Principles of Hydrologic Regionalisation as Exemplified in the Upper Vistula Basin (Poland, East-Central Europe)

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Abstract

The investigated area was divided into 380 regular, geometric elementary units described by five hydrologic and climatic characteristics. Ward's taxonomy and the method of geographic dominant and sub-dominant objects were used to distinguish hydrologic regions in the Upper Vistula basin. The tested procedure can be applied to other areas on different scales and to various characteristics if their values can be assessed for elementary units.

Introduction

The theory and practice of regionalisation has received the attention of many workers in the geographical sciences, but no general methodology for identifying regions is available. However, Grigg (1967) has presented a number of principles of regionalisation on the assumption that it is analogous to classification and should therefore be based upon principles of formal logic. Grigg's principles may be summarised as follow:

- classification should be designed for a specific purpose,
- objects that differ in kind will not easily fit into the same classification system,
- classifications are not absolute but may change as more information becomes available,
- differentiating characteristics should be properties of the objects classified rather than factors assumed to affect or determine the objects,
- classification should be exhaustive (include all objects in a class) and the classes should be exclusive (each object should be assigned to only one class),
- classification should proceed at every stage of classification,
- differentiating characteristics must be important or relevant to the purpose of classification, and
- properties used to classify on broader-scale levels must be more important for the purpose of classification than those on finer-scale (more detailed) levels.

Regionalisation has for many years been a standard hydrological tool to enable data, measured at one point, to be translated to points where measurements have not been carried out, and it also facilitates appraisal of the representativity of various areas. There are other approaches to regionalisation; they all deal with the distribution of water in space and time. However, there is surprisingly little guidance in the literature regarding the details of hydrologic regionalisation.

In previous works, hydrologic regions have been based on watershed boundaries or, for example, geographical criteria (Acreman and Sinclair 1986; Beable and McKerchar 1982; Gottschalk 1985; Stachy 1966; Toebes and Palmer 1969). The use of geographical regions makes it easy to assign an ungauged site to a region, but these regions may not be necesssarily hydrologically homogeous (Wiltshire 1986). In practice, also, many hydrologic regions have been based upon administrative or similar boundaries which may cut across geologic, climatic, and topographic boundaries. Hydrological regionalisation, which is a complex method, should use the principles and logic of numerous disciplines related to hydrology and to a form of regionalisation based on classification.

Purpose

The main goal of the paper is to *identify hydrologic regions* using a less subjective method than those used in previous works. The most appropriate characteristics must be used to discriminante between regions. Hydrologic regions are defined as areas in which *precipitation, runoff, evaporation, and groundwater resources* are similar.

Area of Investigation

The Upper Vistula River basin (50,732 square kilometres) was investigated (Fig. 1). It consists of both high mountains as well as uplands and lowlands, it being advantageous to examine the applied method of regionalisation in various physiographic areas.

Elementary Units

A number of authors consider 'landscape units' which are independent of catchment boundaries to be the basic framework for hydrological homogeneity and thus regionalisation (Arnold and Vermulst 1993; Simo 1986; Solomon 1972). A very simple and reasonable method is to divide the study area into a grid. Units can be of any size directly related to the purpose for which regionalisation is to be carried out. Furthermore, by using grid cells and statistical analyses, units can be quantitatively derived in a non-subjective manner according to the required precision. This system can be used to store, process, and retrieve information. In general, the optimum grid interval I is determined by the size of the basin according to the following (Simmers 1984):

$$0.05ÖA < I < 0.1ÖA \quad (1)$$

where,
A is the area of the whole basin.

One degree of longitude was divided into six equal sections, and one degree of latitude into nine equal sections in Alber's projection of the Upper Vistula basin. The area of elementary units (trapeziums) varies from 144.5 to 150.5 square kilometres. There are 380 units lying within the catchment (Fig. 2). For these elementary units, the five parameters presented in the next chapter have been computed.

