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Using a Web-base Tool-IDF_CC to Update IDF Curves for Takoradi City to Reflect Climate Change Uncertainties

Sulemana Abubakari
Power China Guiyang Engineering Company Limited, Guiyang, Guizhou, China

ABSTRACT

Intensity Duration Frequency (IDF) curves are among the most widely used tools in water resources management. They are derived from historical rainfall records under assumption of stationarity. Climate change makes the use of historical data for development of IDFs for the future unjustifiable. This study uses IDF_CC, a web based tool to develop and update IDF curves for the city of Takoradi to reflect future climate change uncertainties. The capabilities of IDF_CC indicate its effectiveness as a Decision Support System for updating and incorporating climate change impacts into IDF curves for the city of Takoradi. Rainfall intensity is projected to increase in future (2009-2039) for all durations and return periods compared to the historical (1971-2008). Higher increase is projected for longer (25, 50 and 100) than shorter (2, 5 and 10) return periods for RCP 2.6 and RCP 8.5 scenarios whereas slightly higher intensities are projected for shorter than longer return periods for RCP 4.5 scenario. Slightly higher rainfall intensity is projected for longer (2h, 6h, 12h and 24h) than shorter (10 min, 20 min and 1 hr) durations for all scenarios. These therefore call for revision and updating of existing IDF Curves for all major cities and towns in Ghana to take into account effect of climate change.

Keywords – *IDF Curves, Climate Change, IDF_CC, Takoradi, Decision Support System*

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I. INTRODUCTION

Rainfall intensity-duration-frequency (IDF) curves have numerous water management applications in Ghana, such as planning, design, operation and maintenance of stormwater management systems, wastewater systems, stormwater detention ponds, culverts, bridges, dams, pumping stations, roads and master drainage planning. Traditionally, the general assumption underlying the development of IDF curves are that analysis of historical rainfall records can be used to predict future rainfall conditions. This assumption is based on the fact that the environment will behave as it always has; this is commonly referred to as stationarity [1]. According to this assumption, historical data collected at rainfall monitoring stations are analyzed and used to develop statistics that give an indication of the likelihood of future extreme rainfall events. For example, municipal stormwater management systems are typically designed to accommodate flows associated with 2 to 100 year return period events lasting 10 minutes to 24 hours. However, it is widely acknowledged that climate conditions of the past are no longer reflective of future climate, calling into question the reliability of this assumption [1].

According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change [2], average global surface temperature are projected to rise to about 0.3 to 4.8°C by the year 2100 compared to the reference period 1986-2005. This is likely to have a major impact on the magnitude and frequency of extreme precipitation events in some regions [3-6]. According to the AR5, changing climate conditions are expected to increase the occurrence, frequency, intensity, and/or amount of precipitation of heavy precipitation events.

As a result of changing conditions, it is imperative that IDF values ought to be updated more frequently than in the past and climate change scenarios are required in order to inform IDF calculations [1]. The inclusion of these probable changes into the planning, design, operations and maintenance of water infrastructure would go a long way to decreasing any unforeseen future uncertainties that may emanate from the projected increase in frequency and magnitude of extreme rainfall events [7]. Research conducted by [6, 8-12] indicate that there is very limited information available on how to bring climate change into the IDF calculations and even less information is available on how to implement updated IDF curves in practice [7].

The IDF curves developed by Dankwa [13] is what is used in Ghana for the design of drainage structures in various cities. These IDF curves were developed based on the rainfall data available at that time. But as has been proved in recent history, climatic variability and trends do exist and their effects on precipitation have not been negligible [14]. Climate change has lead to droughts and floods around the world, and long term trends in rainfall, both increases and decreases, have been seen in different parts of the world including Ghana [14]. There is therefore a possibility that the rainfall intensities used by Dankwa [13] for the development of the IDF curves might have changed. The IDF curves developed by Dankwa have not been revised or updated, however, drainage engineers in Ghana still rely on these curves for their designs. This might lead to over-design or under-design due to the changes in climatic conditions that might have occurred after 1974. Over-designing leads to economic losses as bigger structures are designed whereas under-designing leads to drains of inadequate capacity leading to increased incidents of flooding. In both cases economic losses are incurred. To reduce economic losses due to over design or under design of drainage structures that might occur using IDF curves developed by Dankwa [13], there is therefore the need for its revision./updating to reflect future climate change uncertainties. This study therefore uses a web-based tool (IDF_CC Tool) developed by Simonovic et al [1] to update IDF curves that incorporate projected climate change uncertainties for the city of Takoradi-Ghana.

II. MATERIALS AND METHODS

2.1 Study Area

Takoradi (figure 1) lies on Latitude 4° 55' 0.12" N and Longitude 1° 46' 0.12" W. It is located at the south-eastern part of the western region of Ghana. It is the biggest city in the region, but the third largest in Ghana.

