresponding to five time-windows (1-hr, 3-hr, 6-hr, 12-hr, and 24-hr) for eight return periods (5-

yr, 10-yr, 25-yr, 50-yr, 100-yr, 300-yr, 500-yr and 1000-yr). EVI is the agreed probability distribution for meteorological and hydrological studies (Bhagat, 2017; Bharali, 2015; Coronado-Hernández et al., 2020; de Paola et al., 2014; Gebremedhin, 2017; Gebru, 2020; Tesfay and Quraishi, 2017). In this case, for respective storm duration and recurrence interval, PMP was computed using Equation 1.

$$PMP_{T_d} = \bar{X}_d + K_T S_d \quad \ldots (1)$$

Where: $\bar{X}_d$ and S_d are the mean and the standard deviation of each set of annual maximum precipitation series (function of storm duration), respectively, and K_T is a frequency factor depending on the return period (*T*), and calculated using Equation 2 (Mujere, 2011).

$$K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right] \quad \ldots (2)$$

Estimation of intensity: Using the values of PMP, the rainfall intensity was determined as the average precipitation depth that falls per time increment, and measured in millimeter per hour (de Paola et al., 2014; Tesfay and Quraishi, 2017). Accordingly, the rainfall intensity was computed by dividing probable maximum precipitation for the corresponding storm duration (Equation 3). This helped to identify the relationships of the features of extreme rainfall (intensity, duration and return period). The relations were checked for self-similarity (Erena et al., 2018a); i.e., they are assumed to have a consistent pattern for each return period.

$$I_d = \frac{PMP_{T_d}}{d} \quad \ldots (3)$$

Where: PMP_{T_d} probable maximum precipitation (mm) corresponding to a T-year event for the *d*-rainfall duration, and *d* is storm duration (hour).

Deriving IDF model equations: the empirical equations (mathematical models) used to describe the IDF relationships were derived using bi-parameter power-regression model. For each return period, a functional relationship between the corresponding extreme rainfall intensity and the storm duration can be expressed as Equation 4 (de Paola et al., 2014). In this case, values of fitting parameters (i.e., $a(T)$ and b) are regressed for each return period, and they were calculated by Equations 5 and 6.

$$I(d,T) = a(T)d^b \quad \ldots(4)$$

$$b = \frac{n\sum_{i=1}^{n}(ln\ x_i\ ln\ y_i) - \sum_{i=1}^{n}(ln\ x_i)\sum_{i=1}^{n}(ln\ y_i)}{n\sum_{i=1}^{n}(ln\ x_i)^2 - (\sum_{i=1}^{n} ln\ x_i)^2} \quad \ldots(5)$$

$$a(T) = e^{\left(\frac{\sum_{i=1}^{n}(ln\ y_i) - b\sum_{i=1}^{n}(ln\ x_i)}{n}\right)} \quad \ldots(6)$$

Where: *a(T)* and *b* are the regression parameters, *n* is the number of number of storm durations (time-windows) considered, x_i and y_i are storm durations (hour) and corresponding intensity (mm/hr.), respectively.

Model validation: the model of IDF relationship was validated using graphical and statistical method. First, the self-similarity of n values was checked for each return period; i.e., uniform pattern is expected (Erena and Worku, 2018). Second, the goodness-of-fit of the mathematical models was assessed using two statistical parameters: coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE), which were determined using Equations 7 and 8, respectively. The

value of R^2 ranges -1 to 1 and that of NSE can vary from -∞ to 1. The optimum value of the two chosen parameters is 1, indicating the perfect fit of the derived model to the data (Lacombe et al., 2014; Waseem et al., 2017). In this study, the minimum criteria recommended by (Moriasi et al., 2007) for both parameters (NSE > 0.5 and R^2 > 0.7) were adopted. The model is considered valid only if it satisfies these criteria at a time.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(x_{O_i} - \bar{x}_O)(x_{P_i} - \bar{x}_P)}{\sqrt{\sum_{i=1}^{n}(x_{O_i} - \bar{x}_O)^2}\sqrt{\sum_{i=1}^{n}(x_{P_i} - \bar{x}_P)^2}}\right]^2 \quad \ldots (7)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(x_{O_i} - x_{P_i}\right)^2}{\sum_{i=1}^{n}\left(x_{O_i} - \bar{x}_O\right)^2} \quad \ldots (8)$$

