行政院國家科學委員會專題研究計畫成果報告

- 雨量站網設計中地形高程效應之影響(二)

Study on the Orographic Effect on Raingauge Network Design

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一、中文摘要

本研究應用克利金推估及隨機變域模擬，探討地形對雨量站網設計之影響。針對淡水河流域32**個雨量站之時雨量變異元分析結果顯示地形對雨量之空間變異具局部性、小尺度之影響；故雨量站網設計中區域站之設立應否考慮地形效應，需視研究區域大小及站網設置目標而定。對小區域之水文模擬而言，地形效應相對重要；對大區域之水文模擬，則地形效應不顯著。隨機變域條件模擬之結果，顯示所選用雨量站中有** 7 **站屬基本站，**17 **站屬區域站，其餘** 8 **站則可捨棄而不致影響站網之觀測效率。基本站所收集之時雨量資料無法代表流域時雨量變異特性；然而針對年雨量所進行之隨機變域模擬，則顯示基本站之年雨量所得之變異元函數足以代表年雨量之空間變異。**

關鍵詞：克利金推估、隨機變域模擬、雨量站網

Abstract

Raingauge network in Tan-sui River watershed is evaluated by theory of geostatistics and random field simulation. Dimensionless variogram of hourly rainfall was established using hourly rainfall data observed at thirty-two raingauge stations. With reference to global kriging variances, a sequential algorithm determines the reasonable number of raingauges that should be retained and basic raingauges that are required to detect the trend of rainfall spatial variation. Finally, a random field simulation model (HYDRO_GEN) generates realizations of an hourly rainfall random field with predetermined probability distribution and variogram. Using these simulated realizations, we demonstrate that probability distribution and variogram of the hourly rainfall random field are successfully recovered by the retained raingauges. However, the basic raingauges fail to recover the stochastic characteristics of hourly rainfall field; instead, variogram of annual rainfall field is recovered.

Keywords: kriging estimation, Random field simulation, raingauge network

二、Introduction

Information of spatial and temporal distribution of rainfall is essential to water resources planning, design of hydraulic structures, flood mitigation, drainage project, etc. Rainfall data of different observation intervals like hourly, daily and annual rainfall are regarded as rainfall of different time scales. Direct measurement of rainfall is accomplished by raingauges and is considered as point rainfall since the catching area of a raingauge is very small compared to the areal extent of a storm. Rainfall data of different time and spatial scales exhibit different characteristics of spatial variation. For example, hourly rainfall of severe storms exhibits much higher spatial variation than annual rainfall. The dependence of spatial variation characteristics on time scale inevitably affects the optimum density of raingauges from which representative picture of spatial rainfall variation can be obtained. For the purpose of water resources planning, rainfall of large time scales (long observation intervals) like monthly and annual rainfalls are needed whereas hourly rainfall data are used for flood forecasting and drainage project. Clearly, flood forecasting requires higher raingauge density than water resources planning.

Over the last two decades, spatial distribution of rainfall was widely considered as a random field and theory of geostatistics and techniques of conditional random field simulation were applied to describe the spatial variation of a rainfall field. The objective of this study is to investigate the orographic effect on spatial variation of rainfall and to evaluate the performance of an existing raingauge network by technique of conditional random field simulation.

三、Theory

Kriging Estimation

Let x_i, i=1, 2,⋯, n be spatial locations where measurements $Z(x_i)$ are made. Measurements $\{Z(x_i), i=1, 2,\ldots, n\}$ form a realization of random field (RF) $Z(x,\xi)$ where ξ represents the state variable of realizations. For simplicity, we drop the notation of ξ hereafter. It is assumed that the random field $Z(x)$ is isotropic and fulfills the intrinsic assumptions:

$$E[Z(x)] = \text{«}_z \qquad (1)$$

$$\gamma(x_i, x_j)= \gamma(|x_i - x_j|) \qquad (2)$$

where $\gamma(x_i, x_j)$ is the variogram of $Z(x)$ and is defined as

$$\gamma(x_i, x_j)=\frac{1}{2}Var[Z(x_i) - Z(x_j)] \qquad (3)$$

For a particular realization of $Z(x)$, the kriging estimate of $Z(x_0)$ at ungauged location x_0, using measurements $Z(x_1)$, $Z(x_2)$,....,$Z(x_n)$, is represented as a linear weighted average

$$\hat{Z}(x_0) = \sum_{i=1}^{n} a_i Z(x_i) \qquad (4)$$

Weights a_i being assigned to the n measurements are determined by solving the following equations of *ordinary kriging system*:

$$\left.\begin{aligned} &\sum_{i=1}^{n} a_i = 1 \\ &\sum_{j=1}^{n} a_j \gamma(x_i - x_j) + \mu = \gamma(x_0 - x_i) \end{aligned}\right\} \qquad \begin{aligned} &(5) \\ &(i=1,2,\ldots,n) \quad (6) \end{aligned}$$

The variance of estimation error, or the kriging variance, is:

$$\begin{aligned} \pm_k^2 &= Var[\hat{Z}(x_0) - Z(x_0)] \\ &= \text{«} + \sum_{i=1}^{n} a_i \text{¥}(x_0 - x_i) \qquad (7) \end{aligned}$$

Monitoring network design

Since kriging estimate $\hat{Z}(x_0)$ is unbiased, smaller kriging variance implies better estimation of $Z(x_0)$ using $Z(x_1)$, $Z(x_2)$,...., and $Z(x_n)$. In view of network design, a very small kriging variance at x_0 means much of the information at x_0 can be transferred from information at x_1, x_2,....,and x_n. Thus, it is not necessary to have a station installed at x_0, whereas locations with large kriging variance would necessitate gauge installations.