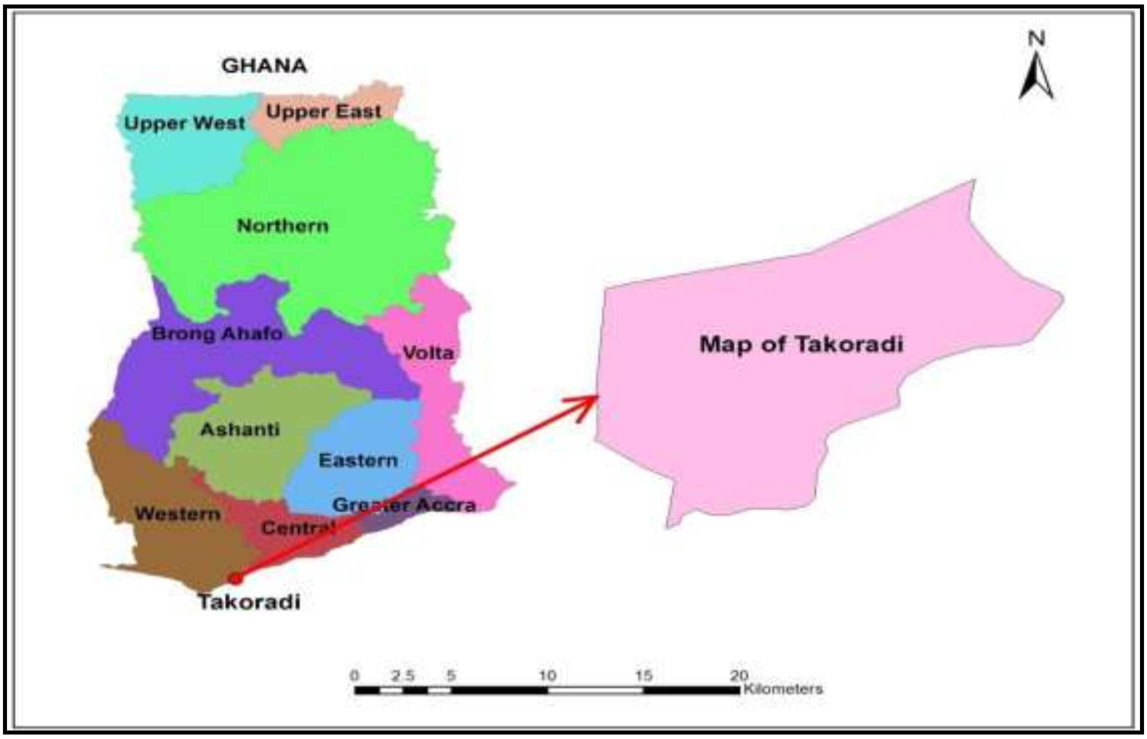


Figure 1: Map of Takoradi

The metropolis is characterized by an equatorial type of climate. Average annual precipitation at Takoradi is approximately 1200 mm, with May and June being the wettest months, when over 250 mm of rain falls each month. Overall, there is very little temperature variation throughout the year, with mean daily maxima averaging 27°C from July through September and reaching 30°C to 31°C, between November and April. Mean daily minimum temperatures vary only between 21°C to 23°C. Average relative humidity shows a consistent daily variation, reaching 95% overnight and decreasing to 70% to 80% during the day [15]. The city of Takoradi has a varied topography, with the central area being low lying and occupied by muddy lagoons interspersed with ridges and hills. The city is bordered to the west by the Whin River, with its main tributary, the Ayire, joining the Whin lagoon before entering the sea. On the east also flows the Pra River [16].

2.2. Data Collection

The data used in this study (Table 1) was obtained from the Ghana meteorological Services Department.

Table 1: Summary of Data Gathered

Duration	No. of years with some records
10 min	27
20 min	27
1.0 hr	27
2.0 hr	27
6.0 hr	27
12.0 hr	27
24.0 hr	27

The data consists of annual maximum series (AMS) of rainfall depth over a period of 1971-2008 for seven (7) laps of time: 10min, 20min, 1hour, 2hours, 6hours, 12 hours, and 24 hours.

2.3. IDF_CC Tool

This study uses IDF_CC Tool Version 2 (Beta) developed by Simonovic et al [1]. The tool was designed as a simple decision support system (DSS) to generate local IDF curve information that accounts for the impacts of climate change. It has been publicly accessible online as of March 1, 2015 at www.idf-cc-uwo.ca.The IDF_CC Tool was originally developed to be used in Canada but can be applied to all regions around the world. This model was adopted for the study because it adopts Gumbel distribution which is the same distribution used in Ghana for fitting annual maximum precipitation (AMP). The Gumbel distribution for annual extremes can be expressed as:

$$Q_t = \mu + K_T \sigma \quad \text{....} (1)$$

Where Q_t is the exceedance value, μ and σ are the population mean and standard deviation of the annual extremes, T is the return period and K_T is the Gumbel frequency given by:

$$-\frac{\sqrt{6}}{\pi}\left\{0.577216 + In\left[In\frac{T}{T-1}\right]\right\} \quad \text{....} (2)$$

2.4. Climate Change Scenarios

The main assumption in the process of developing IDF curves is that historical series are stationary and therefore can be used to represent future extreme conditions; however under rapidly changing climatic conditions, IDF curves that rely only on historical observations will misrepresent future conditions [1].

