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Frequency analysis of annual maximum hourly precipitation and determination of best fit probability distribution for regions in Japan

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ABSTRACT

In the design of irrigation and other hydraulic structures, evaluating the extreme rainfall for a specific probability of occurrence is important. The capacity of such structures is usually designed to cater to the probability of occurrence of extreme rainfall during its lifetime. In this study, a frequency analysis of annual maximum hourly rainfall for 15 locations in Japan was carried out using the Expanded Automated Meteorological Data Acquisition System (EA) weather data of 20 years from 1981 to 2000. Eight formulas were used to expect the return period in years of annual maximum hourly rainfall. Five different probability distribution functions (PDFs) were adopted to predict the probability distribution of occurrence of annual maximum hourly rainfall. The goodness of fit was evaluated using Chi-square test. It indicated that the Log-Pearson type 3 (LP3) distribution is the overall best fit PDF for annual maximum hourly rainfall at most locations of Japan.

1. Introduction

Extreme rainfall events and the resulting floods can take thousands of lives and cause billions of dollars in damage. Flood plain management and designers for flood control works, reservoirs, bridges, and other investigations need to reflect the likelihood or probability of such events. Hydrologic studies also need to address the impact of unusually low stream flows and pollutant loadings because of their effects on water quality and water supplies (Stedinger, 1983).

Frequency analysis is used to predict how often certain values of a variable phenomenon may occur and to assess the reliability of prediction. It is a tool for determining design rainfalls and design discharges for drainage works and drainage structures, especially in relation to their required hydraulic capacity. Designers of drainage works and drainage structures commonly use one of two methods to determine the design discharge. One is to select a design discharge from a time series of measured or calculated discharges that show a large variation. Another is to select a design rainfall from a time series of variable rainfalls and calculate the corresponding discharge via a rainfall-runoff transformation (Oosterbaan, 1988). Frequency analysis is also an information problem: if one had a

Abbreviations: P ($X \geq x$), probability of occurrence; T, return period or recurrence interval; m, rank of a value in a list ordered by descending magnitude; n, total number of values to be plotted; b, a parameter which is different in different formulas; X_T, maximum value of event corresponding to return period (T); μ, mean of annual maximum hourly rainfall of observed years; δ, standard deviation of annual maximum hourly rainfall of observed years; w, a value of an intermediate variable; z, a value corresponding to an exceedance probability of P; χ^2, Chi-square test; $F(x)$, cumulative density function (CDF); E_i, expected annual maximum hourly rainfall; Q_i, observed annual maximum hourly rainfall; i, the number of observations (1, 2, ………, k)

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sufficiently long record of rainfall, flood flows, or pollutant loadings, then a frequency distribution for a site could be precisely determined, so long as change over time due to urbanization or natural processed did not alter the relationships of concern (Stedinger et al., 1993).

Assessing the statistics of extreme rainfall events is important as the frequency of extreme events will affect the design, implementation and operation of measures for preventing floods (Liu et al., 2015). In hydrology, this includes selecting an appropriate probability distribution function (PDF) for assessing extreme rainfall events in regions. If the theoretical PDF fits the actual consecutive hourly, daily, monthly or yearly observed values of rainfall, it can be used to predict the probability of extreme rainfall events in the future. Distribution fitting is the procedure of selecting a statistical distribution that best fits to a data set generated by some random processes. PDF is an important tool for dealing with uncertainty (Khudri and Sadia, 2013). A research by Upadhaya and Singh (1998) reported that it is possible to predict precipitation fairly accurately by employing different probability distributions for certain return periods although the precipitation varies with respect to space, time and has an erratic nature.

In most cases, the return periods of interest exceed usually the periods of available records and could not be extracted directly from recorded data. Therefore, in current engineering practice, the estimation of extreme rainfall is accomplished based on statistical frequency analysis of maximum precipitation records where available sample data could be used to calculate the parameters of a selected frequency distribution. The fitted distribution is then used to estimate event magnitudes corresponding to return periods greater than or less than those of the recorded events. Accurate estimation of extreme rainfall could help to alleviate the damage caused by storms and can help to achieve more efficient design of hydraulic structures (Olofintoye et al., 2009). Many PDFs used in hydrology are the Normal, Log-Normal (LN), Gumbel, Gamma 2 (G2), Pearson type 3 (P3), Log-Pearson type 3 (LP3) and Weibull distributions (Aksoy, 2000). The Weibull and Gumbel distributions are commonly used for extreme values of hydrological variables. Ogunlela (2001) used five PDFs to analyze frequency of maximum daily and monthly rainfall for Ilorin, Nigeria. The result showed that the LP3 distribution best suited the maximum daily rainfall data while the normal distribution best described the maximum monthly rainfall for Ilorin. Salami (2004) reported the flow along the Asa River and established probability distribution models for the prediction of the annual flow regime in his study. The result showed that the LP3 and Gumbel distributions respectively were recommended for minimum and maximum flows. The applicability of LP3 distribution to flood and maximum rainfall data and its general use in fitting annual rainfall and stream flow sequences was evaluated by Phien and Ajirajah (1984). Nguyen et al. (2002) reported that several probability models have been developed to describe the distribution of annual extreme rainfalls at a single site. However, the choice of an appropriate PDF is still one of the major issues in engineering practice since there is no general agreement as to which distribution could be used for the frequency analysis of extreme rainfalls. Thus, it is necessary to evaluate many available PDFs in order to find an appropriate model that could provide accurate extreme rainfall estimations.

This study aims to study the distribution characteristics of annual maximum hourly rainfall for nine regions including 15 locations of Japan, using different PDFs such as Normal, LN, Gumbel, G2, P3 and LP3 distributions, and determine the best-fit PDF in terms of annual maximum hourly rainfall of 20 years from 1981 to 2000.

2. Observation sites and rainfall data

2.1. Weather observation sites of Japan

The regions of Japan are mainly divided into nine parts, which include Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku,

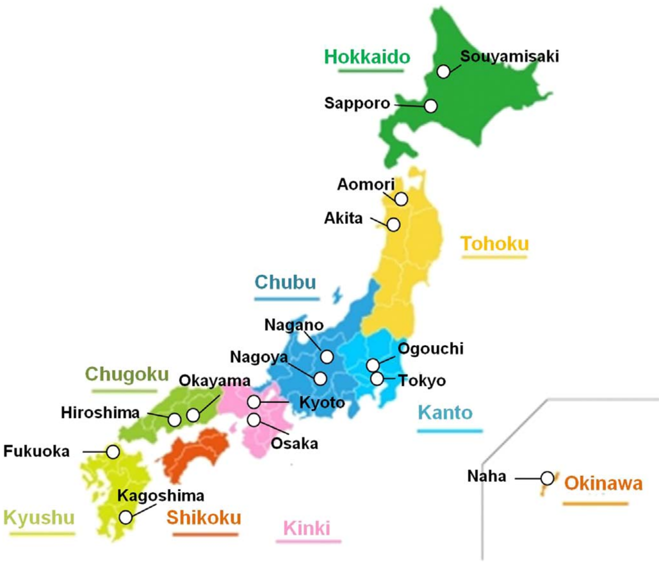

Fig. 1. Map of 15 locations in nine regions of Japan.