Where: x_O and x_P are observed (used for calibration) and simulated (computed using IDF equations) rainfall intensities, respectively; and $\bar{x}_O$ and $\bar{x}_P$ are the corresponding mean values

Correlation analysis: It was carried to assess the extent to which the power-law fitting parameters are linear related to the return period. It was determined based on value of Pearson's correlation coefficient (r) computed using return periods and the values of both parameters in the validated IDF models. The strength of the relationship was described using the absolute value of correlation coefficient: very weak (|r| < 0.19), weak (|r| < 0.39), moderate (|r| < 0.59), strong (|r| < 0.79), very strong (|r| < 1). Moreover, the statistical significance of the relationships was assessed based on p-value statistics at 95% confidence level (p < 0.05).

2.2.3 Analysis of changes in precipitation intensity

The potential changes in extreme precipitation intensity were assessed in two ways. First, the changes in intensity were assessed using graphical comparison by overlaying the IDF curves of historical and future periods. Second, the magnitude of changes was determined in terms of relative percentage difference between the intensity of corresponding storm durations and return periods. For this reason, the extreme precipitation intensity for a range of storm durations and return periods were calculated using the IDF models developed in this study. The percentage of relative differences were then determined using Equation 8, a widely used approach in most climate change studies (Gebru, 2020; Solaiman and Simonovic, 2011; Tesfay and Quraishi, 2017).

$$Relative\ difference\ (\%) = \frac{x_F - x_H}{\frac{1}{2}(x_F + x_H)} * 100 \quad \ldots (8)$$

Where: x_F and x_H are extreme rainfall intensities computed based on the future and the historical IDF relationships, respectively.

3 Results

3.1 Annual maximum precipitation series

Daily rainfall data recorded during 1967-2016 and predicted for the future 2021-2070 under two GCMs were disaggregated into shorter time scales. AMAX rainfall series of storm durations 1-hr, 3-hr, 6-hr, 12-hr and 24-hr was extracted for respective analysis timelines. Skewness index was computed for each dataset. The computed values of skewness are summarized in Table 2, and provides information about the shape of the distribution of the datasets. In all the cases, the values

are found to be positive and less than 2.0; i.e., within the criteria considered for normal distribution (-2<skewness<+2). The AMAX sub-daily rainfall series obtained through disaggregation process has similar distribution, with that of the corresponding daily precipitation.

Table 2 Skewness of AMAX daily and sub-daily rainfall series during the past and future timelines

3.2 Rainfall IDF relationships

3.2.1 IDF curves

Fig. 2 illustrates the IDF curves of extreme rainfall in Adama city for the periods 1967-2016, historical (a), HadCM3 (b) CanESM2 (c). They are developed by fitting GEV I to the respective AMAX precipitation series. The curves give information about the magnitude of rainfall intensity as a function of storm durations from 1-hr to 24-hr and return periods from 5-yr to 300-yr.

The IDF curves clearly show that rainfall intensity decreases, as duration of the storm increases from 1-hr to 24-hr. For storms from 1-hr to 24-hr, the rainfall intensity increases, as return period increases from 5-yr to 300-yr. The results confirm that the pattern of the IDF curves of the respective study periods satisfied self-similarity and are consistent with the expected behavior of the IDF curve. Comparatively, the HadCM3 curves do not show significant difference in intensity for storms longer than 12-hr.

Fig. 2 Precipitation IDF curves of the past and future timelines a) historical 1967-2016, future projection b) HadCM3, and c) CanESM2

3.2.2 IDF models

Results summarized in Table 3 show the mathematical equations of respective IDF models alongside the computed values of coefficient of determination and Nash-Sutcliffe efficiency. From the equations of the respective IDF models, it is evident that the value of coefficient parameter increases, as frequency decreases from more frequent (5-yr) to less frequent (300-yr) storms, in all datasets. Similarly, the value (absolute) of exponent parameter increases, with return period for the historical and HadCM3 datasets and on the contrary of CanESM2.