Global Climate Modeling (GCM) is one of the most efficient ways to address changing climate conditions for future periods (i.e., nonstationary conditions). GCM spatial grid size scales are too coarse for the application in updating IDF curves, and usually range above $1.5^o*1.5^o$. Therefore, GCM data has to be spatially interpolated for station coordinates for use in downscaling. The inverse square distance weighting method is applied in the IDF_CC tool. The nearest four GCM grid points to the station are used by weighting the precipitation value by the distance between the station and the GCM grid points [1]. In this way the GCM grid points that are closer to the station are weighted more than the grid points further away. The mathematical expression for the inverse square distance weighting method is given as [1]:

$$w_i = \frac{\frac{i}{d_i^2}}{\sum_{i=1}^{k}\frac{i}{d_i^2}} \quad \text{....} (3)$$

Where d_i is the distance between the ith GCM grid point and the station and k is the number of nearest grid points (equal to 4 in the IDF_CC tool).

There are four Representative Concentration Pathways (RCP) (i.e., RCP 2.6, 4.5, 6.0 and 8.5) adopted by the Intergovernmental Panel on Climate Change. These emission scenarios represent a range of climate change impacts, from low to high severity. The most severe impacts are predicted if no climate policy is adopted, while the lowest risks are associated with stringent requirements for climate policy that limit and reduce greenhouse gas emissions [17]. Based on (AR5) of the Intergovernmental Panel on Climate Change [2] definition: RCP2.6 is one pathway where radiative forcing peaks at approximately 3 W m-2 before 2100 and then declines. RCP 4.5 and RCP 6.0 are two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m^{-2}

and 6.0 W m^{-2} respectively after 2100. RCP 8.5 is a one high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some time.

The future emission scenarios used in the IDF_CC tool are based on RCP 2.6, RCP 4.5 and RCP 8.5. RCP2.6 represents the lower bound, followed by RCP4.5 as an intermediate level and RCP 8.5 as the higher bound. 22 GCMs that have all the three future emission scenarios are incorporated for updating IDF curves. The tool also applies a skill score algorithm based on quantile regression (QRSS) proposed by Srivastav et al. [18] to assess and rank the performance of different GCM models available for use within the tool. This study employs the HadGEM2-ES GCM model developed by the Met Office Hadley Centre, UK, It has a spatial resolution of 1.25^{o} *1.875^{o} and the time selected for the IDF curve update is from 2010-2040.

2.5. Developing and Updating IDF Curves using IDF_CC Tool

The IDF_CC tool adopts an equidistant quantile-matching (EQM) method for updating IDF curves, developed by Srivastav et al. [18]. Fig. 2 and 3 explain a simplified approach for EQM method and the flow chart of the utilization of IDF_CC tool to update IDF curves.

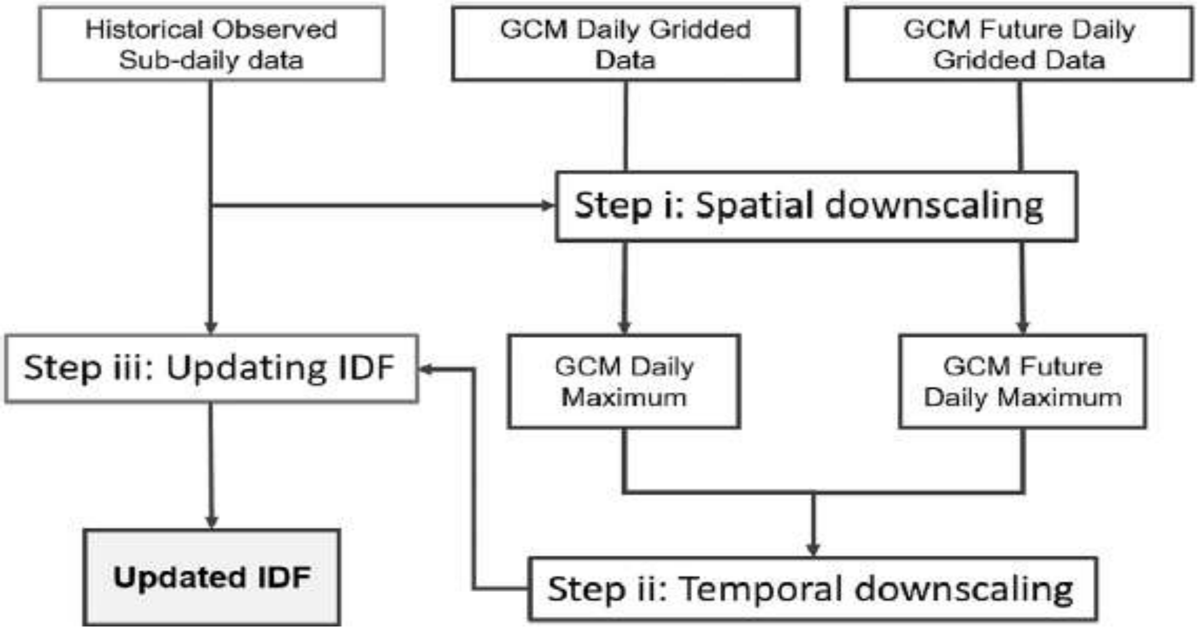


Figure 2. Schematic representation of equidistance quantile matching (EQM) method implementation for updating IDF curves [1]

