Regional analysis of hydrological variables in Greece

MARIA MIMIKOU
Division of Water Resources, Hydraulic and Maritime Engineering, Civil Engineering Department, Technical University of Athens, Greece

Abstract In this paper recent research work is presented on the regional analysis of various hydrological variables in Greece. The spatial variation of parameters of suspended sediment-water discharge rating curves, of maximum observed flood discharges, of lag times and unitgraph peaks for a certain storm duration, of parameters of flow duration curves and of mean annual floods for basins in the northwest and west of Greece are significantly explained in terms of physiographic and climatological characteristics of the basins by using multiple regression techniques. The developed regional models are successfully used in predicting hydrological variables for ungauged basins within the regions studied.

Analyse régionale des variables hydrologiques en Grèce

Résumé Dans cet article nous essayons de présenter nos recherches récentes sur l'analyse régionale de plusieurs variables hydrologiques en Grèce. La variation spatiale des paramètres des courbes de tarage des débits et des sédiments en suspension, des débits maximum des crues des temps de réponse et des pointes des hydrogrammes unitaires pour des averses de durée donnée, des paramètres des courbes de valeurs classées et des crues annuelles moyennes dans les régions nord-ouest et ouest de la Grèce sont expliquées au moyen des caractéristiques physiographiques et climatologiques des bassins en utilisant des techniques de régressions multiples. Les modèles régionaux qui résultent de cette étude sont appliqués avec succès pour la prévision des variables hydrologiques des bassins non jaugés de la région étudiée.

INTRODUCTION

The transfer of hydrological data, parameters or relationships obtained from one basin to others, or their estimation for ungauged basins, has obvious practical importance. Usually, the small projects and several large hydroprojects as well, are located at ungauged sites and their scale or their location does not permit pre-project data acquisition at the site. Therefore, the hydrological design of these projects is based on data spatially transferred from other gauged sites. Experience has shown that the transfer over long distances of hydrological information, especially of runoff characteristics, by
using regression analysis, rainfall-runoff analysis, etc. is not appropriate and has been proved untenable in most of the cases. The method which seems to be appropriate is the spatial transfer of information through regionalization (USGS, 1967; Cordery et al., 1981; Mimikou, 1984).

In this paper recent research work is presented which has been done in order to develop regional models for predicting hydrological variables in the hydrologically homogeneous regions of northwestern and western Greece (Mimikou, 1982, 1984; Mimikou & Kaemaki, 1985; Mimikou & Gordios, 1989). The major rivers of the country are concentrated, and the main interest for water resources development is focused in the northwestern and western regions of the country.

Regional prediction models are developed, which are found to explain significantly the spatial variation of the analysed hydrological variables within the regions by using as inputs physiographic and climatological characteristics of the drainage basins. The developed models are shown to predict accurately hydrological variables for ungauged basins in the regions studied, needed for the hydrological design of water resources development systems.

DATA USED

Data from several drainage basins of the five major rivers (the Aliakmon, Acheloos, Arachthos, Aoos and Kalamas) in western and northwestern Greece have been used in this study. The regionalized hydrological variables are the following (dependent variables)

(a) The parameters \( \alpha \) and \( \beta \) of suspended sediment \( M (kg \ s^{-1}) \) - water discharge \( Q (m^3 \ s^{-1}) \) rating curve of the following exponential form: \( M = \alpha Q^\beta \).

(b) Maximum observed floodflows (instantaneous peak discharges) \( Q_p (m^3 \ s^{-1}) \), which are found to be the largest events in the \( N = 29 \)-years long floodflows records of the studied area. No reliable earlier historical flood information could be found. Thus using the plotting position: \( T = N + 1 \) for the return period \( T \) of the largest event, the return period which could be now assigned to the floodflows \( Q_p \) of the analysis is: \( T = 30 \) years. Apparently, this return period increases with increasing \( N \). Besides, the maximum observed peak discharges need to be modified and, thus the envelope curves presented in the following to be appropriately adapted, whenever new floodflow observations exceed the analysed flood data (Mimikou, 1984).

(c) Lag time \( t_L \) (h) and unitgraph peak \( q_p (m^3 \ s^{-1}) \) for unitgraphs resulting from 6-h storm duration.

(d) Parameters \( a, b, c, d \) of the monthly flow duration curve, which is a plot of the monthly discharge \( Q (m^3 \ s^{-1}) \) vs. the percentage of time \( D \) during the period of the record in which the particular discharge is equalled or exceeded. (The appropriate model for the parameterization of the monthly flow duration curves in the regions of the study is shown (Mimikou & Kaemaki, 1985) to be a cubic model of the following form: \( Q = a - bD + cD^2 - dD^3. \))
The mean annual flood $Q$ (m$^3$ s$^{-1}$) estimated for both the daily and the instantaneous annual maximum flow records of the regions (29 years of record available).