Table 3 Summary of the IDF model equations for the present and future rainfall in Adama city (d: rainfall duration (hour)) and the corresponding results of model performance evaluation (R^2: Coefficient of determination, NSE: Nash-Sutcliffe efficiency)

With regard to the results of model performance evaluation, high values are obtained for the selected statistical parameters. The computed value of coefficient of determination ranges 0.996 – 1.0 and that of Nash-Sutcliffe efficiency is between 0.584 and 0.998, for the analysis periods and datasets considered in this study. The results greater than the threshold considered for both parameters in this study (NSE > 0.5 and R^2 > 0.7), and satisfied all considered model performance evaluation criteria at a time.

3.3.3 Relationship of return periods and IDF model parameters

The extent of the relationship between return period and the individual model parameters (i.e., coefficient and exponent parameters) was also assessed using correlation analysis. The computed correlation coefficient and the p-value are shown in Table 4. The results show that the fitting parameters of IDF models are positively correlated with the return periods. The observed

relationships are found to be very strong (i.e., r > 0.79) for most of the cases and strong (r > 0.59) for exponent parameter in the case of historical and CanESM2.

Moreover, the significance test of the linear relationship of coefficient parameter with return periods resulted in the p-value smaller than 0.05 in all of the cases, indicates the relationship is statistically significant. On the other hand, the p-value is found to be greater than 0.05 for the case of exponent parameter, indicates the observed linear relationship is not significant, at the selected analysis level.

Table 4 Results of correlation analysis between fitting parameters power-law function ($i = aD^b$) and return periods

3.3 Future changes in rainfall intensity

The potential changes in extreme precipitation intensity in the future period as compared to the baseline period were assessed based on the two GCMs. Fig. 3 compares the historical IDF curves with that of future period based on the selected GCMs, HadCM3 and CanESM2. Table 5 also provides information about the magnitude and direction of changes in the future extreme rainfall intensity relative to that of the baseline climate condition at 1-hr, 3-hr, 6-hr, 12-hr and 24-hr rainfall durations and all return periods considered in this study.

Fig. 3 Comparison of historical IDF curves (1967-2016) with Projected IDF curves (2021-2070)

Table 5 Percentage change of future intensity relative to historical condition (T: return period (year), d: storm duration (hour))

Overall, the IDF curves demonstrate that the rainfall intensity over the future period will be different from the baseline period. In all the cases, the HadCM3 curves show smaller intensity than

that of historical and CanESM2. Except for 5-yr return period, IDF curves corresponding to CanESM2 GCM show that intensity of the extreme rainfall will be higher, for longer storms and will be lower for shorter storms than the baseline condition. In this regard, extreme rainfall events with 15-hr, 7-hr, 5-hr, 4-hr and 3-hr storm durations corresponding to return periods 10-yr, 25-yr, 50-yr, 100-yr and 300-yr, respectively, will approximately reproduce historical rainfall intensity. However, IDF curves HadCM3 show less intensified rainfall than that of the baseline period under all storm durations and return periods. The decreasing magnitude is maximum for the shortest storm (1-hr), despite the value is found to decline towards the longest storm (24-hr).

Turning to the results summarized in Table 5, rainfall intensity in Adama city will change in the future by significant percentage relative to that of the baseline period. In addition, significant difference can be seen in the identified changes by the GCMs. With regard to HadCM3 projection, future rainfall intensity will decrease by significant percentage, for all storm durations and return periods. The magnitude of percentage changes is also found to increase from more frequent rainfall of shorter duration (1-hr 5-yr) to less frequent rainfall of longer duration (24-hr 300-yr). Conversely, results based on CanESM2 projections reveal that the magnitude of decreasing change in intensity predicted by CanESM2 GCM declines and that of increasing changes increases, with return periods and respective storm durations. It is also evident that HadCM3 predicted the relative decrease future daily rainfall intensity ranges 87.5%(T=5-yr)-106.2%(T=300-yr). With similar length of storm (24-hr), CanESM2 predicted 13.3% decrease corresponding to 5-yr return period and an increase in intensity by 9.1% (T=10-yr)-49.5% (T=300-yr).