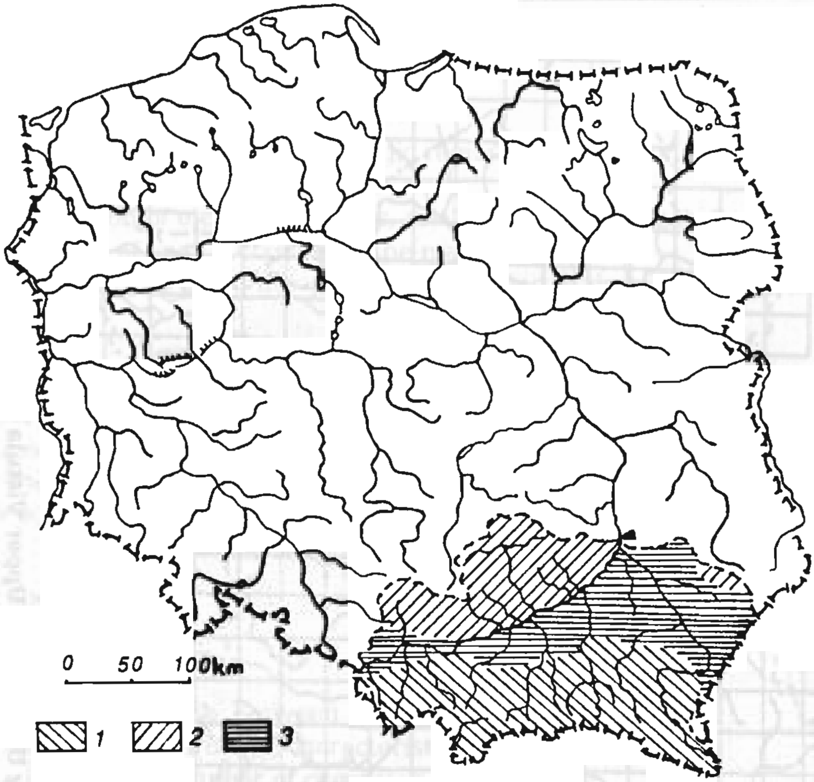

Figure 1: The Investigated Area
1) Mountains, 2) Uplands, and 3) Lowlands

Classification Criteria

It is necessary to define the exact criteria related to regionalisation. They should be based on hydrologic characteristics descriptive of water resources rather than on other geographic features (Mosley 1981). According to the definition of a hydrologic region presented in PURPOSE, regionalisation has been approached on the basis of a few parameters such as mean annual precipitation, runoff, evaporation, groundwater resources, and annual amplitude of mean monthly air temperature. The last parameter attempts to express the effect of oceanicity on the variation in river runoff during a year.

Data on precipitation, amplitude of air temperature, and groundwater resources were obtained from maps (*Atlas zasobow zwyklych...* 1976; Niedzwiedz and Obrebska-Starklowa 1991; Wiszniewski and Chelchowski 1975). Runoff and evaporation information have been processed in a different way. Runoff was obtained by using the regional formulas based on correlations between meteorologic, physiographic, and hydrologic characteristics (Dobija 1974; Krzanowski 1976; Stachy 1966). Actual evaporation was estimated for each elementary unit using Turc's formula, which relates actual evaporation to precipitation and temperature (Stachy 1966).