The basin characteristics which have been used in explaining the spatial variation of the hydrological variables are the following (independent variables): drainage area $A$ (km$^2$); mean annual areal precipitation $P$ (mm); hypsometric fall $H$ (km or m); length $L$ (km); the average bedslope $S$ (m km$^{-1}$) of the main river course from the divide of the basin to the site of interest; stream frequency $SF$ (junctions km$^{-2}$, measured by counting channel junctions on the 1:25 000 map of each drainage basin and dividing by the drainage area); intensity of the one-day rainfall of five-year return period $M51D$ (mm h$^{-1}$); and a soil type index $SO$. The soil index is based on a 1:500 000 scale soil map of the area studied, where seven classes of soil have been distinguished in accordance to their "winter rain acceptance potential". Weights $R_i$ ($i = 1, \ldots, 7$) were assigned to each soil class. The soil index $SO$ is estimated by measuring the fractions $S_i$ ($i = 1, \ldots, 7$) of the basin within each soil class and adopting a weighted mean of these soil fractions as follows:

$$SO = \frac{\sum_{i=1}^{7} (R_i S_i)}{\sum_{i=1}^{7} S_i} \quad \text{(Institute of Hydrology, UK, 1978)}$$

The number of the flow measuring stations used for the calibration of the regional models differs from case to case. Six stations (the Arta, Plaka and Tsimovo stations on the Aracthos River, the Konitsa station on the Aoos River, the Ilarion station on the Aliakmon River and the Kioteki station on the Kalamas River) have been used to calibrate the prediction equations for the parameters of the sediment rating curves, whereas 11 stations located on the Aliakmon, Aracthos, Acheloos, Aoos and Kalamas Rivers have been used for each of the rest of the variables, even though the specific stations differ from case to case. This difference is due to the availability and the reliability of the analysed variable. For the maximum observed floodflow, the lag-time and the peak of the 6-h unitgraph, the following stations have been used: Avlaki, Kremasta, Tsimovo, Plaka, Arta in the western region and Vrossina, Vovoussa, Konitsa, Siatista, Ilarion, Venetikos in the northwestern region. For the parameters of the flow duration curve, the group of stations is the following: Avlaki, Tsimovo, Plaka, Gogos in the western region and Vrossina, Soulopolou, Vovoussa, Konitsa, Siatista, Ilarion, Venetikos in the northwestern region. Finally, the group of stations used for the mean annual flood is as follows: Avlaki, Mesohora, Tsimovo, Plaka, Arta in the western region and Kioteki, Vovoussa, Konitsa, Siatista, Ilarion, Venetikos in the northwestern region. The location of the stations is shown in Fig. 1. All stations belong to the Greek Public Power Corporation (PPC). The hydrological and climatological data used have been taken from the archives of the PPC, whereas the physiographic characteristics of the basins have been estimated from maps.
THE REGIONAL MODELS

The regional models for predicting the hydrological variables were developed by stepwise multiple regression. A logarithmic transformation was used for both dependent and independent variables, since this improved the linear association between them. Variables in the multiple regression analysis were included according to standard statistical texts (Haan, 1977). The coefficient of determination $r^2$ is used as a measure of the association of the variables. A $t$-test was used to check that the regression coefficient of each independent variable was not significantly different from zero.

The regional regression equations developed for each of the analysed hydrological variables are given in the following along with the corresponding coefficient of determination $r^2$. The independent variables finally used and given in each of the following regression equations are the variables which

Fig. 1 Location of the measuring stations.
play significant role (at the 95% confidence level) in explaining the spatial variation in the associated dependent variable. The independent variables in the equations are arranged in decreasing order of the significance of their contribution.

(a) For the sediment rating curve parameters, \( \alpha \) and \( \beta \), and for both the northwestern and western regions, two groups of equations have been developed, one for the wet season (from December to May) and one for the dry season (from June to November) (Mimikou, 1982) as follows:

**Wet season:**

\[
\begin{align*}
\alpha \times 10^6 & = 1.1222 \times 10^{33} P^{-7.9628} A^{2.0601} H^{-0.3753} & r^2 = 0.65 \\
\beta & = 0.0464 P^{0.4940} A^{0.0819} H^{0.0132} & r^2 = 0.86
\end{align*}
\]

**Dry season:**

\[
\begin{align*}
\alpha \times 10^6 & = 8.2770 \times 10^{14} P^{-2.9099} A^{1.2885} H^{0.3749} & r^2 = 0.43 \\
\beta & = 1.9493 P^{0.0166} A^{0.0100} H^{0.1560} & r^2 = 0.59
\end{align*}
\]

with \( A \) in \( \text{km}^2 \), \( P \) in mm and \( H \) in km.

From equations (1)–(4) one can see that the constant \( \alpha \) is inversely related to all physical variables with the exception of the river's hypsometric fall \( H \), to which it is proportional in the dry season only. Exponent \( b \) is related to the variables in the opposite way, since it is inversely related to \( \alpha \).