4 Discussion

The changes in the characteristics of extreme rainfall due to global climate change have contributed to the increased rainfall-induced urban flooding in most parts of the world. Adama city is among flood-vulnerable urban settings in Ethiopia. An improved understanding of how the characteristics of extreme rainfall do change due to climate change, at a local scale is imperative for planning effective management strategies of the potential risks. By disaggregating daily rainfall records and future projections of GCMs, the IDF models were developed, and applied for examining the extent to which the present-day extreme rainfall intensity will be reproduced under future climate condition.

In the process of fitting bi-parametric power-law function ($i = a\ D^b$) to the data, high values are obtained for coefficient of determination in all the cases and for Nash-Sutcliffe efficiency in most of the cases, indicate a good agreement of the observed (i.e., computed from rainfall depths) and simulated rainfall intensity using the developed IDF models. The results are comparable with that of similar studies (Erena et al., 2018b; Ewea et al., 2018; Gebru, 2020), and confirm a good performance of the IDF models in explaining the relationship between intensity, duration and frequency of extreme precipitation in Adama city under the study's conditions (i. e., datasets, storm durations, return periods and analysis timelines). In addition, the findings reflect the successful application of Gumbel's type I probability distribution and the bi-parametric power-regression function, for constructing IDF curves and for deriving the equations of the models, respectively.

Statistically significant direct linear relationship is obtained between the values of coefficient parameter (i.e., parameter a) and the corresponding return periods, in all models developed using the observed and projected rainfall datasets and on the contrary for exponent parameter (i.e.,

parameter b). This finding is consistent with the findings of (Ewea et al., 2018) who modeled IDF curves in Makkah Al Mukarramah region for designing stormwater infrastructures.

Moreover, the findings reveal that the extreme rainfall intensity in the future period in Adama city would rise or decline, depending on GCM, storm duration and return period considered. Under the projection of CanESM2, the intensity of shorter storms will decrease and that of longer storms increase, under all return periods greater than 5-yr. The results based on HadCM3 prediction reveal that the intensity of future extreme precipitation will decrease more than by half of its historical value, in all the cases. In accordance with these findings, studies have documented mixed results, decreasing and increasing, of changes in extreme rainfall intensity due to climate change in different areas of the country, including Mekele city (Gebreigziabher, 2020), some parts of Tigray region (Gebru, 2020) and Chiro and Hurso (Tesfay and Quraishi, 2017). The findings of the present study are pertaining to Adama city which has received little attention. The significant differences between the results of the GCMs used in this study could be associated with uncertainties in the GCMs in predicting rainfall pattern (Noor et al., 2018), and highlight the results of climate change impacts studies could be affected by our choice of GCMs for future climate projections. For planning of mitigation and adaption measures, it is ideal to consider the variations under the increasing scenario.

Considering the findings, it is reasonable to conclude that extreme rainfall intensity over the coming 50 years (2021-2070) in Adama city likely to change due to climate change. An increase rainfall intensity could have an impact on the conveyance capacity of the existing stormwater drainage system, and could result more frequent and severe floods than in the past years. Moreover, the current practice of stormwater infrastructure design based on the assumption of time-invariant

rainfall distribution may not provide reliable result to maintain the future potential increase in extreme rainfall due to climate change.

With respect to the increasing concern of management of climate change-induced urban flooding in general and in Adama city in particular, the significance of this study can be explained in different ways. The potential changes in extreme rainfall intensity identified here contribute to a clear understanding of the effects of climate change on the future extreme precipitation characteristics, and support local climate change adaption planning as well as decision-making. The findings can also be used in revision of the current regulations and standards for the planning and designing of urban drainage systems at local level. Moreover, they have paramount importance of future studies, particularly the assessment of flood hazard and risk of the City under the effects of changes in global climate in order to formulate effective flood mitigation and adaption strategies.

In urban settings, reliably established relationships between features of extreme rainfall has a primary importance of designing a new stormwater infrastructures and assessing the potential risk of existing drainage system. The IDF models developed in this study enable to estimate extreme precipitation intensity for a wider range of storm durations and for a number of return periods; i.e., from more frequent rainfall of shorter duration (1-hr 5-yr) to less frequent rainfall of longer duration (24-hr 300-yr) over different analysis periods. IDF models of more-frequent shorter durations can be used for stormwater management applications and a less-frequent longer-duration events are useful for flood risk management in the City under future climate conditions. Moreover, mathematical equations of the rainfall IDF relationships can reduce the dependency on the graphical versions of the models and allow to better determine any of the three features of the

425 storm (intensity, duration, frequency) using the other two attributes, at specific duration from 1-hr
426 to 24-hr.

