RAINBOW: a software package for analysing hydrologic data

D. Raes, D. Mallants, Z. Song
K.U. Leuven University, Faculty of Agricultural and Applied Biological Sciences, Institute for Land and Water Management, Vital Decosterstraat 102, B-3000 Leuven, Belgium

Abstract

RAINBOW is a software package developed by the Institute for Land and Water Management of the K.U.Leuven. The programme is designed to test the homogeneity of hydrologic records and to execute a frequency analysis of rainfall and evaporation data. The program is especially suitable for predicting the probability of occurrence of either low or high rainfall amounts, both of which are important variables in the design and management of irrigation systems, drainage network, and reservoirs. The RAINBOW software is a menu-driven programme and runs on an IBM compatible personal computer. The software is freely available from the authors upon request.

1 Introduction

Of all the water on Earth, which is estimated to be 1.4 billion cubic kilometres, almost 98 percent is saline. The fresh water is for more than half permanently locked away in ice or is deep fossil water. The demand for fresh water will increase in the next fifty years. Today, it is estimated that irrigated agriculture accounts for 73 percent of the world water consumption. The current irrigated area of the world covers about 18 % of the total cultivated area but contributes about one third of the world's food production. If agriculture is intending to maintain or increase its current crop production, the limited water resources will have to be used in a more efficient way. A key solution is to improve irrigation management, by using more skilful irrigation techniques in addition to better estimates of irrigation requirement, optimal sowing date, and better design of small-scale water reservoirs. Computer models are much-needed tools that assist the irrigation manager in meeting the above challenges, for instance by analysing long records of rainfall data from which irrigation requirements or alternative irrigation strategies may be deduced.

This paper describes such a computer model that was designed to statistically analyse hydrologic data. It is primarily used for frequency analysis of rainfall and evaporation data, but it can be equally well used to investigate the distribution characteristic of streamflow data. The latter may be of use for flood and drought hazard assessment. Potential applications of the RAINBOW software are demonstrated.

2 Model

2.1 Frequency analysis and probability plotting

The frequency analysis of data available from a subset of population, consists in building and interpreting a probability distribution. In RAINBOW the analysis is based on ranking. After ranking the data values in a descending order and assigning a serial rank number to each value, a plotting position is obtained. The plotting position corresponds with the frequency of exceedance on the probability scale of the probability plot (Fig.1). Several relationships can be used to calculate the plotting position (Table 1). After the selection of the calculation of the plotting position and the distributional assumption, the observations are plotted and the theoretical distribution line is drawn (Fig. 1). In RAINBOW either the normal or the Gumbel (extreme value type I) distribution (Gumbel,[1] Haan,[2] Oosterbaan[3]) can be selected. Instead of drawing the theoretical line, a straight line can be fitted through the data points by the methods of least squares. Information on the goodness of fit (R^2) is then displayed. If the plotted data fall in a reasonable alignment, it may be assumed that the data can be approximated by the assumed distribution. The magnitude of the events corresponding to various probabilities and return periods is derived from the probability plot and displayed in a table.

Table 1. Plotting position relationships.
(r = rank number and n = number of observations)

Name	Relationship
California	r/n
Hazen	(2r - 1)/2n
Weibull	r/(n + 1)
Gringorten	(r - 0.44)/(n + 0.12)

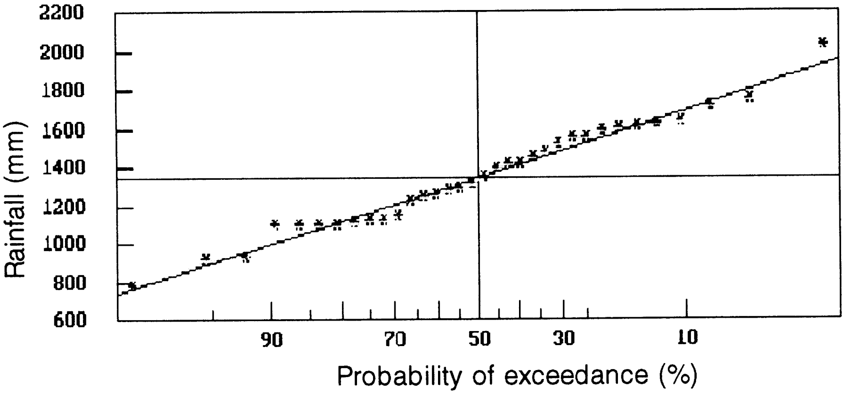

Figure 1: Probability plot of total annual rainfall data (1960-1994) of Antananarivo (18°54'S & 47°32'E), Madagascar.

