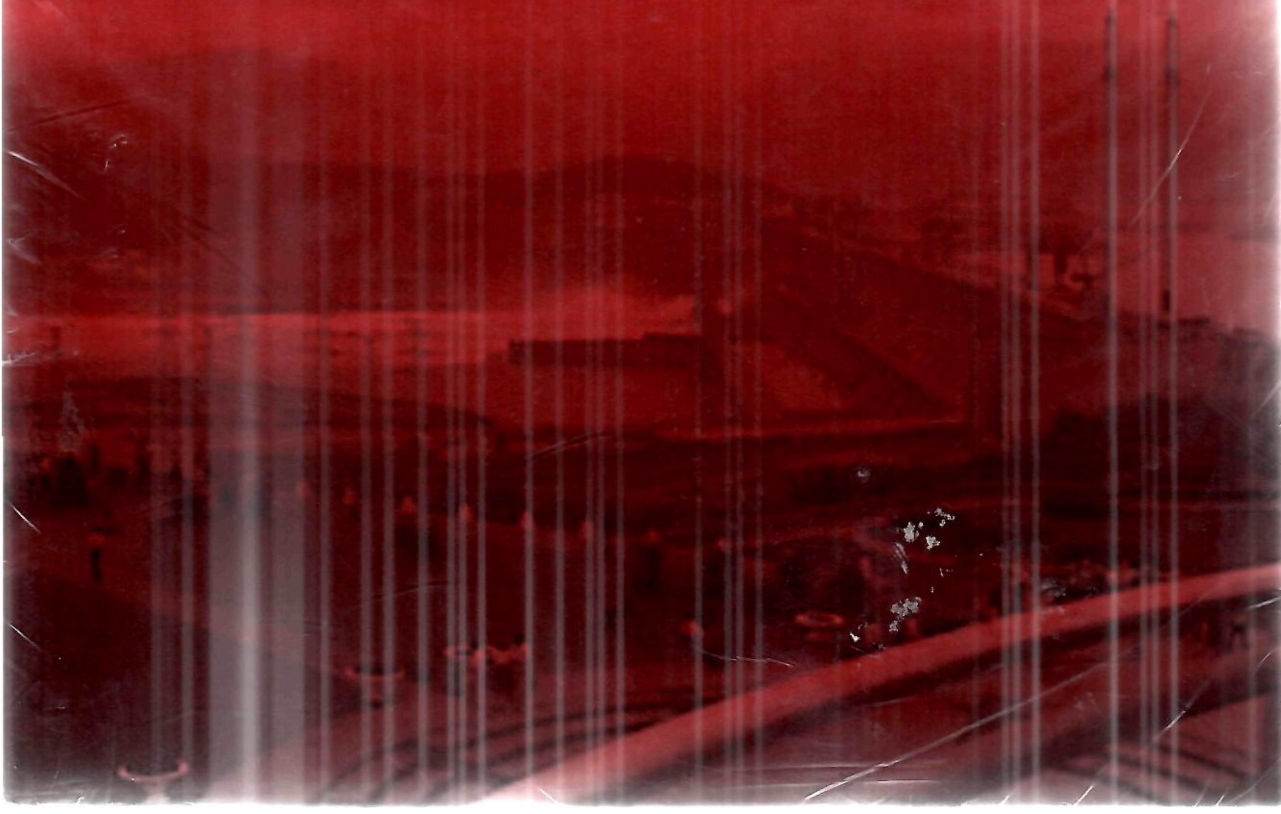
IAHS Publication 289
ISSN 0144-7815

GIS and Remote Sensing in Hydrology, Water Resources and Environment

Edited by
Yangbo Chen, Kaoru Takara, Ian Cluckie &
F. Hilaire De Smedt



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Cover illustration: The Three Gorges Dam on the Yangtze River in Sandouping, Yichang, Hubei Province, China (photograph by Dehua Zhu).

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GIS and Remote Sensing in Hydrology, Water Resources and Environment

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IAHS Publication 289

in the IAHS Series of Proceedings and Reports

Published by the International Association of Hydrological Sciences 2004
IAHS Press, Centre for Ecology and Hydrology, Wallingford, Oxfordshire OX10 8BB, UK
IAHS Publication 289
ISBN 1-901502-72-4

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

The papers included in this volume have been peer reviewed and some were extensively revised before publication.

IAHS is indebted to the employers of the Editors for the invaluable support and services provided that enabled them to carry out their task effectively and efficiently.

The papers were checked, formatted and assembled by Penny Farnell and Cate Gardner at IAHS Press, Wallingford, UK.

Publications in the series of Proceedings and Reports are available *only* from:
IAHS Press, Centre for Ecology and Hydrology, Wallingford, Oxfordshire OX10 8BB, UK
tel.: +44 1491 692442; fax: +44 1491 692448; e-mail: jilly@iahs.demon.co.uk

Printed in The Netherlands by Krips BV, Meppel.