427 On top of satisfying the objectives of this study, the findings build on existing evidences and
428 offers valuable insights into the influences of climate change on extreme precipitation; the
429 uncertainties of GCMs in the predicting precipitation characteristics; the relationships between
430 return period and fitting parameters of the power-law function and the potential application of
431 methodology used in the present study.

432 5 Conclusions

433 The intent of this study was to provide information about the potential influences of climate
434 change on IDF of extreme rainfall in Adama city. For this, daily precipitation records of 1967-
435 2016 and projected for 2021-2070 periods were disaggregated into shorter time scale, and used for
436 developing rainfall IDF models. By computing rainfall intensity for a range of storm durations and
437 return periods using the models, the percentage change of future rainfall intensity relative to the
438 current climate condition was determined.

439 A close agreement is obtained between the observed and the modeled rainfall intensity with
440 high values of coefficient of determination and Nash-Sutcliffe efficiency. Besides, statistically
441 significant ($p<0.05$) direct linear relationship is found between return periods and coefficient
442 parameter of IDF models. Moreover, the intensity of extreme precipitation over the years 2021-
443 2070 in Adama city would be different from the historical condition, depending on GCM, storm
444 duration and return period considered. For storm duration (24-hr), the maximum increase is 49.5%
445 (CanESM2) and decrease up to 106.2% (HadCM3).

446

This study suggests the characteristics of extreme rainfall in Adama city over the coming 50 years likely to change due to global climate change. This could have consequences of the way the city's drainage infrastructures are designed, operated and sustained. The city has experienced devastating rainfall-induced flood events in the past and could experience more frequent and severe floods in the future due to the possible rise in extreme precipitation intensity under changing climate. Hence, future research is needed to assess the potential flood hazard under changing climate in order to formulate effective mitigation and adaption strategies for the associated risks. Moreover, the standards and guidelines presently employed by the city for the design of stormwater management infrastructure should be revised in order to reflect the global climate change impacts.

