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Developing Short Duration Rainfall Intensity Frequency Curves for Accra in Ghana

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Abstract: **Estimation of rainfall Intensity-Duration-Frequency (IDF) is commonly required for the design of hydraulic control structures and for water resources engineering planning and development. The relationship between rainfall intensity, duration and the return period of a certain rainfall amount can be determined through statistical analysis of rainfall data. Rainfall data collected from the four meteorological stations in the Greater Accra Region of Ghana were used to develop the rainfall intensity duration frequency curves with return periods ranging from 2 to 100 years and using the Gumbel distribution for rainfall intensity values for durations of 15, 30, 60, 120, 240 and 360 minutes. The rainfall intensity duration frequency curves developed for these stations are recommended for the prediction of rainfall intensities for Accra.**

Keywords: Rainfall intensity, return period, Intensity-Duration-Frequency (IDF) curve, Ghana

INTRODUCTION

Rainfall Intensity Duration Frequency (IDF) relationship is one of the most important tools in water resources engineering for accessing the risk and vulnerability of water resources structures as well as for planning, design and operation [1]. The IDF is a mathematical equation representing the relationship between maximum rainfall intensity as a dependable variable, the rainfall duration and the return period as independent variable [2]. There are several commonly used IDF functions found in the literature of hydrology applications ([2], [3], [4] and [5]) and Mathematically, the IDF relation can be presented as a function of the return period and the duration of rainfall (Eq. 1).

$$i = f(T, d) \quad \text{Eq. (1)}$$

where i is the rainfall intensity, T is the return period (years) and d is the rainfall duration (hr).

The Rainfall IDF curves are graphical representations of the rainfall intensity within a given time period. The development of IDF curves for a location or region is very important for engineering application due to the following reasons: (i) it helps to predict when a location or a region will be flooded; (ii) it helps to pinpoint when a certain rainfall rate or a specific volume of flow will recur in a location or region in the future and (iii) it helps in the estimation of design discharge for flood control structures. The information derived from the IDF curves is then used in hydraulic design to size culverts and pipes [6].

The development of the rainfall IDF for Accra is very crucial with the recent devastations caused by flood in the metropolis. Most of these floods in Accra have been attributed to poor design of the drainage systems, most of which are under-sized and cannot hold recent runoff volumes and as a result causing floods [7]. This therefore suggests that, most of the drainage systems in Accra were designed without considering the appropriate rainfall intensity values of the metropolis.

A. *Objectives*

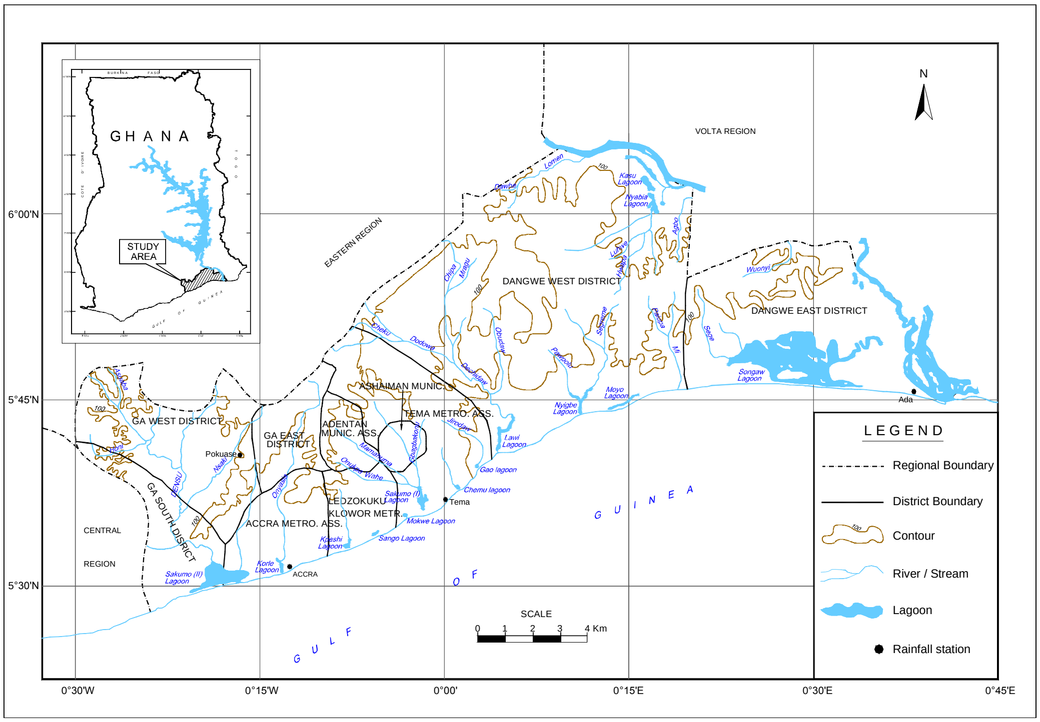
This paper proposes the development of rainfall IDF curves for Accra using empirical equations with data from four meteorological stations within the Greater Accra Region. The specific objective is to develop IDF curves for Accra for the estimation of rainfall intensity using different return periods.