(b) For the maximum observed floodflows \( Q_p (\text{m}^3 \text{s}^{-1}) \), the lag time \( t_L \) and the unitgraph peaks \( q_p (\text{m}^3 \text{s}^{-1}) \), the drainage area \( A \) (\( \text{km}^2 \)) alone is found to play the most significant role, explaining more than 90% of the variance in the regression equations. Especially for the floodflows \( Q_p \), two different envelope curves have been developed one for the western and another one for the northwestern region (Mimikou, 1984), whereas the developed model for the unitgraph characteristics cover both the studied regions. The regional models are the following:

**Western region:** \( Q_p = 2.948 A^{0.892} \)

\( r^2 = 0.96 \)  \( (5) \)

**Northwestern region:** \( Q_p = 26.140 A^{0.511} \)

\( r^2 = 0.98 \)  \( (6) \)

\( t_L = 0.430 A^{0.418} \)

\( r^2 = 0.95 \)  \( (7) \)

\( q_p = 2.270 A^{0.657} \)

\( r^2 = 0.92 \)  \( (8) \)

(c) The regional models developed for the parameter \( a, b, c, d \) of the monthly duration curves, in the two regions of the study, as previously defined, are the following (Mimikou & Kaemaki, 1985):
Maria Mimikou

\[ a = 0.011 \, P^{0.526} \, A^{0.608} \, H^{0.007} \, L^{0.253} \quad \rho^2 = 0.76 \quad (9) \]

\[ b = 0.053 \, P^{0.511} \, A^{0.684} \, H^{0.181} \, L^{0.278} \quad \rho^2 = 0.76 \quad (10) \]

\[ c = 0.010 \, P^{0.708} \, A^{0.952} \, H^{0.315} \, L^{0.073} \quad \rho^2 = 0.71 \quad (11) \]

\[ d = 4.215 \times 10^{-6} \, P^{7.157} \, A^{1.637} \, H^{-0.053} \, L^{-0.687} \quad \rho^2 = 0.70 \quad (12) \]

with \( A \) in km\(^2\), \( P \) in mm, \( H \) in m and \( L \) in km.

(d) The regional model for the mean annual flood \( Q \) (m\(^3\) s\(^{-1}\)) of the daily extremes, for both the northwestern and western regions, is the following (Mimikou & Gordios, 1989):

\[ Q = 2.793 \times 10^{-8} \, A^{1.072} \, P^{2.317} \, S^{0.982} \, (SF)^{0.216} \, (SO)^{3.266} \quad \rho^2 = 0.75 \quad (13) \]

For the instantaneous extremes, the regional regression equation has the following form:

\[ Q = 2.244 \times 10^{-4} \, (SF)^{0.635} \, A^{1.385} \, (M5ID)^{1.805} \, (SO)^{3.278} \, S^{2.414} \quad \rho^2 = 0.90 \quad (14) \]

with \( A \) in km\(^2\), \( P \) in mm, \( SF \) in junctions km\(^{-2}\), \( S \) in m km\(^{-1}\) and \( M5ID \) in mm h\(^{-1}\).

**PREDICTION ACCURACY**

The accuracy of the regional models in predicting the hydrological variables is estimated by the mean error \( e \) given by:

\[ e = n^{-1} \sum_{i=1}^{n} |(y_i - \hat{y}_i)|/y_i | \times 100 \quad (15) \]

with \( y_i \) the actual value of the dependent variable, \( \hat{y}_i \) the value estimated from the corresponding regression equation and \( n \) the number of cases for which the prediction accuracy is tested and averaged. The prediction accuracy of the regional models has been verified in all cases by using data from another two test basins (\( n = 2 \)) in the regions, which have not been used in the calibration phase. The mean errors \( e \) for all equations (1)–(14) are given in Table 1. For practical reasons, the mean errors \( e \) for the parameters of the monthly duration curve and for the envelope curves of \( Q_p \) in the western and northwestern regions have been averaged for the four equations (9)–(12) and for the two equations (5) and (6), respectively.

The regional models in equations (1)–(14) are used in predicting accurately sediment rating curves, maximum (expected) flood events, unitgraphs, monthly flow duration curves and mean annual floods for ungauged basins in the regions studied, needed for the hydrological design of water resources development systems.
Regional analysis of hydrological variables in Greece

Table 1 Prediction accuracy of the regional models

<table>
<thead>
<tr>
<th>Regression equation:</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5) &amp; (6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9) - (12)</th>
<th>(13)</th>
<th>(14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error € %:</td>
<td>62.0</td>
<td>3.7</td>
<td>110</td>
<td>6.6</td>
<td>5.0</td>
<td>2.0</td>
<td>10.0</td>
<td>7.0</td>
<td>23.7</td>
<td>18.6</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Regionalization is shown to be a powerful tool in transferring hydrological information from gauged sites to other remote ungauged sites within the homogeneous region of regional analysis.

The developed regional models are used in predicting accurately hydrological information, such as sediment rating curves, maximum flood events, unitgraphs, flow duration curves and mean annual floods for ungauged basins in the northwestern and western regions of Greece, needed for the hydrological design of water resources development systems.

REFERENCES