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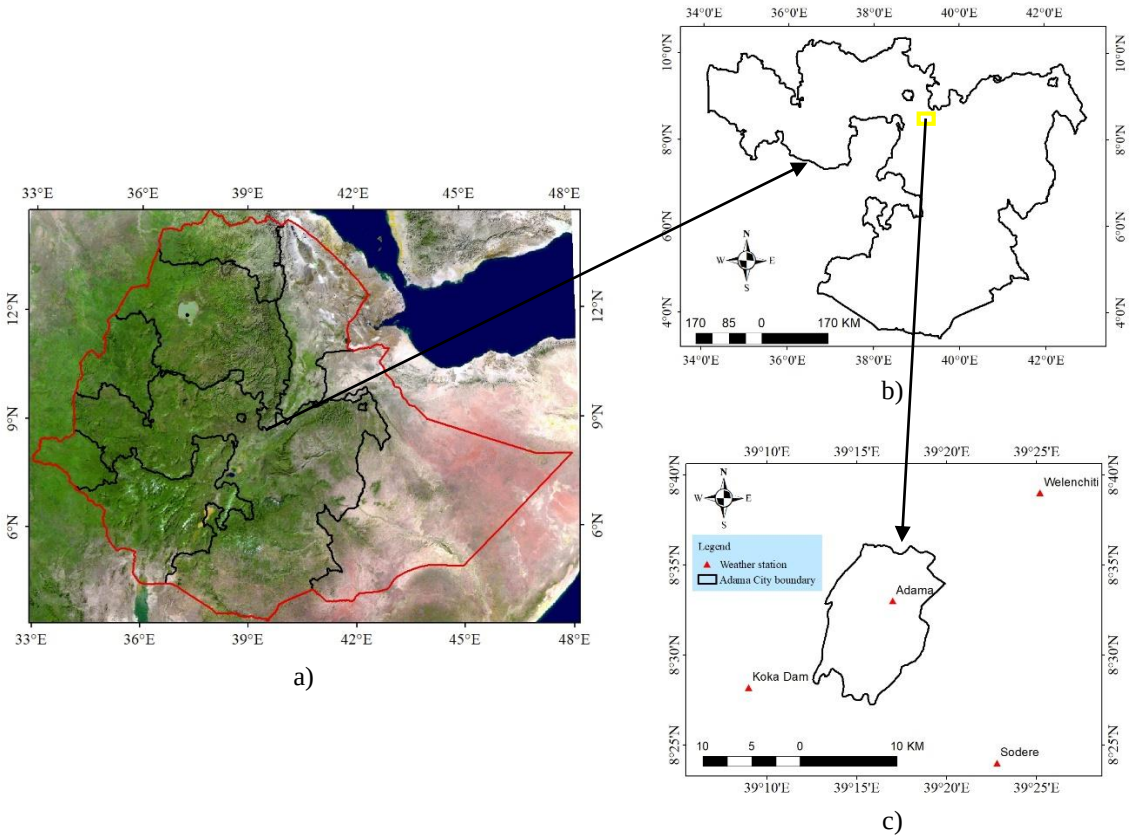
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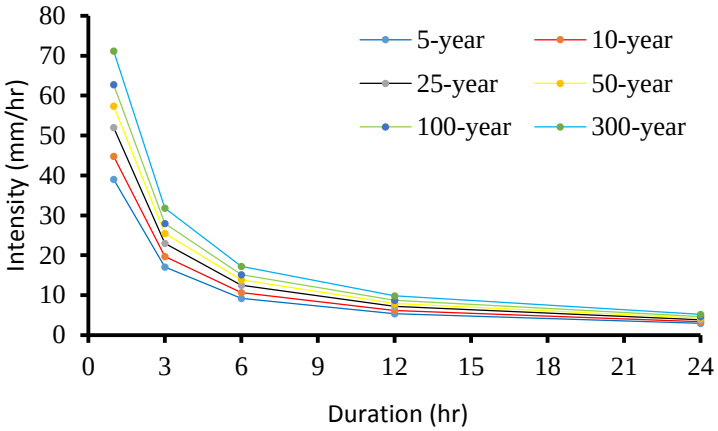
Fig. 1



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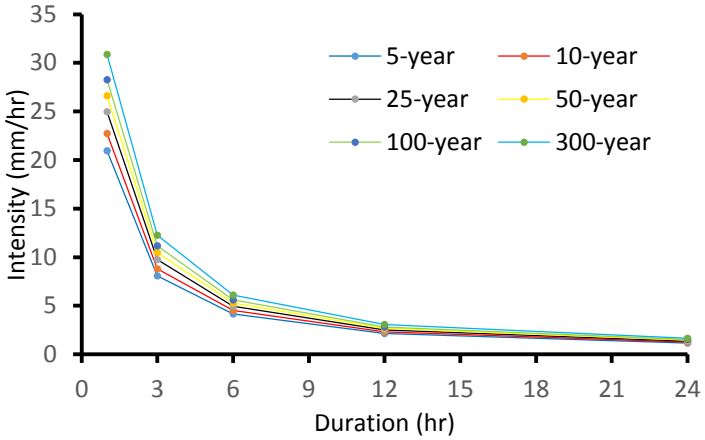
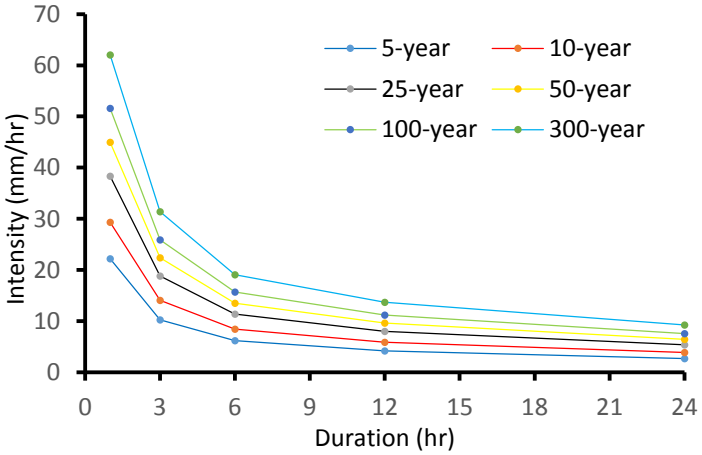
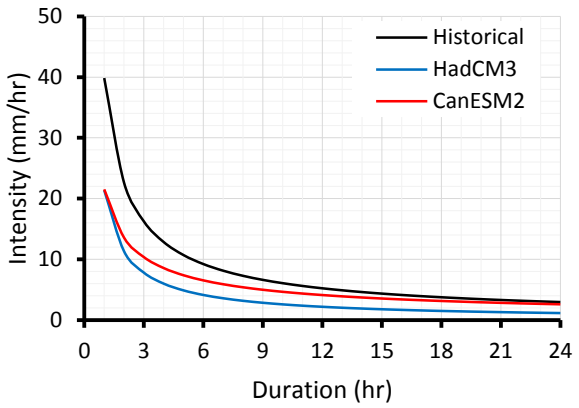


