Rainfall reliability, drought and flood vulnerability in Botswana

Rejoice Tsheko
University of Botswana, Faculty of Agriculture, Department of Agricultural Engineering and Land Planning, Private Bag 0027, Gaborone, Botswana

Abstract

Rainfall data from 14 stations (cities, towns and major villages) spanning 26 years (1970 to 1995) were used to calculate reliability and vulnerability of rainfall in Botswana. Time series data for 72 years were generated from the long-term rainfall gauging stations and the number of wet and dry years determined. Apart from Mahalapye, most places have rainfall reliability greater than 0.5 but less than 0.7. Palapye and Serowe are the most vulnerable to flooding. During the 1995 floods, 87% of casualties were from these areas. Other factors such as rivers, topography, land use etc. can influence flooding vulnerability, but these have not been dealt with in the study, and hence vulnerability is purely based on rainfall amounts. Using two methods, the correlation coefficient is 0.9 ($p<0.005$) for reliability and risk values. The first method was originally developed for water resource system performance evaluation and the second method is based on dry/wet year sequences.

Keywords: rainfall, reliability, risk, flood, drought, vulnerability, Botswana.

Introduction

It is well known that rainfall in Botswana is generally low, erratic and unreliable. To define how severe and how frequent periods of droughts and floods are, it is useful to quantify the above statement. Hashimoto et al., 1982 proposed criteria that capture particular aspects of possible water resource system (WRS) performance. These criteria are very important during drought, peak demands, or extreme weather sequences. The two criteria for evaluating the performance of a WRS are reliability, which measures how likely a system is to fail, and vulnerability, which measures the severity of the consequences of failure (Hashimoto et al., 1982). Failure frequency and system reliability are indices, which are normally used to describe the system's performance (Hall and Dracup, 1970). It has been customary to refer to the safe yield of a reservoir as if it were a guaranteed minimum yield. Analysis of the historical record or simulated stream flow provides no evidence regarding the reliability of a reservoir (Linsly et al., 1982). When a stochastic analysis is accepted as a realistic example of what may happen in the future, storage probability curves can provide useful information (Linsly et al., 1982).

A system's output state or status can be denoted by a random variable X_t at time t, where t is discrete. The possible values of X_t can be partitioned into two sets: S, the set of all satisfactory outputs, and F, the set of all failure outputs. At any time t the system output can be in any of the two sets, hence the reliability of a system can be described by frequency or probability α that a system is in a satisfactory state (i.e. rainfall of year **n** is above long-term mean rainfall) (Loucks et al., 1981; Hashimoto et al., 1982).

$$\alpha = \text{Prob}[X_t \in S] \quad (1)$$

The risk, **r** or probability of failure is one minus the reliability.

(2)

☎ +267 3650128; fax: +267 328753; e-mail: rtsheko@bca.bw

Received 7 February 2003; accepted in revised form 23 July 2003.

System vulnerability refers to the likely magnitude of failure, if failure occurs. It should be noted that even if the probability of failure is small, attention should be paid to consequences of failure.

To construct a mathematical index of system vulnerability ν, assume that the system performance variable X_t can take discrete values $x_1, \ldots, x_n$. To construct a quantitative indicator of system vulnerability to severe failure, assign to each failure state $x_j \in F$ a numerical indicator of the severity of the state (i.e. cost function, denoted by s_j. Let e_j be the probability that x_j, corresponding to s_j, is the most unsatisfactory and severe outcome, hence vulnerability (Loucks et al. 1981; Hashimoto et al. 1982) is estimated as:

$$\nu = 1 \sum_{j \in F} \alpha s_j e_j \quad (3)$$

Windsor (1973) developed and provided a solution for non-linear cost function curves for the damage centres; these types of functions will be needed if Eq. (3) is to be used to calculate vulnerability. Equation (4) does not require estimation of a cost function although it gives the most unsatisfactory and severe outcome, hence vulnerability. This equation is used to calculate vulnerability in this work.

$$v = \underset{t}{Max}[X_t - X_o] \quad (4)$$

where X_o is some threshold value i.e. the mean long-term minimum or maximum rainfall. For drought vulnerability, X_o is the mean long-term minimum rainfall, while for flood vulnerability X_o is the mean long-term maximum rainfall at a station.

In this paper we borrow the Hashimoto et al. (1982) criteria developed for WRS to quantify rainfall characteristics in semi-arid Botswana.

The rainfall pattern impacts on the lives of Batswana in several ways. There have been severe floods and droughts in the past whereby a great deal of human suffering resulted. Rivers are subject to many random influences such as rainfall extremes, giving rise to floods or drought (Hall and Dracup, 1970). During the 1983/84 drought, it cost the Botswana Government US$ M51 939 to mitigate the impacts of drought (CSO, 2000). Most of the Batswana still depend on agriculture (commercial and subsistence) for both food and income, hence rainfall deficiency affects crop and livestock production. During the 1985 drought, there was a reduction