EQM can capture the distribution of changes between the projected time period and the baseline period (temporal downscaling) in addition to spatial downscaling the annual maximum precipitation (AMP) derived from the GCM data and the observed sub-daily data [1]. In the case of the EQM method, the quantile-mapping functions are directly applied to annual maximum precipitation (AMP) to establish the statistical relationships between the AMPs of GCM and sub-daily observed (historical) data rather than using complete daily precipitation records [19]. This methodology is relatively simple (in terms of modelling complexities) and computationally efficient. The three main steps which are involved in using EQM method are: (i) establish statistical relationship between the AMPs of the GCM and the observed station of interest, which is referred as spatial downscaling and (ii) establish statistical relationship between the AMPs of the base period GCM and the future period GCM, which is which is referred as temporal downscaling and (iii) establish statistical relationship between steps (i) and (ii) to update the IDF curves for future periods. For complete information on all background methods used to generate IDF curves based on historical and GCM data, reference can be made from the IDF_CC tool Technical Manual [19].

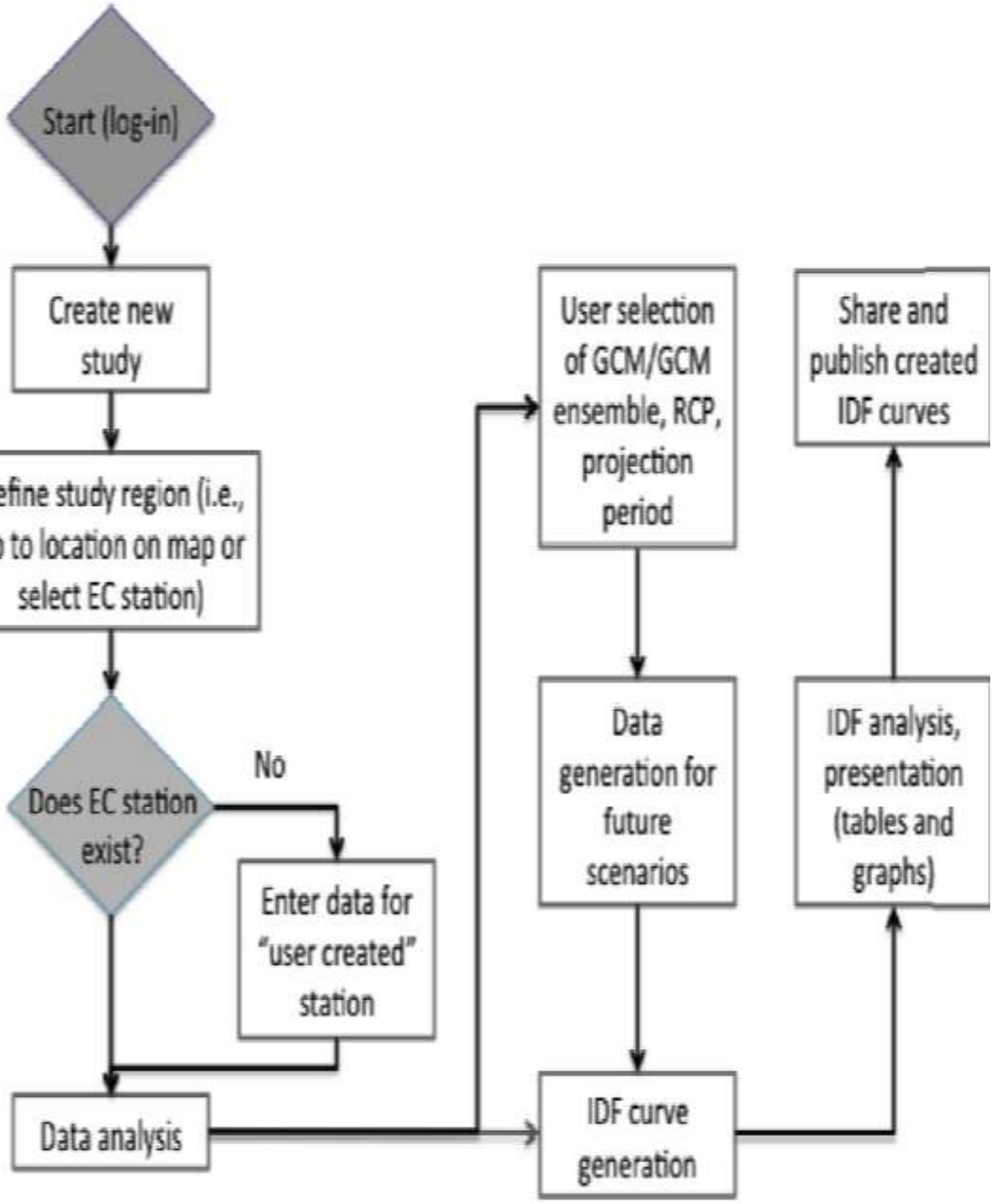


Figure 3. IDF_CC tool use flowchart (after Sandink et al. [7])