When probability plots of hydrologic data are made, frequently one or two extreme events are present that appear to be from a different population because they plot far off the line defined by the other points. In RAINBOW these so-called 'outliers' can be excluded, if desired.

A skewed frequency distribution, where points in the probability plot do not fall in a reasonable alignment, may often mean that the data is not distributed as the selected distribution. To convert the distribution to normality, a transformation can be attempted. In RAINBOW three functions (logarithm, square and square root) are available to perform a transformation of the data. The transformed data usually will be closer to the symmetrical normal distribution.

2.2 Total probability

A rainfall data set is often bounded on the left by zero values. In RAINBOW the theorem of total probability is used to analyse a set of data with zero and non-zero values,

$$G_X(x) = p + (1 - p)\ F_X(x) \qquad (1)$$

where $G_X(x)$ is the cumulative probability distribution of all X (prob($X \leq x \mid X \geq 0$)), p is the probability that X is zero, and $F_X(x)$ is the cumulative probability distribution of the non-zero values of X (i.e. prob($X \leq x \mid X \# 0$)). This type of mixed distribution with a finite probability that $X = 0$ and a continuous distribution of probability for $X > 0$ is discussed by

Haan[2].

To offer the possibility to exclude also small - although not zero- events from the cumulative probability distribution, RAINBOW allows the specification of a NIL value different from zero. Observations equal to or smaller than the specified value will be treated as zero value events.

2.3 Homogeneity test

In RAINBOW the test for homogeneity is based on the adjusted partial sums or cumulative deviations from the mean (Buishand,[4] Demarée & Chadilly[5]),

$$S_k = \sum\nolimits_{i=1\ldots k} (X_i - \overline{X}), \qquad k = 1,..,n \qquad (2)$$

where X_i are the records of the partial duration series X_1, X_2, ..., X_n and $\overline{X}$ the mean. For a homogeneous record one may expect that the S_k's fluctuate around zero since their is no systematic pattern in the deviations of the X_i's from their average value. IN RAINBOW the rescaled cumulative deviations, obtained by dividing the S_k's by the sample standard deviation value (σ_x), are displayed (Fig. 2).

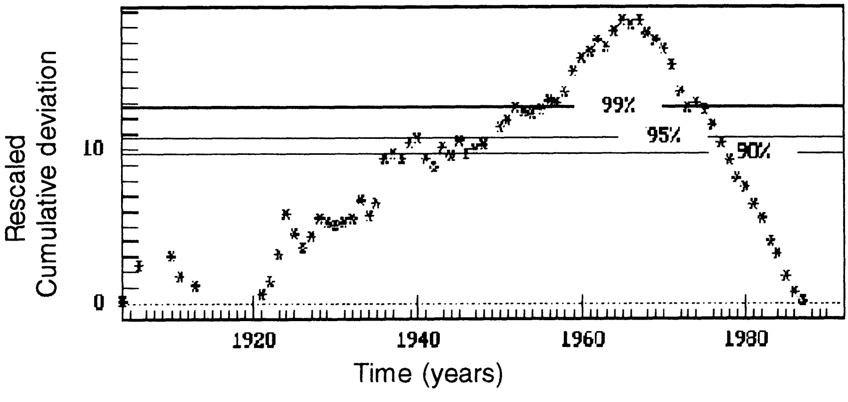

Figure 2: Rescaled cumulative deviations (*) from the mean (dotted line) of the total annual rainfall of Kaëdi (16°09'N & 13°31'E), Mauritania for the period 1905-1987. Full lines reject the hypothesis of homogeneity at various probability levels.

Transactions on Ecology and the Environment vol 12, © 1996 WIT Press, www.witpress.com, ISSN 1743-3541

A statistic which is sensitive to departures from homogeneity is,

$$Q = \max \left| S_k / \sigma_x \right| \qquad k = 0,\dots,n \qquad (3)$$

High values of Q are an indication for a change in the mean level. Another statistic which is used for testing the homogeneity is the range,

$$R = \max(S_k / \sigma_x) - \min(S_k / \sigma_x) \qquad k = 0,\dots,n \qquad (4)$$

Shifts in the mean usually give rise to high values of the range. Values presented by Buishand[4] of the maximum cumulative deviation (Q) and the range (R) are used in RAINBOW to decide whether or not to reject the homogeneity of the data (Fig. 2).