Assuming that there are n raingauges in a watershed, the importance of each raingauge in the network can be evaluated by a sequential approach (Cheng et al., 1996). Results of the sequential approach suggested that seven basic stations and 17 local stations are enough to provide almost the same amount of information that could be provided by all 32 stations.

Random field simulation

Assumed a stationary random field $Z(x)$ with given statistical distribution $N(«_z, \pm_z^2)$, realizations of the random field were generated using HYDRO_GEN, based on theory of conditional probability. Let the mean and variance of the random variable $Z(x_0)$ are known and observed value of Z at x_0 be $z(x_0)$. The conditional mean and variance of the random variable defined at x_1, $Z(x_1)$, are

$$E[Z^c(x_1)] = E[Z(x_1 \mid z(x_0)] = m_z(x_1) + a_1(x_1)[z(x_0) - m_z(x_0)] \quad (8)$$

and

$$\pm_z^{2c}(x_1) = \pm_z^2 - a_1(x_1)C_z(x_1, x_0) \quad (9)$$

where $C_z(x_0, x_1)$ is the covariance function of random variables $Z(x_0)$ and $Z(x_0)$, and $a_1(x) = \frac{C_z(x_0, x_1)}{\pm_z^2}$. The HYDRO_GEN used an iterative scheme to generate realizations of a random field with given distribution and spatial structure, i.e. the covariance function.

四、Results

The study area was discretized into grid network with various grid intervals. Using subsets of the given raingauge network, experimental variogram of the rainfall field were calculated and used to investigate their capability of capturing the spatial variation structure of the random field.

The simulation results revealed that with 24 stations (7 basic stations + 17 local stations), at least 180 realizations were needed to accurately estimate the variogram of the rainfall field. With only seven basic stations, variogram estimation was not successful even using more than 250 realizations. However, using annual rainfall measurements at the seven basic stations, the variogram of annual rainfall field was estimated accurately using only 150 realizations. The results of this study were consistent with results of a previous research by the author. Previous research applied a sequential algorithm to decide the minimum number of raingauges needed to capture most of the information, however, it did not explicitly show the capabilities of the basic and the local stations in terms of variogram estimation. In contrast, the technique of conditional random field simulation clearly demonstrated the spatial characteristics of rainfall data collected by the basic stations and the local stations.

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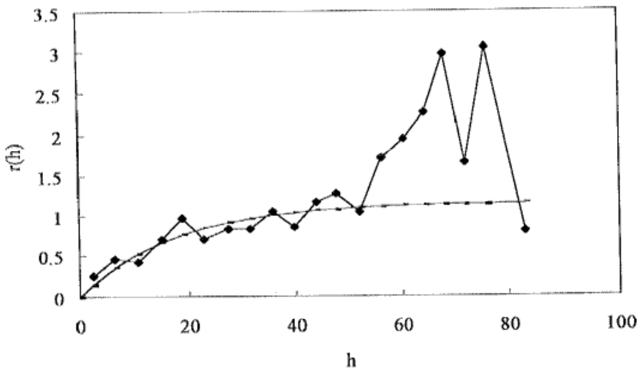

Fig.1 Dimensionless variogram of average annual rainfall.

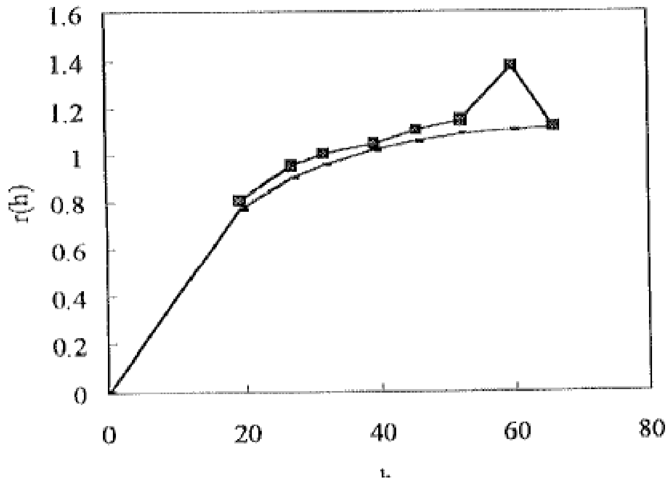

Fig2 Simulated variogram of average annual rainfall using seven basic stations and 150 realizations.

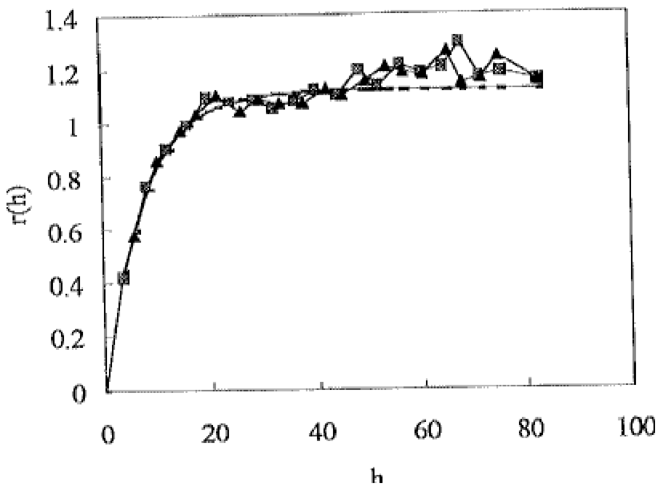

Fig3.Variogram estimations using 24 and 32 stations and 150 realizations.