III. RESULTS AND DISCUSSION

Table 2 and Figure 4 show the rainfall intensities and IDF curves derived using the IDF_CC Tool for historical climate conditions (1971-2008) and future climate change conditions (2009-2039) for RCP 2.6, 4.5, and 8.5 scenarios. Higher increase in rainfall intensity is projected for longer return periods (25, 50 and 100) than shorter return periods (2, 5 and 10) for RCP 2.6 and RCP 8.5 scenarios whereas higher intensities are projected for shorter return periods than longer return periods for RCP 4.5 scenario. Table 3 shows the projected increases in future for all scenarios. For longer return periods, the projected change is highest for RCP 8.5, followed by RCP 4.5 with RCP 2.6 showing the least change whilst for shorter durations; the change is highest for RCP 4.5, followed by RCP 8.6 with the least change occurring in RCP 2.6 scenario. Average percentage increases for shorter and longer return periods are 2.80% and 3.36% respectively for RCP 2.6, 15.55% and 14.81% respectively for RCP 4.5 and 11.37% and 17.96% respectively for RCP 8.5.

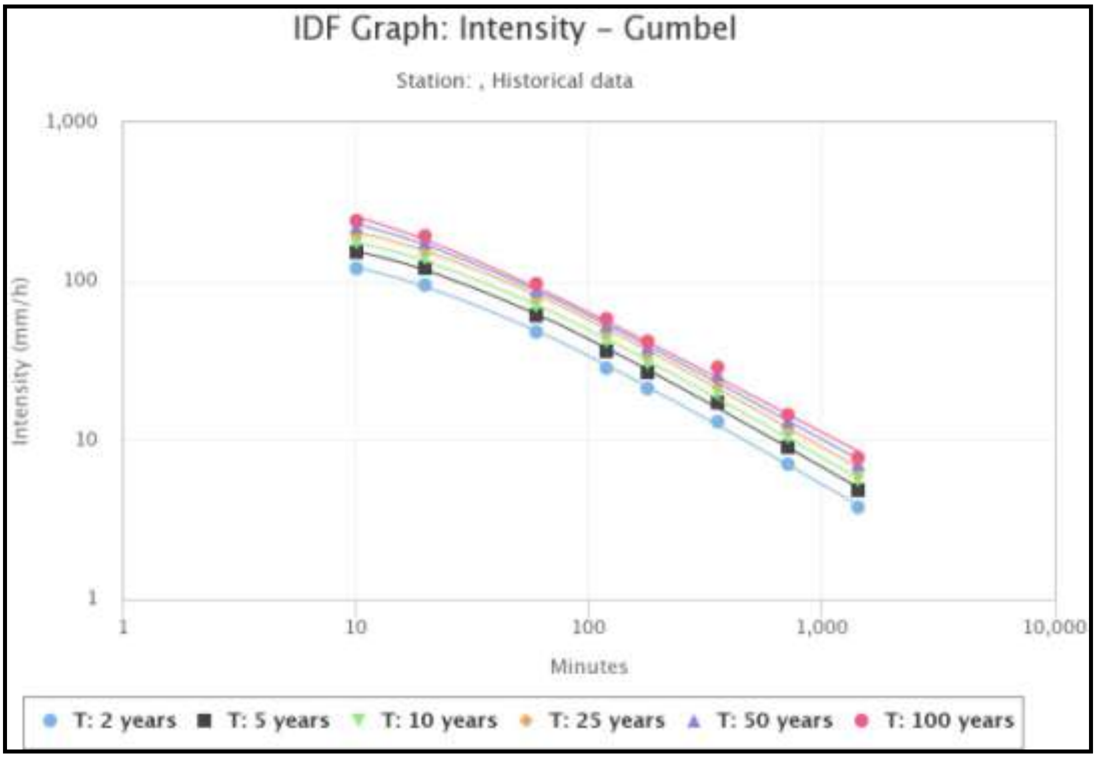
Furthermore, slightly higher rainfall intensity is projected for longer durations (2h, 6h, 12h and 24h) than shorter durations (10 min, 20 min and 1 hr) for all scenarios. For all durations, the average projected change in rainfall intensity is highest for RCP 4.5, followed by RCP 8.5 with RCP 2.6 scenario showing the least change.

Average percentage increase for shorter and longer durations are 3.00% and 3.14% respectively for RCP 2.6, 14.84% and 15.43% respectively for RCP 4.5 and 14.50% and 14.79% respectively for RCP 8.5.