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Statistical modelling and estimating the irrigation and man-made effects on annual runoff and water resources

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Abstract New techniques were developed to model pond, reservoir and irrigation effects on the statistical parameters of annual runoff time series and the state of water resources. Due to the shortage of available runoff series, statistical testing was applied to investigate the manner and extent of human influence on water resources. The resultant method enabled for the allowance of (separately and jointly) the effects of artificial basins and of irrigation on the normal runoff and the coefficients of variation and asymmetry. The method developed was applied to the assessment of water resources of the Republic of Moldavia and the south of the Ukraine.

Key words irrigation and man-made effects; statistical modelling; water resources of Ukraine and Moldova

INTRODUCTION

Modern land use activity and the necessity of governing by complex water systems in order to provide a rational use stimulate the technological direction of hydrological science; calculation and estimation of river runoff changes due to land use activities and anthropogenic effects are important.

Use of water resources for the needs of collective farm, irrigation and others is possible due to the use of the annual runoff of rivers, which are regulated by pond and water reservoirs. A differential estimate of the annual runoff changes due to the irrigation and artificial water reservoirs effect is possible due to the availability of sufficiently long sets of natural runoff and detailed information about the dynamics of factors which determine the level of the watershed's technological use. As a rule, such data are only available for large river basins. For little and middle-sized rivers an account of water use is carried out non-systematically or is entirely absent. It is therefore of great importance to carry out the imitative numeric models for runoff on the basis of modelling runoff sets with the use of initially known parameters of the functioning technological water systems.

In our paper a new technique is developed to carry out modelling the pond, reservoir and irrigation effects on the statistical parameters of annual runoff time series and state of water resources. We started from new statistical models which are presented in Loboda (1998a,b, 2001a,b).

STATISTICAL MODELLING THE IRRIGATION EFFECTS OF ANNUAL RUNOFF

It is well known that the use of statistical modelling methods in land use studies is based on the hypothesis of stationarity for the runoff temporal sets. An effect of the land use activity on the water resources is provided by natural factors (link with climate stochastic vibrations) and by the land use activity level. In order to model the influence of ponds and reservoirs as an artificial land shaft object, one can write the balance equation:

$$Y_b F = Y_e (F - \Sigma F_b) - (Z_b - X) \Sigma F_b \tag{1}$$

where Y_b is the annual runoff layer under availability of the ponds and reservoirs in the watershed; ΣF_b, resulting area of water surface of the artificial water reservoirs; X, atmospheric precipitation; Z_b, the layer of evaporation from the water reservoirs surface; F is the watershed area; Y_e is the annual runoff layer in the conditions of the non broken regime. In Loboda (2001a) it was shown that the simple balance equation (1) is a particular case of more generalized memory functions formalism. It is thought that more reliable expressions with an account of the key hydrological cycle physics aspects can be derived. The value of the annual runoff losses can be expressed as:

$$\Delta Y_b = Y_e f_b + (Z_b - X) f_b \tag{2}$$

Here f_s is expressed in the fractions of the general watershed area ΣF_s. The more reasonable equations which account for the hydrological cycle physics can be written within the memory functions formalism and multi-fractal approaches (Loboda, 1998a,b, 2001a; Neal, 2002; Khaled & Balkhair, 2002). A modelling of the annual runoff sets under fixed values f_b can be realized on the basis of equation (2) using the Monte Carlo methods. Necessary parameters for the annual runoff set generation are the norm, variation and asymmetry coefficients and also information about inside set correlation. For generating the broken runoff sets equation (1) is useful to rewrite as follows:

$$Y_b = Y_e (1 - f_b \alpha), \quad \alpha = 1 + (Z_b - X) / Y_e \tag{3}$$

The coefficient α may be represented as a function of the year watery degree: $\alpha = \varphi(Y_e)$ (Loboda, 1998b). This link is used for the co-ordination of the year watery degree with difference $(Z_b - X)$; anthropogenic factor f_b is changed in some limits. For every realization of the broken runoff one can calculate the norm $\overline{Y}_b$, coefficients of variability $C_{v\,b}$ and asymmetry $C_{s\,b}$. Then it is possible to construct the dependences of a kind:

$$Y_b = \varphi(f_b)$$

$$C_{v\,b} = \varphi(f_b)$$

$$C_{s\,b} = \varphi(f_b)$$

which allows assessment of the statistical parameters for broken runoff in accordance to the acceptable level of land use. The broken runoff modelling for a case of the irrigation water use can be fulfilled in an analogous manner (Loboda, 1998b; some new ideas are presented by Nixon *et al.*, 2001 and Hoi, 2001):

$$Y_{op} = Y_e - M f_{op}\,(1 - \alpha_B)\eta \qquad (4)$$

Here Y_{op} is a runoff layer from the watershed under availability of the irrigating activity; f_{op} is the relative area of irrigating land; η is the irrigating system efficiency coefficient; M is the irrigating norm; α_B is a coefficient of so called returning water.