MATERIALS AND METHOD

A. *Study Area*

Accra is the capital of Ghana as well as the capital of the Accra Metropolitan Assembly (AMA), located along the western coast of Africa in the dry savannah coastal zone of the southern part of the country. It is approximately 5.7° N of the Equator and 0.2°

W of the Greenwich Meridian (Fig. 1). The AMA covers an area of about 240 km² [8]. It has a total population of 4,358,263. The current growth rate in Accra is 3.3% per annum and a daily influx of about 300,000 visitors [9].



Fi. 1 Map of the Greater Accra Area of Ghana

1) *Climate:* The weather in the Greater Accra Metropolitan Assembly is predominantly sunny with a bimodal rainfall pattern. Rainfall in the region starts from April and ends in October, with peaks in June and September and August the driest. The average annual rainfall in the region is about 810 mm, occurring in less than 80 days ([10] and [11]). These rainy seasons are characterized by short storms which results in flooding in some parts of the capital due to poor drainage systems. Temperatures are generally high all year round with mean monthly values ranging from 24 ºC in August to 28 ºC in March [8]. Relative humidity is predominantly high, with average daily values ranging from 65 % to 95 %; the wind blows generally in the SW direction.

2) *Geology and Soil:* The geology of Accra is precambian Dahomeyan schists, granodiorites, granite gneiss, amphibolites and late Precambian Togo series which consist of quartzite, phillites, phylitones and quartz breccias. Others identified include Palaeozoic accraian sediments, sandstones, shales and interbedded sandstone-shale with gypsum lenses [12]. Accra plains are to a less extent underlain by Togo Quartzites and Tertiary Sediments. The geology of Accra gives rise to generally lateritic soil groups, which are readily erodible, and provide a significant source of sediment for the drains. Accra is also located in the southeast coastal savannah soils which comprise ochrosols, lateritic sandy soils, tropical black clays or Akuse soils and coastal sandy soil [12].

3) *Vegetation*: The constraints imposed by the geology and rainfall restrict the vegetation over most part of AMA to savannah scrubland. This limited vegetation is not easily maintained in most part of the metropolitan due to grazing by animals and movement of persons and vehicles.

B. *Data Collection and Analysis*

1) *Rainfall data:* Rainfall data from four meteorological stations in the Greater Accra Region were acquired for the analysis. Daily rainfall data at Tema, Ada and Pokuase were acquired from the Ghana Meteorological Agency (GMet) for the period 1990-2009 whilst the data for Accra was acquired at the meteorological station of the CSIR Water Research Institute at 15 minutes intervals for the period 1990 to 2012.