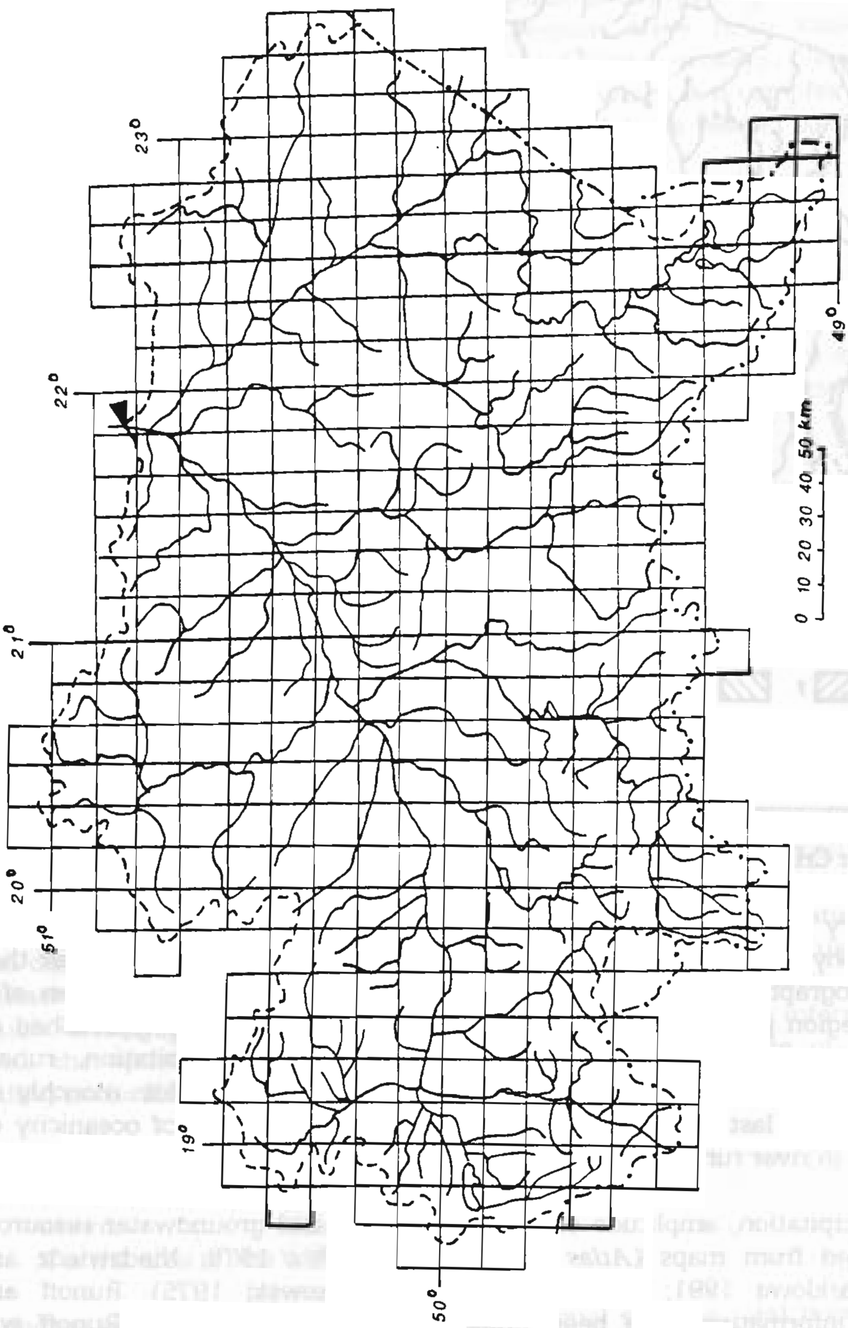

Figure 2: Elementary Units in the Upper Vistula Basin

Each elementary unit is associated with a set of five variables. The correlation coefficients between them are low except for precipitation and runoff. However, no reduction of the matrix was carried out. All variables have been standardised (to have equal weight in computing distances).

Procedure

The procedure of delimitating hydrologic regions consisted of three stages:

1) classification of elementary units, resulting in typological classes,
2) distinction of spatial classes on the map, and
3) regionalisation, using the geographic method of dominant and sub-dominant units.

Four taxonomical methods were tested for the classification of elementary units in the Upper Vistula basin (Grabinski 1992; Lula 1992): a nearest neighbourhood method, a furthest neighbourhood method, a group mean value method, and Ward's method. Similarity between objects was measured by the Euclidian distance coefficient, d_{jk},

$$d_{jk} = \left[\sum_{i=1}^{p}(x_{ij} - x_{ik})^2\right]^{0.5}$$

where,
d_{jk} is the 'distance' between units j and k,
x_{ij} is the ith hydrologic characteristic of unit j, and
p is the total number of characteristics.

On the basis of the statistics describing the efficiency of grouping (measures of intra-group similarity and inter-group dissimilarity) and on that of dendrograms of each method, Ward's taxonomy is clearly the most appropriate tool to use (Fig. 3). In this method two clusters are combined which result in the minimum increase in the total intra-cluster sum of squares.

Grouping was stopped at 14 classes. The choice to stop at 14 classes was not made arbitrarily: dendrograms, statistics measuring the efficiency of grouping, and the spatial distribution of classes on the map were taken into consideration. The spatial distribution of classes (spatial classes) should be neither too detailed nor too general and should serve the purpose of regionalisation. Some spatial classes iterated themselves in the investigated area (Fig. 4). They may occur in different physiographic regions but are similar in a hydrologic sense. They cannot be considered as regions because they are not unique, and geographic location is the only characteristic distinguishing one class from another (Parysek 1982).

Methods of physiographic regionalisation are very helpful in delimiting hydrologic regions on a map (Richling 1982). They can be divided into two groups. The first group is based on a schema of deductive inference (from generals to particulars), dividing a territory into regional units from the highest to the lowest in rank. The second one is based on a schema of inductive reference (from particulars to