b) HadCM3 (2021-2070)



c) CanESM2 (2021-2070)

Fig. 2



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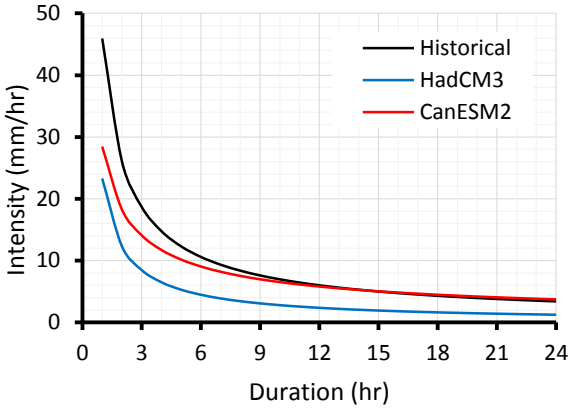

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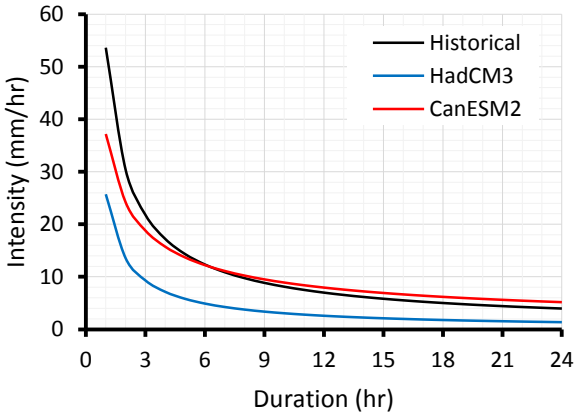

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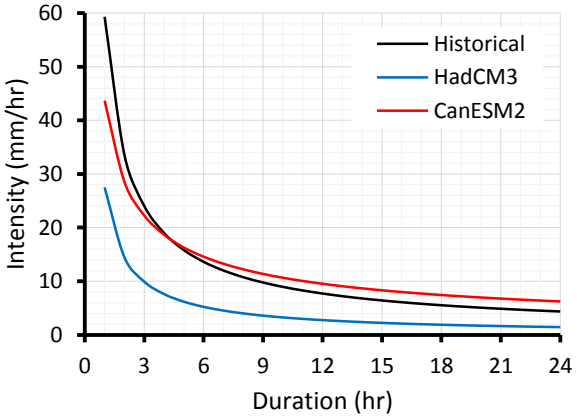

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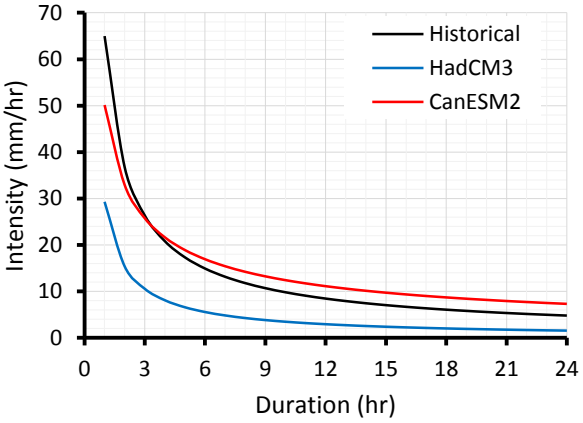
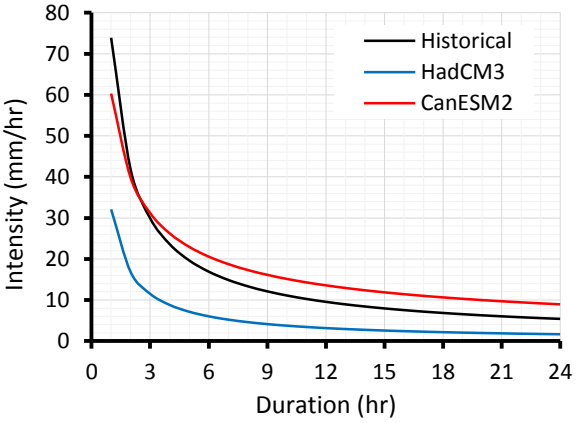