2.4 Structure of the Software

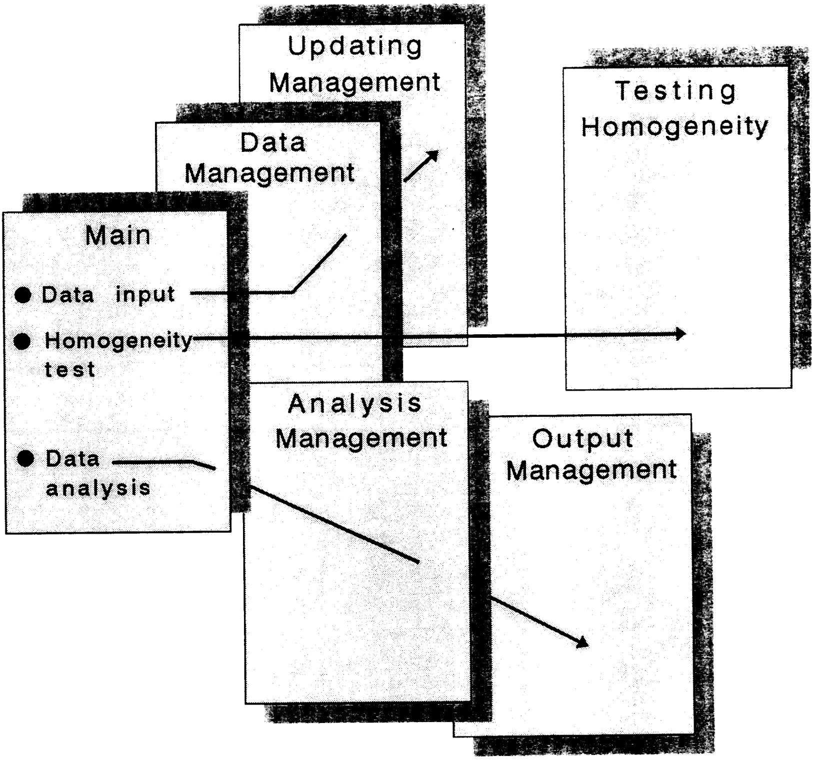

Figure 3: Hierarchical structure of the displays.

In RAINBOW all data is displayed and accessed in a structured and user-friendly way. The hierarchical structure of the displays is given in Figure 3. Input data, stored in files, is loaded in the DATA MANAGEMENT menu and updated in the UPDATING MANAGEMENT menu. The data files are either created by RAINBOW or imported from other programs. Commands in the MAIN menu allow the user to test the data on its homogeneity, and to execute a frequency analysis. The plotting position, type of distribution and transformation function are selected in the ANALYSIS MANAGEMENT menu. The results of the analysis and information on statistical properties are available in the OUTPUT MANAGEMENT menu. The results may be graphically or tabular displayed and saved in print-out files. The print-out files may be edited and printed once the RAINBOW session has been terminated.

3 Practical Applications

Based on examples, we will show the usefulness of RAINBOW in analysing and interpreting records of hydrologic data, in casu rainfall data from the subsaharian African continent.

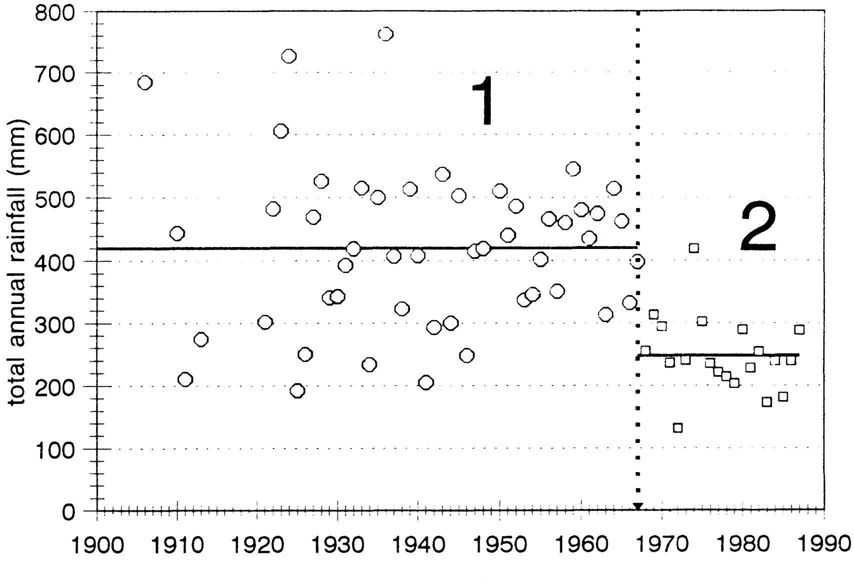

Figure 4: Two statistically significant distinct periods in the annual rainfall data of Kaëdi, with indication of their mean (full line).