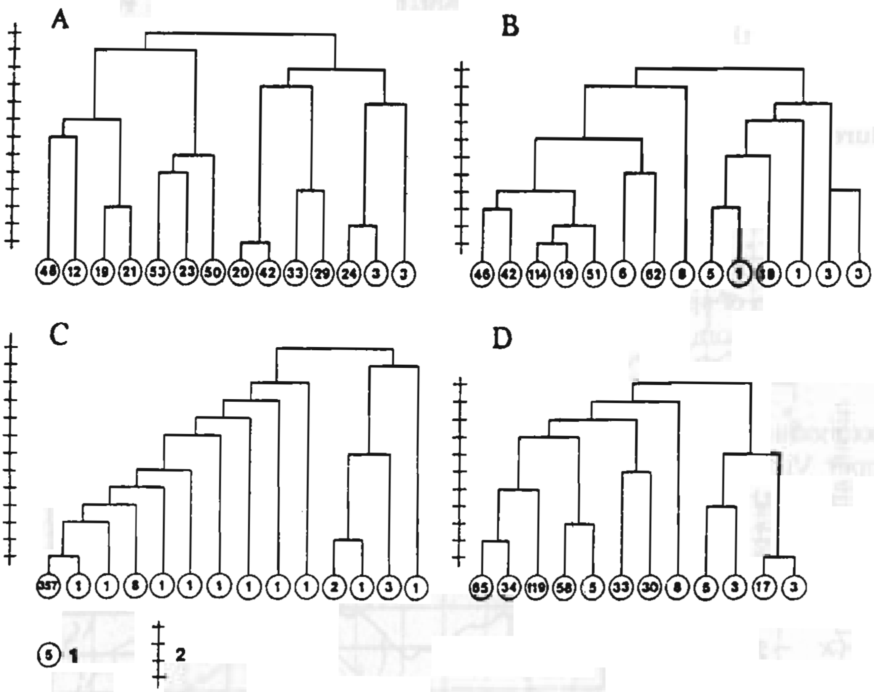

Figure 3: Dendrograms of Grouping
(1 - number of objects, 2 - level of grouping; method: A – Ward's, B – mean value, C – nearest neighbourhood, D – furthest neighbourhood)

generals), combining lower order units into higher order regional units. The second group is comprised of so-called methods of association, or grouping methods. They permit application of formalised regionalisation procedures which preclude subjectivism. This is the main superiority of deductive methods. One of them is the method of dominant and sub-dominant units. It is based on an investigation of internal structure and the dominant elementary units belonging to some class demonstrating the highest percentage of area or greatest frequency. A region is assumed to be an area in which elementary units belong to one dominant typologic class. There can also exist sub-dominant elementary units belonging to another typologic class or classes. This method seems to be relatively objective and easy to use, and therefore it was decided to apply this method to the hydrologic regionalisation procedure.

Results

Fourteen typologic classes and 27 hydrologic regions were distinguished in the Upper Vistula basin. The names of regions consist of two parts: regional names, according to Kondracki's (1978) physiographic division of Poland, and hydrologic names according to the number of parameters taken into account in the classification (Fig. 5). Descriptive statistics were carried out for each region (Fig. 6). A lot of regions consist of elementary units belonging only to one typologic