2) *Estimation of short duration rainfall:* Fig. 2 shows the correlation between observed and reduced maximum 24hr rainfall at Accra. The reduced maximum rainfall values were estimated using the empirical reduction formula in Eq. (2).

$$P_t = P_{24}\left(\frac{t}{24}\right)^{1/3} \qquad \text{Eq. (2)}$$

where P_t is the required rainfall depth in mm at t-hr duration, P_{24} is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in hour [13].

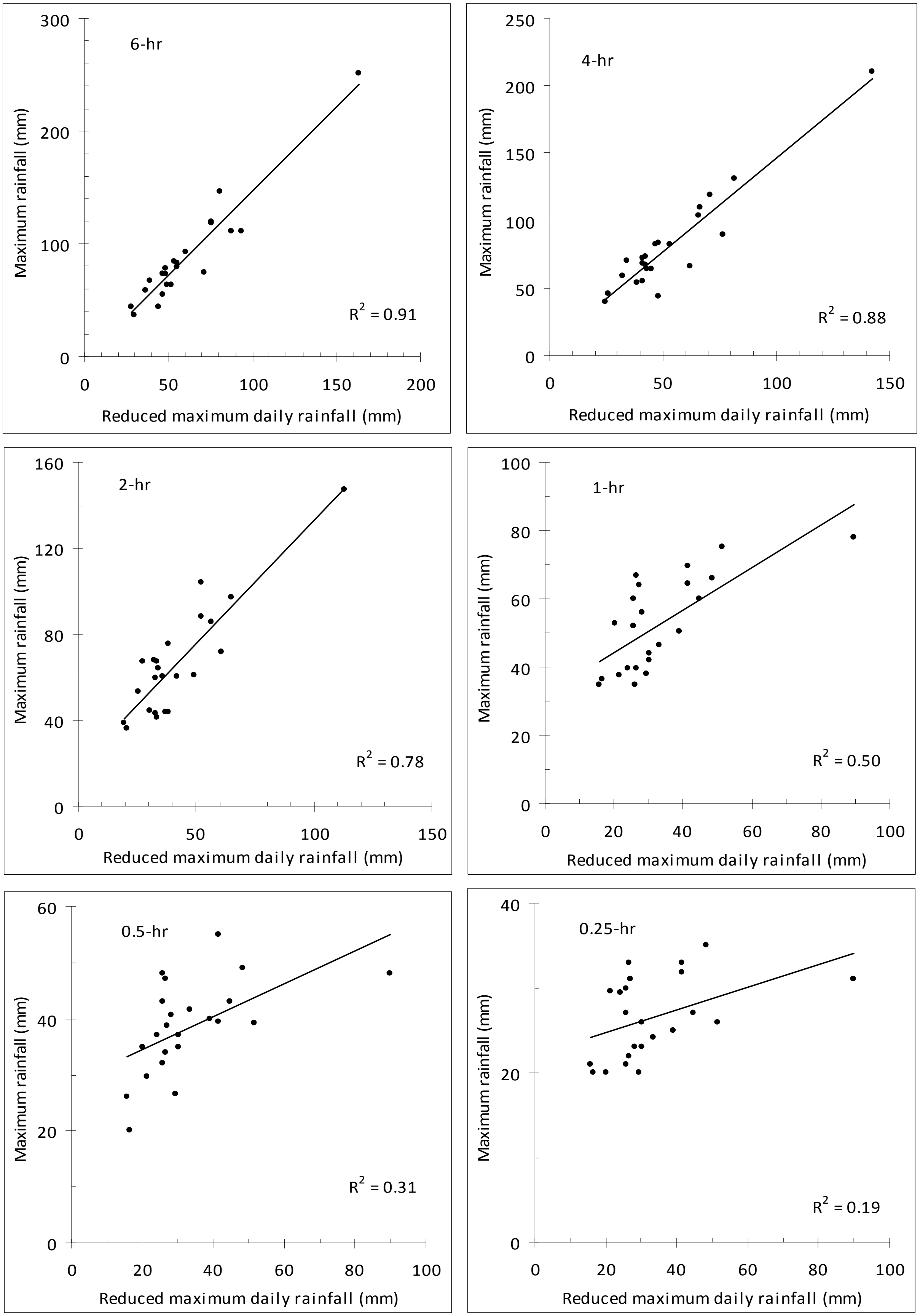


Fig. 2 Correlation between observed and reduced maximum daily rainfall at Accra

This method showed good correlations between observed and reduced values, however, correlation coefficient reduces with reduced duration. This formula was used to breakdown maximum daily rainfall at Tema, Ada and Pokuase to shorter durations of 0.25hr, 0.5hr, 1hr, 2hrs, 4hrs and 6hrs because it was found to give the best estimation of short duration rainfall ([13] and [14]).

3) *Intensity Duration Frequency Curves:* The following steps were used in developing the IDF curves for the stations. The 15 minutes rainfall data at Accra were aggregated to obtain 30, 60, 120, 240 and 360 minutes time series data. Twenty three years of annual maximum rainfall depths were abstracted each for 15, 30, 60, 120, 240 and 360 minutes durations. The mean and standard deviation of the annual maximum rainfall values were estimated for the given rainfall durations by using the functions "$average(x_1, x_2, x_3, ..., x_n)$" and "$stdev(x_1, x_2, x_3, ..., x_n)$", respectively in Microsoft Excel programme.