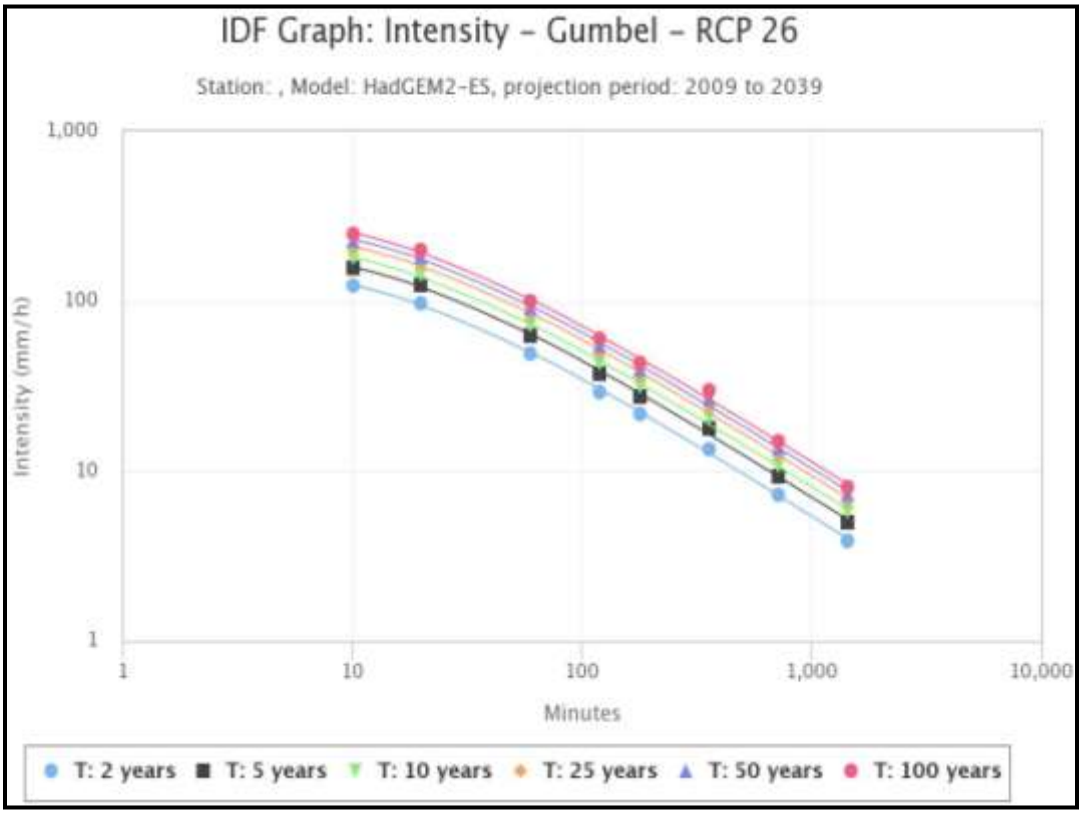
Generally, Rainfall intensity is projected to increase in future (2009-2039) for all durations and return periods compared to the historical or baseline (1971-2008).

Table 2: Rainfall intensities (mm/hr) for historical (1971-2008) and future (2009-2039) for RCP 2.6, 4.5, and 8.5 scenarios for Takoradi