Transactions on Ecology and the Environment vol 12, © 1996 WIT Press, www.witpress.com, ISSN 1743-3541

3.1 Homogeneity test

Figure 2 presents the output of the homogeneity test of RAINBOW on the annual rainfall data of Kaëdi in Mauritania. The rainfall data from 1905 until 1987, extracted from the FAO climatological data bank[6] reveals the major pattern of the Sahelian precipitation climate. The most striking feature is the below normal rainfall over the entire period 1968-1987. From the data, Demarée & Chadilly[5] inferred the existence of a statically significant downward trend in the yearly precipitation depths. The reference period 1905-1987 can be split up into two statistically significant periods different in the mean: 1905-1967 with a mean annual rainfall of 420 mm and 1968-1987 with a mean of 248 mm (Figure 4). The jump in the mean at the year 1967 separates the two periods.

3.2 Frequency analysis of rainfall data

Rainfall will vary from year to year and therefore, rather than using mean rainfall data a dependable level of rainfall is often used in irrigation. For management and planning purposes the information on the amount of rainfall which one can expect in a specific period under dry, normal and

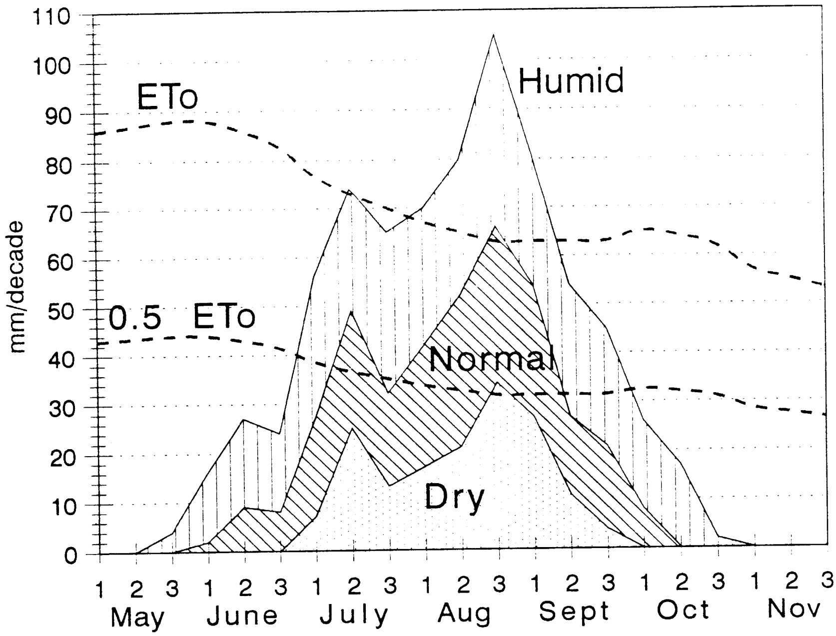

Figure 5: Rainfall amounts for each decade of the rainy period in Bakel (14°54'N & 12°28'W) Senegal with a 20, 50 and 80% probability of exceedance representing a humid, normal and dry decade.

humid conditions is important.

In Figure 5, the rainfall amounts which one can expect with a 80% (dry), 50% (normal) and 20% probability of exceedance (humid) in each of the decades of the rainy period of Bakel are plotted. The three values are useful for the programming of irrigation supply and simulation of irrigation management conditions.

The plotted data are the result from frequency analyses executed with RAINBOW on the 10-day rainfall records of the 1969-1990 period. For nearly all decades, the logarithms of the rainfall depths were normally distributed. Since the data contained zero and non-zero values, the theorem of total probability (eqn 1) was used to analyse the data set.

By plotting the potential evapotranspiration on the same graph useful information on the length of the growing season, the optimal sowing date or the irrigation requirements can be derived. In Bakel, the active growing period is on the average long enough for short-cycle crops such as sorghum and millet. However, the comparison between the evapotranspiration demand and the water contribution by rainfall indicates that water stress and consequently yield deficit might be severe in more than one year out of two.