The rainfall intensity was computed by dividing the designed rainfall depth for a given return period in mm by the given rainfall duration in hours as defined in Eq. (3).

$$i = \frac{X_T}{d} \quad \text{Eq. (3)}$$

where i is the rainfall intensity (mm/hr), X_T is the designed rainfall depth (mm) for a given return period (T) and d is the duration of the rainfall (hours) ([2], [3], [4] and [5]).

The designed rainfall depth X_T, for a given return period (T) was estimated using Eq. (4).

$$X_T = \overline{X} + K_T s \quad \text{Eq. (4)}$$

where $\overline{X}$ and s are the mean and standard deviation, respectively, of the maximum rainfall depths (mm) of a specified duration and K_T is the rainfall frequency factor for a given return period ([2], [3], [4] and [5]).

The frequency factor for 2-, 5-, 10-, 25-, 50- and 100-year return periods were computed using the Gumbel's distribution as given by the expression in Eq. (5).

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \quad \text{Eq. (5)}$$

where K_T is the rainfall frequency factor for a given return period (T) ([2], [3], [4] and [5]).

RESULTS AND DISCUSSION

Fig. 3 shows the variability of maximum 24-hour rainfall for the period 1990 - 2009 in the Greater Accra Region at Accra, ema, Ada and Pokuase. The maximum daily rainfall in a year was observed to be 259.1, 205.7, 129.4 and 139.6 mm at Accra (1995), Ada (2003), Tema (1995) and Pokuase (2008), respectively