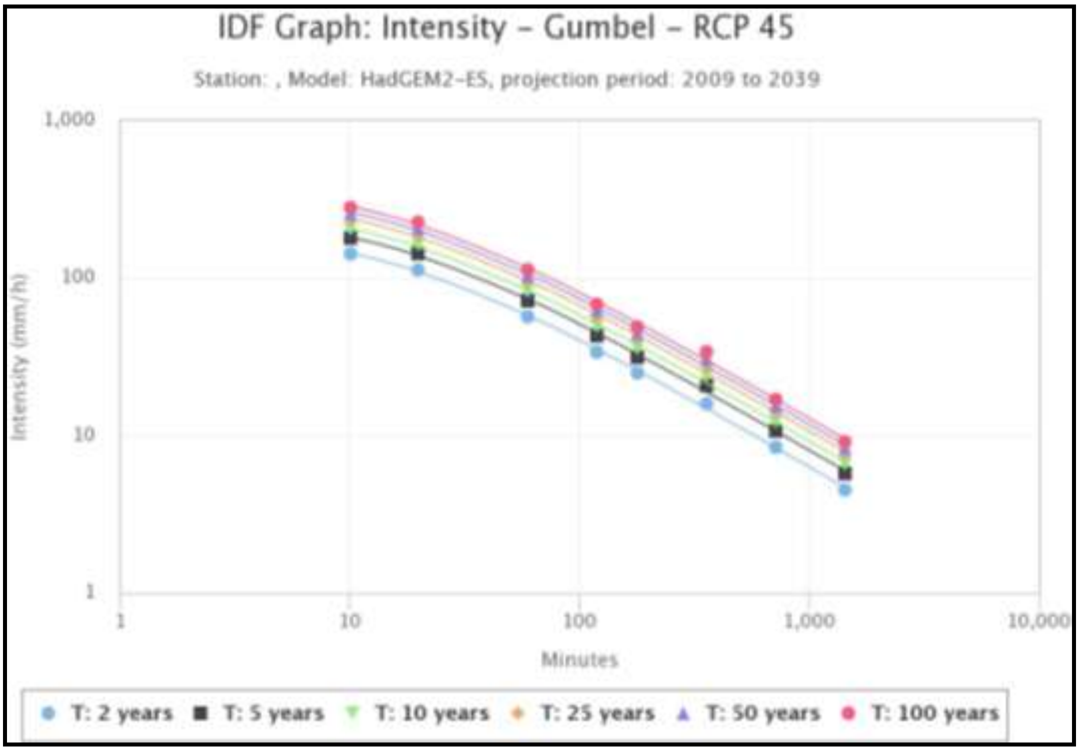
Historical							
T (year)	Duration						
	10min	20min	1h	2h	6h	12h	24h
2	120.7	94.9	48.0	28.5	13.1	7.1	3.8
5	152.8	121.2	61.0	36.4	17.3	9.1	4.9
10	174.1	138.7	69.6	41.7	20.1	10.4	5.6
25	200.9	160.7	80.5	48.3	23.6	12.0	6.5
50	220.8	177.0	88.5	53.2	26.2	13.2	7.1
100	240.6	193.3	96.5	58.1	28.8	14.5	7.8
RCP 2.6							
	10min	20min	1h	2h	6h	12h	24h
2	123.6	97.2	49.2	29.2	13.5	7.3	3.9
5	157.1	124.8	62.8	37.5	17.9	9.3	5.0
10	179.4	143.0	71.8	43.0	20.8	10.7	5.7
25	207.4	166.1	83.1	49.9	24.4	12.4	6.7
50	228.3	183.1	91.5	55.1	27.2	13.7	7.4
100	249.0	200.1	99.9	60.2	29.9	15.0	8.1
RCP 4.5							
	10min	20min	1h	2h	6h	12h	24h
2	142.4	112.7	56.8	33.8	15.9	8.4	4.5
5	179.5	143.1	71.8	43.0	20.8	10.7	5.7
10	204.0	163.2	81.7	49.1	24.0	12.2	6.6
25	235.0	188.7	94.3	56.7	28.1	14.1	7.6
50	258.0	207.5	103.6	62.4	31.1	15.5	8.4
100	280.8	226.3	112.8	68.1	34.1	16.9	9.1
RCP 8.5							
	10min	20min	1h	2h	6h	12h	24h
2	128.8	101.5	51.3	30.5	14.1	7.6	4.1
5	173.7	138.4	69.5	41.6	20.0	10.3	5.6
10	203.4	162.7	81.5	48.9	23.9	12.2	6.5
25	240.9	193.5	96.7	58.2	28.8	14.5	7.8
50	268.8	216.4	107.9	65.1	32.5	16.2	8.7
100	296.4	239.1	119.1	71.9	36.1	17.9	9.0


IDF Graph: Intensity – Gumbel
Station: , Historical data
1,000
100
10
1
Intensity (mm/h)
1
10
100
1,000
10,000
Minutes
T: 2 years
T: 5 years
T: 10 years
T: 25 years
T: 50 years
T: 100 years

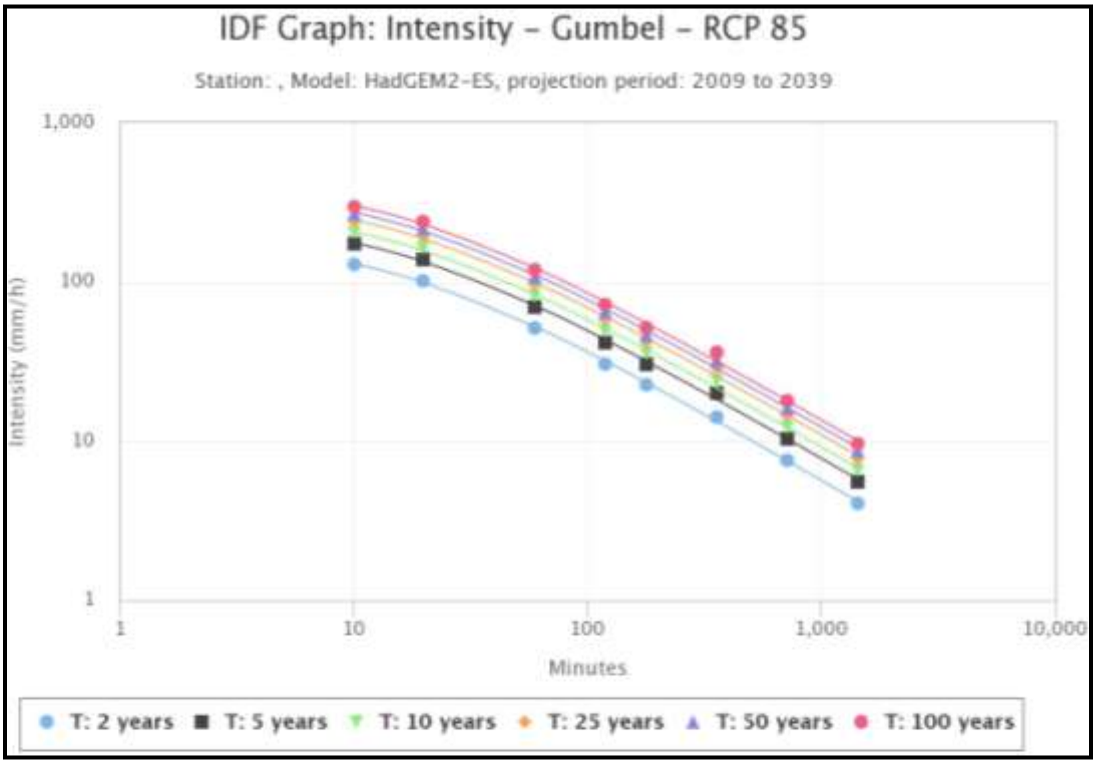
a)