3.3 Irrigation scheduling

The applications of RAINBOW are certainly not limited to the cases described above. Also the model may be used in combination with water budget models and irrigation scheduling models such as IRSIS[7] and CROPWAT[8]. The data flow and interaction between IRSIS and RAINBOW, is presented in Figure 6. When planning practical irrigation schedules in climate with highly variable rainfall, alternative schedules will have to be developed for the different weather conditions. A schedule should not result in excessive deep percolation losses in rainy years or in crop stress in dry years. The combination of computer support systems has proven to be a very useful and efficient tool in the planning and the design of irrigation schedules valid under different climatological conditions (Raes et al.,[9] De Goes et al.[10]).

4 Conclusion

A userfriendly PC-based software package for the statistical analysis of hydrologic data, called RAINBOW, was presented. The model has been used worldwide to assist in the design and management of irrigated agriculture.

Transactions on Ecology and the Environment vol 12, © 1996 WIT Press, www.witpress.com, ISSN 1743-3541

The growing need for a more efficient irrigation based agriculture calls upon easy-to-use computer models such as the one discussed here. It can be used as a stand-alone model, but may equally well be combined with other computer models relevant for irrigation management.

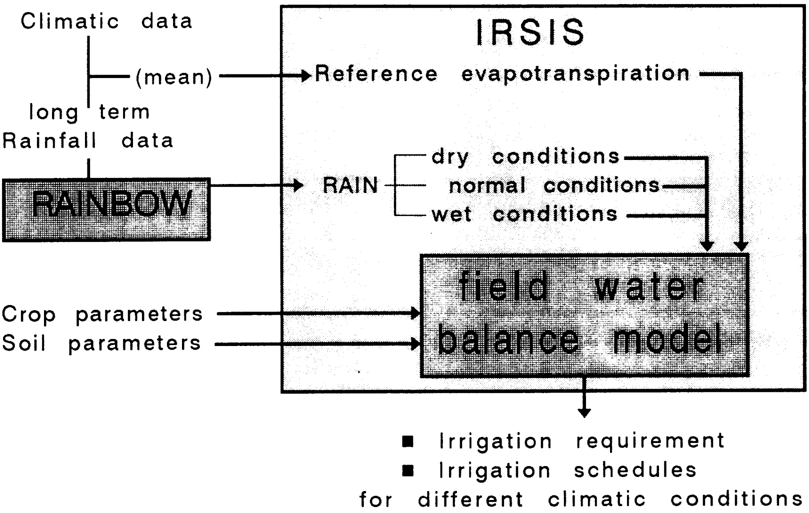

Figure 6: Interaction between RAINBOW and an irrigation scheduling model (IRSIS).

References

1. Gumbel, E.J. Statistics of extremes. Columbia University Press, New York, 1958.

2. Haan, C.T. Statistical methods in Hydrology. The Iowa State University Press, Ames, 1977.

3. Oosterbaan, R.J. Frequency and regression analysis. Twenty-fifth International Course on Land Drainage, Wageningen, The Netherlands, 1986.

4. Buishand, T.A. 1982. Some methods for testing the homogeneity of rainfall records. Journal of Hydrology, 1985, **58,** 11-27.

5. Demarée, G. & Chadilly, M.S. The Sahelian drought(s) as seen from the rainfall data of a Mauritanian station, in Computer methods and water resources (eds. D. Ouazar, C.A. Brebbia & V. de Kosinsky), Vol.3, pp 15-

23, Computational Hydrology Computational Mechanics Publications and Springer-Verlag, 1988.

6. FAO. FAOCLIM - World-wide agroclimatic data base, FAO, Agrometeorology Series, n°11, Rome, 1995.

7. Raes, D., Lemmens, H., Van Aelst, P., Vanden Bulcke, M. & Smith, M. IRSIS - irrigation scheduling information system, K.U.Leuven, Institute for Land and Water Management, Leuven, Belgium, Reference manual n°3, 1988.

8. Smith, M. CROPWAT - a computer program for irrigation planning and management, FAO Irrigation and Drainage Paper n°46, Rome, Italy, 1992.

9. Raes, D., Gullentops, D., Vanden Bulcke, M. & Feyen, J. Planning irrigation schedules by means of the IRSIS software package - A case study: Chateau Porcien, Vol.4, pp. 263-271 in Proceedings of the 15th European Regional Conference on Agricultural Water Management (ICID-meeting), Dubrovnik, Yugoslavia, 1988.

10. De Goes Calmon, M., Gaal Vadas, R., Calasans Rego, N. & Raes, D. Computer support systems for irrigation scheduling - Example: Pirapora Project (Brazil), ICID Bulletin, 1992, Vol.41(2), 19-27.