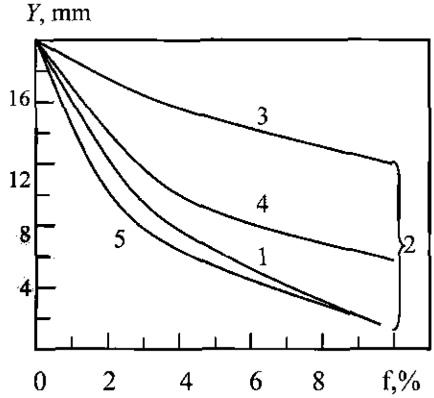

Fig. 1 Dependence of average multi year runoff layer Y for broken runoff set upon the watershed anthropogenic effect (pond, reservoir) (1) and irrigating land use area (2) under different levels of optimum soil moistening (3) $v_0 = 0.8$; (4) $v_0 = 0.9$; (5) $v_0 = 1.0$ for the natural runoff norm: $Y_c = 20$ mm (south of Ukraine and Moldavia).

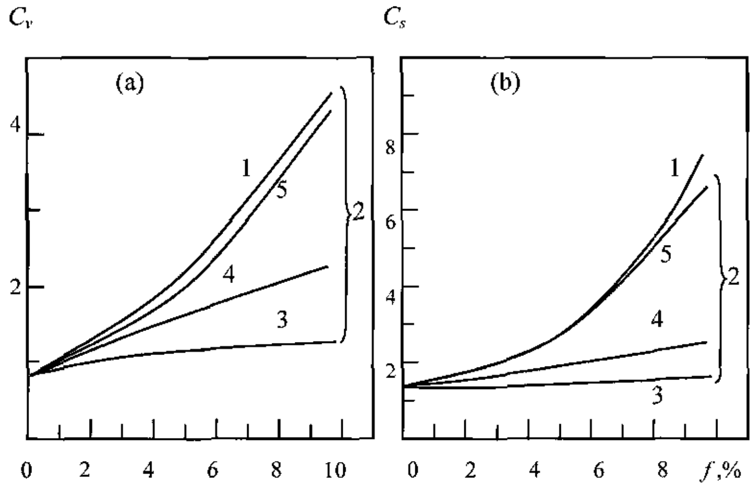

Fig. 2 Dependence of variation *Cv* (a) and asymmetry *Cs* (b) for broken runoff set upon the watershed anthropogenic effect (pond, reservoir) (1) and irrigating land use area (2) under different levels of optimum soil moistening: (3) $v_0 = 0.8$; (4) $v_0 = 0.9$; (5) $v_0 = 1.0$ for the natural runoff norm: $Y_c = 20$ mm (south of Ukraine and Moldavia).

RESULTS

In Figs 1 and 2 we present the calculated curves $\bar{Y}_b = \varphi\ (f_b)$, $C_{v\ b} = \varphi\ (f_b)$ и $C_{s\ b} = \varphi\ (f_b)$ and $Y_{op} = \varphi\ (f_{op})$, $C_{v\ op} = \varphi\ (f_{op})$ и $C_{s\ op} = \varphi\ (f_{op})$ for the territories of south of the Ukraine and Republic of Moldavia. The effect of anthropogenic activity is to a significant degree defined by the moisture of territory. Consideration of the more arid territories shows the natural water resources are decreased and the anthropogenic factor role is increased.

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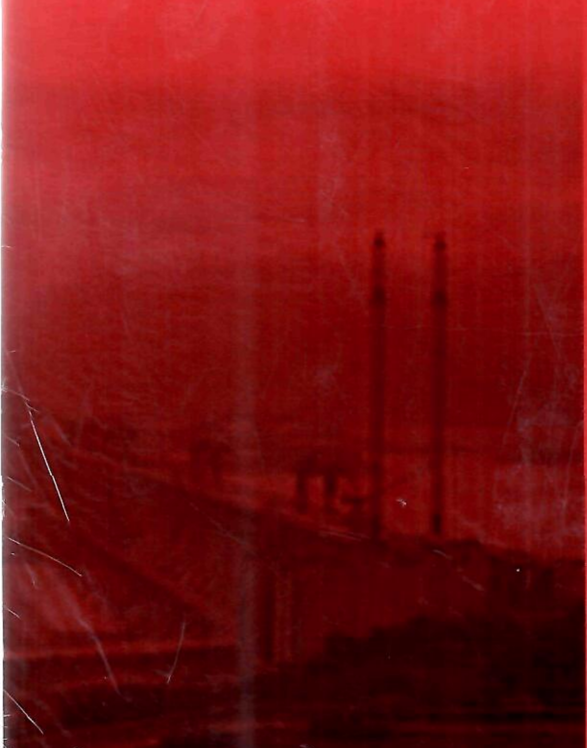

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IAHS Publication 289 ISBN 1-901502-72-4 ISSN 0144-7815