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ORIGINAL ARTICLE

Developing an empirical formulae to estimate rainfall intensity in Riyadh region

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Abstract The purpose of this paper is to develop an empirical formula to estimate design rainfall intensity based on intensity–duration–frequency (IDF) curves. These curves have been generated from a 32-year recorded rainfall data for Riyadh region. Rainfall intensity–duration–frequency curves describe rainfall intensity as a function of duration for a given return period which are important for the design of storm water drainage systems and hydraulic structures. The formula is derived using the analysis of results of three different frequency methods, namely: Gumbel, Log Pearson III, and Log normal. These methods are used to obtain the IDF curves for six different durations (10, 20, 30 min, and 1, 2, 24 h) and six frequency periods (2, 5, 10, 25, 50, 100 years) where the best method of IDF estimation is recommended for future analysis. The equation can predict rainfall intensity in Riyadh region for any return period with a given storm duration and calibrated parameters obtained from IDF curves. Good match was achieved between its results and other analytical methods results such as Gumbel method. Moreover, it allows incorporating data from non-recording stations, thus remedying the problem of establishing IDF curves in places with a sparse network of rain-recording stations.

1. Introduction

Statistics and evaluation of extreme rainfall data are important in water resources planning and management for design purposes in construction of sewerage and storm systems, determination of the required discharge capacity of channels, and capacity of pumping stations. So they are important in order to prevent flooding, thereby reducing the loss of life and property, insurance of water damage, and evaluation of hazardous weather. Studies on the rainfall IDF relationship have received much attention in past few decades. See for example, Stewart et al. (1999) for more on this subject. Miller et al. (1973) developed various rainfall contour maps to provide the design rainfall

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depths for various return periods and durations. Buishand (1993) studied the influence of correlation on the determination of IDF curves for Debit (the Netherlands) using the annual maximum amounts for durations between 1 and 10 days.

A Gumbel distribution was fitted to these annual maxima. It was demonstrated that ignorance of the correlation between the estimated Gumbel parameters results in an underestimation of the standard deviation of the estimated quintiles from the IDF curves.

Endreny and Imbeah (2009) used two separate rainfall datasets in the country of Ghana with two different probability distribution frequency analysis methods to estimate intensity–duration–frequency (IDF) parameters. General extreme value type II (GEV-II) probability distributions were fit containing N-min to 24 h durations at 5–24 years record lengths, and from 381 TRMM satellite precipitation bins covering the country, containing 3–24 h duration at 9 years record length in 2007. It was shown that it is essential to combine meteorological and TRMM satellite data for IDF generation in Ghana. Madsen et al. (2009) used a regional model for estimation of extreme rainfall characteristics in Denmark and updated it with data from the augmented rain database for the period (1997–2005). They showed that for the durations (30 min to 3 h), and return periods (~10 years) typical for most urban drainage designs, the increase in rainfall intensity is in the order of 10%.

Many researchers have developed various formulae for design storm based on the construction of IDF curves. For example, Chen (1983) derived a generalized IDF formula for any location in the United States using three basic rainfall depths, that is, $R1^{10}$ (1 h, 10-year rainfall depth), $R24^{10}$ (24 h, 10-year rainfall depth), and $R1^{100}$ (1 h, 100-year rainfall depth). Baghirathan and Shaw (1978) and Gert et al. (1987) developed various types of regional IDF formulae for ungauged areas as many water resource projects are commonly located at an ungauged area in the early planning stage. Koutsoyiannis et al. (1998) proposed new approach to formulate and construct the IDF curves, which constitutes an efficient parameterization, facilitating the description of the geographical variability and rationalization of IDF curves and allows incorporating data from non-recording stations for construction the IDF curves at ungauged sites. Pao-Shan (2004) developed regional Intensity–duration–frequency (IDF) formulas for non-recording sites based on the scaling theory. Forty-six recording raingauges over northern Taiwan provide the data set for analysis. Three scaling homogeneous regions were classified by different scaling regimes and regional IDF scaling formulas were developed in each region. The analyzed results reveal that the regional IDF scaling formulas proposed resulted in reasonable simulations and verifications.

2. Rainfall data analysis

2.1. General

One tool for relating storm frequency to precipitation is the well-known Intensity–duration–frequency (IDF) relationship. It is mainly used to obtain "design storm" for different water system projects of certain reoccurrence interval. It is important to note that IDF relationships are not derived from a particular storm and therefore do not depict the likelihood of the occurrence of a particular storm. The relationships depict the probability of intense bursts of precipitation based upon data from many unrelated storms. Some variables are needed to be determined in order to obtain IDF relationship.

The typical estimation procedure for IDF curves as presented by Chow et al. (1988) and Singh (1992) consists of three steps. The first step consists of fitting a probability distribution function to each group comprised of the data values for a specific duration. In the second step, the rainfall intensities for each duration and a set of selected return periods (e.g. 2, 5, 10, 25, 50, 100 years, etc.) are calculated. This is done by using the probability distribution functions of the first step. In the third step, the final IDF relationship can be obtained in two different ways: either (a) for each selected return period the rainfall intensities are computed and a graphical relationship of intensity and duration for different return periods is established, or (b) the rainfall intensity is related in functional relationship to the rainfall duration and the return period using mathematical and regression analysis to derive such equation.

2.2. Design storms

Design storm for a catchment can be derived on the basis of the IDF-relationships. For any project and for a given return period and specified rainfall duration, the required design storm intensity can be obtained either from IDF-curves plots, or from derived IDF formula. An example of design storms is the so-called 'composite storm' of Keifer and Chu (1957). In that storm, the average precipitation intensity over each centered duration equals the IDF-value for the given return period of the storm. Such a storm thus contains the most important statistical precipitation information for hydrological applications: precipitation intensities and storm volumes for different return periods. They may be useful for the simple design of sewer and storm conduits, dikes, dams, and irrigation systems.

Nguyen et al. (1998) proposed a generalized extreme value (GEV) distribution model for regional estimation of short duration design storms based on the scaling theory. The suggested methodology has been applied to extreme rainfall data from a network of 14 recording raingauges in Quebec (Canada). Results of the numerical application have indicated that for partially-gagged sites the proposed scaling method is able to provide design storm estimates which are comparable with those based on available at-site rainfall data.

Application of Geographical Information System (GIS) to automate the evaluation, the design storm prediction and the flood discharge associated with a selected risk level has been done by Castrogiovanni et al. (2005). Some of the best-known probability distributions have been implemented within the GIS in order to estimate the point and/or areal rain values once duration and return period have been defined. They aim to allow remote users to access a centralized database and processing-power to serve the needs of knowledge and to get prediction of design storm without complex hardware/software infrastructures.

2.3. Determination of statistical variables

The annual extreme values of precipitation for six different recorded durations, namely: 10, 20, 30 min and 1, 2, 24 h have been extracted from historical precipitation records of Riyadh