e) 100-yr



f) 300-yr

Fig. 3

Table 1

Parameter	α	κ	$\emptyset$	$\lambda\ (d^{-1})$	$\mu_x\ (mm\ d^{-1})$	$v\ (d)$
Values	97.99	65.87	25	2.25	95.94	0.92839

Table 2

Scenarios	**Storm duration**				
	1-hr	**3-hr**	**6-hr**	**12-hr**	**24-hr**
Historical	1.279	0.997	1.370	0.772	0.806
HadCM3	0.510	0.754	0.577	0.371	0.356
CanESM2	1.314	1.160	1.561	1.699	1.616

Table 3

	Historical			**HadCM3**			**CanESM2**		
T	**Equations**	**R^2**	**NSE**	**Equations**	**R^2**	**NSE**	**Equations**	**R^2**	**NSE**
5-yr	$39.8d^{-0.816}$	0.999	0.998	$21.4d^{-0.916}$	1.000	0.968	$21.5d^{-0.665}$	0.998	0.991
10-yr	$45.9d^{-0.818}$	0.999	0.998	$23.3d^{-0.920}$	0.999	0.922	$28.4d^{-0.639}$	0.997	0.939
25-yr	$53.6d^{-0.820}$	0.999	0.997	$25.7d^{-0.925}$	0.999	0.853	$37.2d^{-0.621}$	0.997	0.820
50-yr	$59.3d^{-0.821}$	0.999	0.997	$27.5d^{-0.927}$	0.999	0.803	$43.7d^{-0.613}$	0.997	0.722
100-yr	$65.0d^{-0.822}$	0.998	0.997	$29.3d^{-0.930}$	0.999	0.757	$50.1d^{-0.607}$	0.996	0.626
300-yr	$73.9d^{-0.823}$	0.998	0.996	$32.1d^{-0.933}$	0.999	0.691	$60.3d^{-0.600}$	0.996	0.584

Table 4

Model parameters	Test Statistics	Historical (1967-2016)	Future (2021-2070)	
			HadCM3	CanESM2
Coefficient parameter (a)	*r*	0.863	0.864	0.864
	p	0.027	0.026	0.027
Exponent parameter (b)	*r*	0.757	0.796	0.683
	p	0.081	0.058	0.135

Table 5

T	Duration	Change in intensity (%)		T	Duration	Change in intensity (%)	
		HadCM3	CanESM2			HadCM3	CanESM2
5-yr	1	-60.3	-59.7	50-yr	1	-73.3	-30.4
	3	-70.1	-44.1		3	-83.1	-7.7
	6	-76.1	-34.0		6	-89.1	6.8
	12	-81.9	-23.7		12	-94.9	21.1
	24	-87.5	-13.3		24	-100.5	35.3
10-yr	1	-65.4	-47.0	100-yr	1	-75.7	-25.8
	3	-75.2	-28.0		3	-85.7	-2.3
	6	-81.2	-15.8		6	-91.7	12.6
	12	-87.0	-3.4		12	-97.5	27.4
	24	-92.6	9.1		24	-103.1	41.9
25-yr	1	-70.4	-36.2	300-yr	1	-78.9	-20.3
	3	-80.2	-14.7		3	-88.8	4.2
	6	-86.2	-0.9		6	-94.8	19.6
	12	-92.1	12.9		12	-100.6	34.7
	24	-97.7	26.5		24	-106.2	49.5