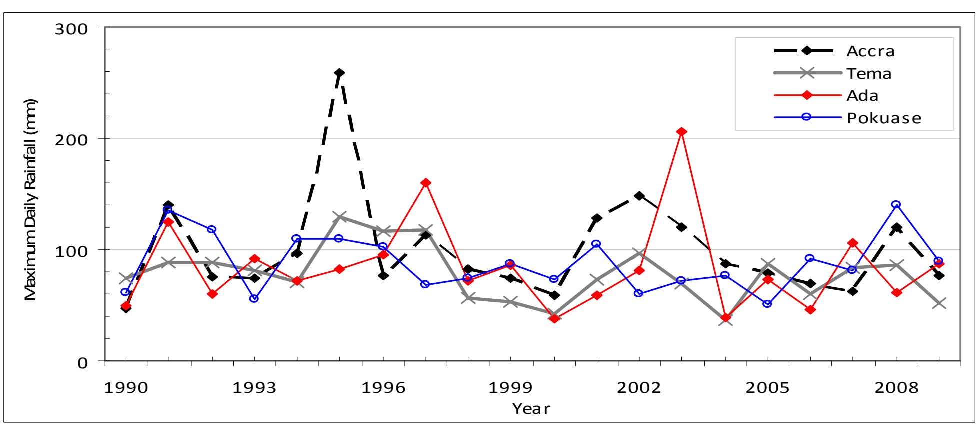


Fig. 3 Maximum daily rainfall amount at the stations for the period 1990-2012

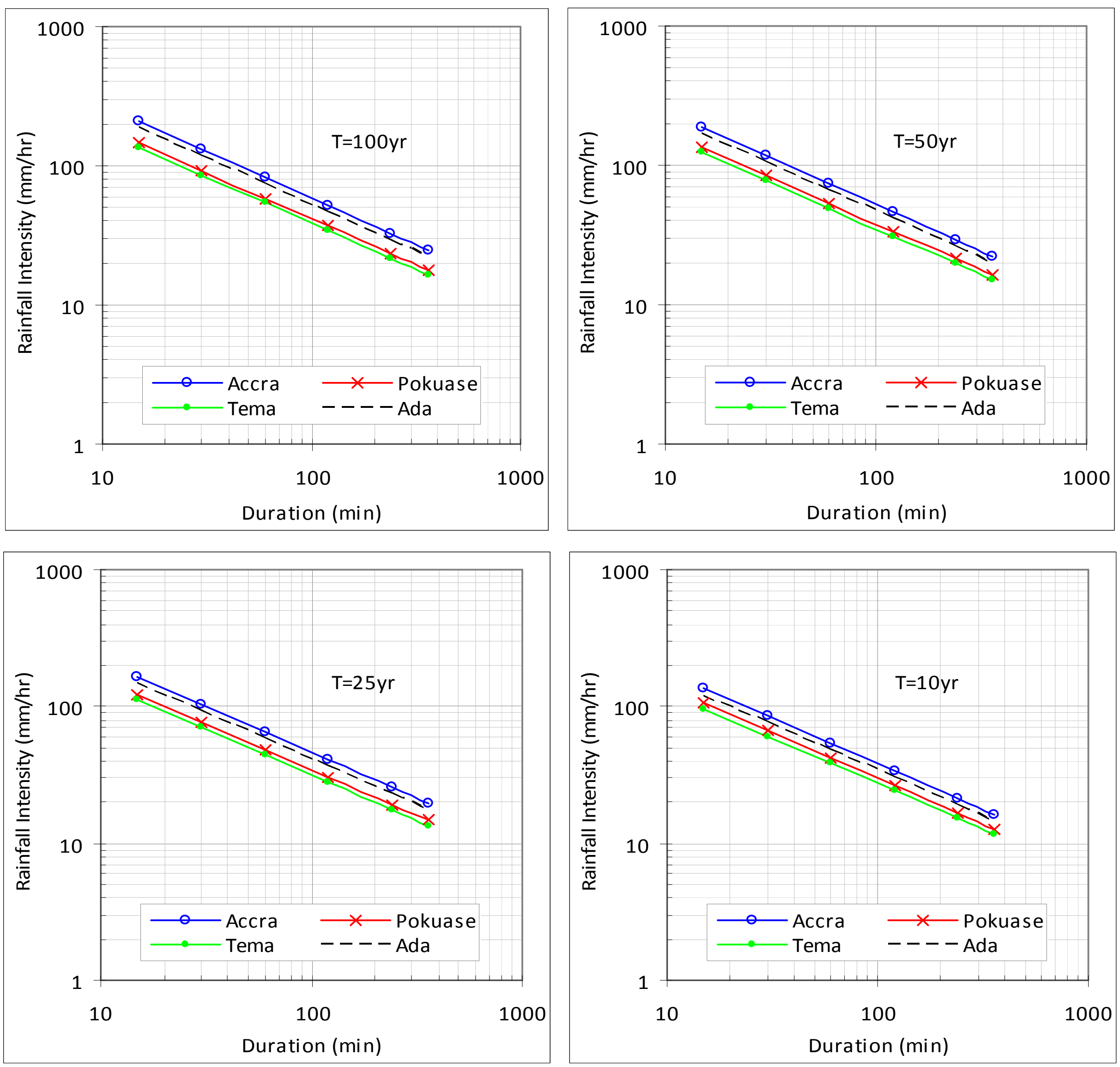
The frequency factors for the given return periods are tabulated in the Table 3.