IDF Graph: Intensity – Gumbel – RCP 26
Station: , Model: HadGEM2-ES, projection period: 2009 to 2039
1,000
100
10
1
Intensity (mm/h)
1
10
100
1,000
10,000
Minutes
T: 2 years
T: 5 years
T: 10 years
T: 25 years
T: 50 years
T: 100 years

b)



c)



d)

Figure 4. Kumasi IDF Curves for a) Historical data b) RCP 2.6 c) RCP 4.5 and d) RCP 8.5 for future time period of 2010-2040

Table 3: Percentage change in rainfall intensities in future (2009-2039) for RCP 2.6, 4.5, and 8.5 scenarios compared to historical (1971-2008)

RCP 2.6							
	10min	20min	1h	2h	6h	12h	24h
2	2.31	2.41	2.36	2.43	2.75	2.48	2.32
5	2.76	2.85	2.79	2.86	3.19	2.90	2.80
10	2.96	3.05	2.98	3.05	3.32	3.09	3.14
25	3.15	3.23	3.18	3.25	3.48	3.22	3.30
50	3.26	3.34	3.29	3.34	3.57	3.36	3.40
100	3.36	3.43	3.39	3.44	3.65	3.47	3.48
RCP 4.5							
	10min	20min	1h	2h	6h	12h	24h
2	15.24	15.80	15.46	15.88	17.84	15.93	15.96
5	14.86	15.29	15.03	15.35	16.84	15.42	15.33
10	14.68	15.05	14.82	15.10	16.34	15.15	15.24
25	14.51	14.83	14.63	14.88	15.90	14.87	14.91
50	14.41	14.70	14.51	14.74	15.67	14.75	14.85
100	14.32	14.59	14.43	14.62	15.47	14.64	14.71
RCP 8.5							
	10min	20min	1h	2h	6h	12h	24h
2	6.30	6.56	6.39	6.60	7.50	6.61	6.65
5	12.03	12.39	12.17	12.44	13.69	12.48	12.43
10	14.43	14.80	14.57	14.84	16.06	14.87	14.98
25	16.61	16.97	16.75	17.03	18.18	16.99	17.10
50	17.84	18.19	17.97	18.24	19.33	18.27	18.37
100	18.83	19.16	18.97	19.21	20.27	19.22	13.67

IV. CONCLUSION AND RECOMMENDATION

This study uses a web-based tool (IDF_CC) developed by Simonovic et al [1] to update IDF curves that incorporate projected climate change uncertainties for the city of Takoradi-Ghana. The capabilities of the web-based tool (IDF_CC) indicate that it can be used as a Decision Support System (DSS) for updating and incorporating climate change impacts into rainfall intensity duration frequency (IDF) curves for Takoradi.

Generally, Rainfall intensity is projected to increase in future (2009-2039) for all durations and return periods compared to the historical or baseline (1971-2008). Higher increase in rainfall intensity is projected for longer return periods (25, 50 and 100) than shorter return periods (2, 5 and 10) for RCP 2.6 and RCP 8.5 scenarios whereas higher intensities are projected for shorter return periods than longer return periods for RCP 4.5 scenario. Furthermore, slightly higher rainfall intensity is projected for longer durations (2h, 6h, 12h and 24h) than shorter durations (10 min, 20 min and 1 hr) for all scenarios. For all durations, the average projected change in rainfall intensity is highest for RCP 4.5, followed by RCP 8.5 with RCP 2.6 scenario showing the least change. The results indicate that climate change has had significant impact on the observed (historical) rainfall intensities and this has had effect on the historical IDF curves for Takoradi.

These therefore call for the revision and updating of the existing IDF Curves for all the major cities and towns in Ghana to take into account the effect of climate change.

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