Table 1: Estimated frequency factors for a given return period

Return Period (T)	Frequency Factor (K)
2	-0.16
5	0.72
10	1.30
25	2.04
50	2.59
100	3.14

C. *IDF Curves Developed*

The developed IDF curve for Accra is shown in Fig. 4. These were obtained by plotting the rainfall intensity values against their durations for the different return periods. Other rainfall IDF values can be spatially interpolated to obtain rainfall depth for all durations and return periods.



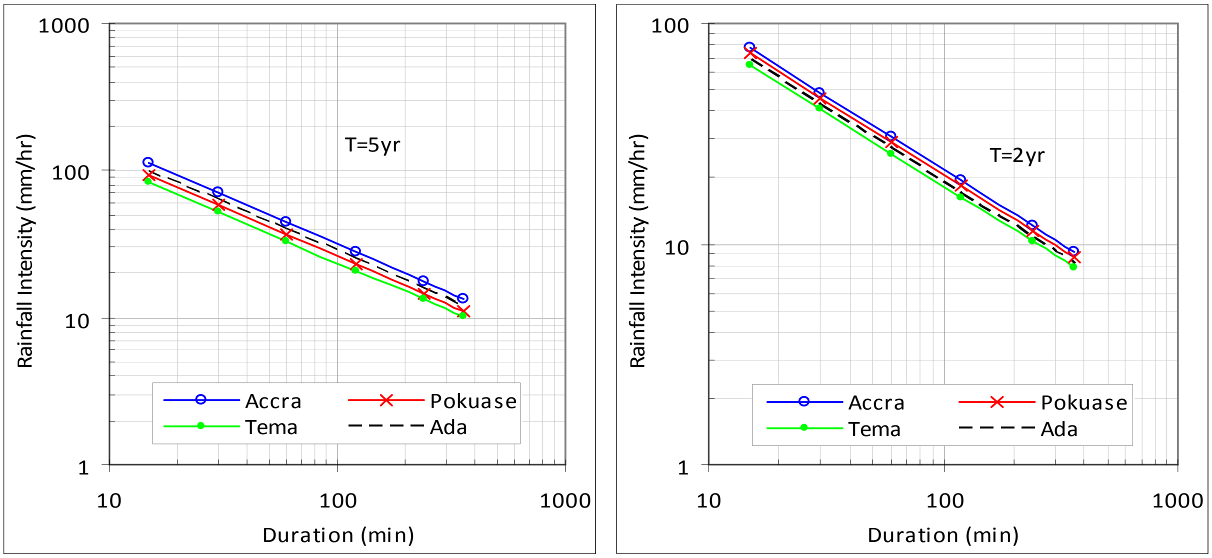


Fig. 4 Rainfall Intensity Frequency Curves in the Greater Accra Region.

CONCLUSIONS

In this study, the maximum annual rainfall values were abstracted for different durations and the rainfall IDF curves developed for stations in Greater Accra Region by assuming that the data followed a Gumbel distribution. Data derived from the rainfall intensity-duration-frequency curves are needed by hydrologist and engineers involved in planning and design of water resources projects. The maximum rainfall intensity of any storm over any return period for Accra can be obtained from the IDF curve. The therefore provides useful design data for water resources development in the region. The rainfall intensity curves developed in this study at short duration are useful design data for water resources development in the Greater Accra Region. The IDF curves are therefore recommended for the prediction of rainfall intensities and designs in the region.

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