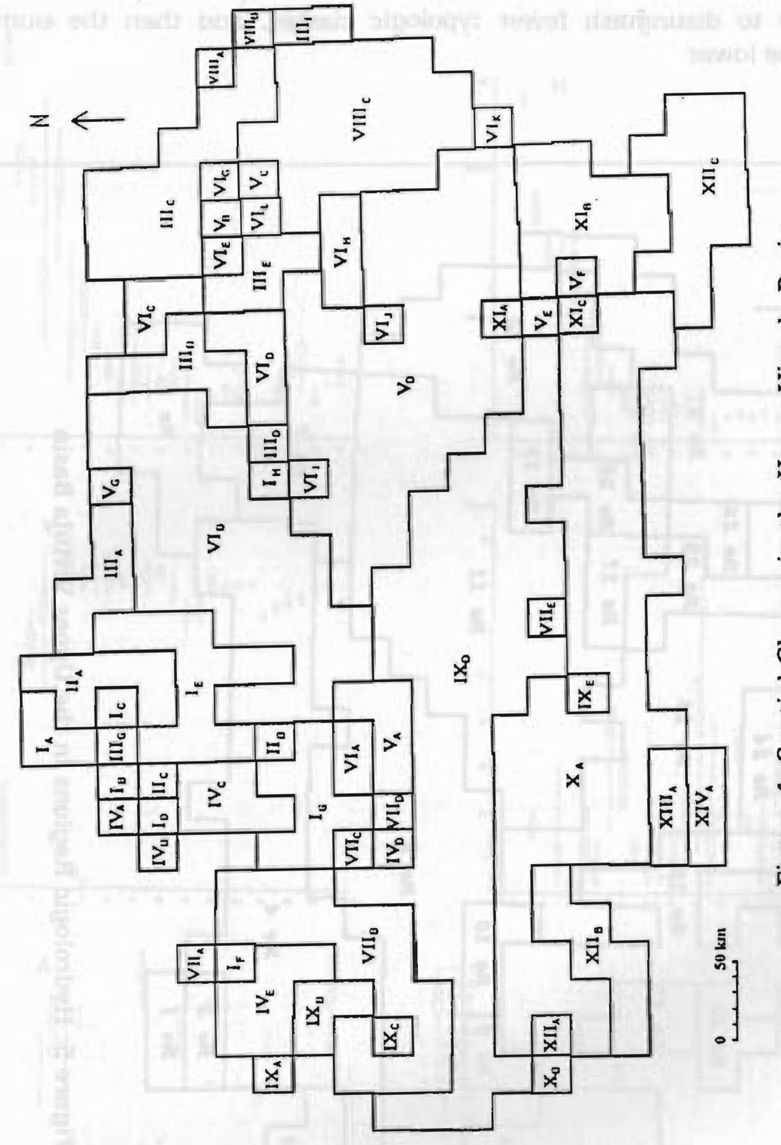

Figure 4: Spatial Classes in the Upper Vistula Basin

class. This means that they are very similar from a hydrologic point of view. Geographic location is the only characteristic that differs from one region to another.

Boundaries of hydrologic regions refer to geographic boundaries only in general. There are, in fact, a lot of differences. Grouping elementary objects on the basis of similarity of hydrologic characteristics demonstrates clearly that several hydrologic regions may occur in one geographic region; in other words, the geographic region is not hydrologically homogeneity. And in the opposite situation: one hydrologic region may include several geographic regions.

There is a possibility that if generalisation is done on the basis of regionalisation the regional division is too numerous. It is necessary to stop classification at higher levels to distinguish fewer typologic classes, and then the number of regions will be lower.

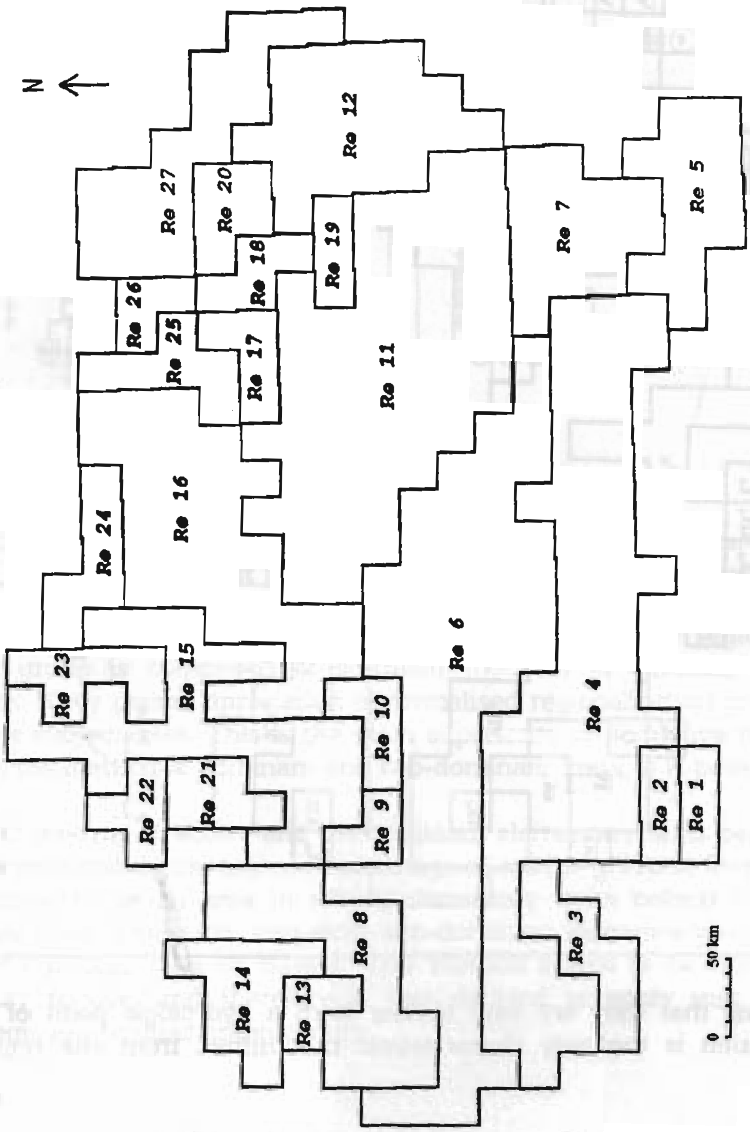

Figure 5: Hydrologic Regions in the Upper Vistula Basin

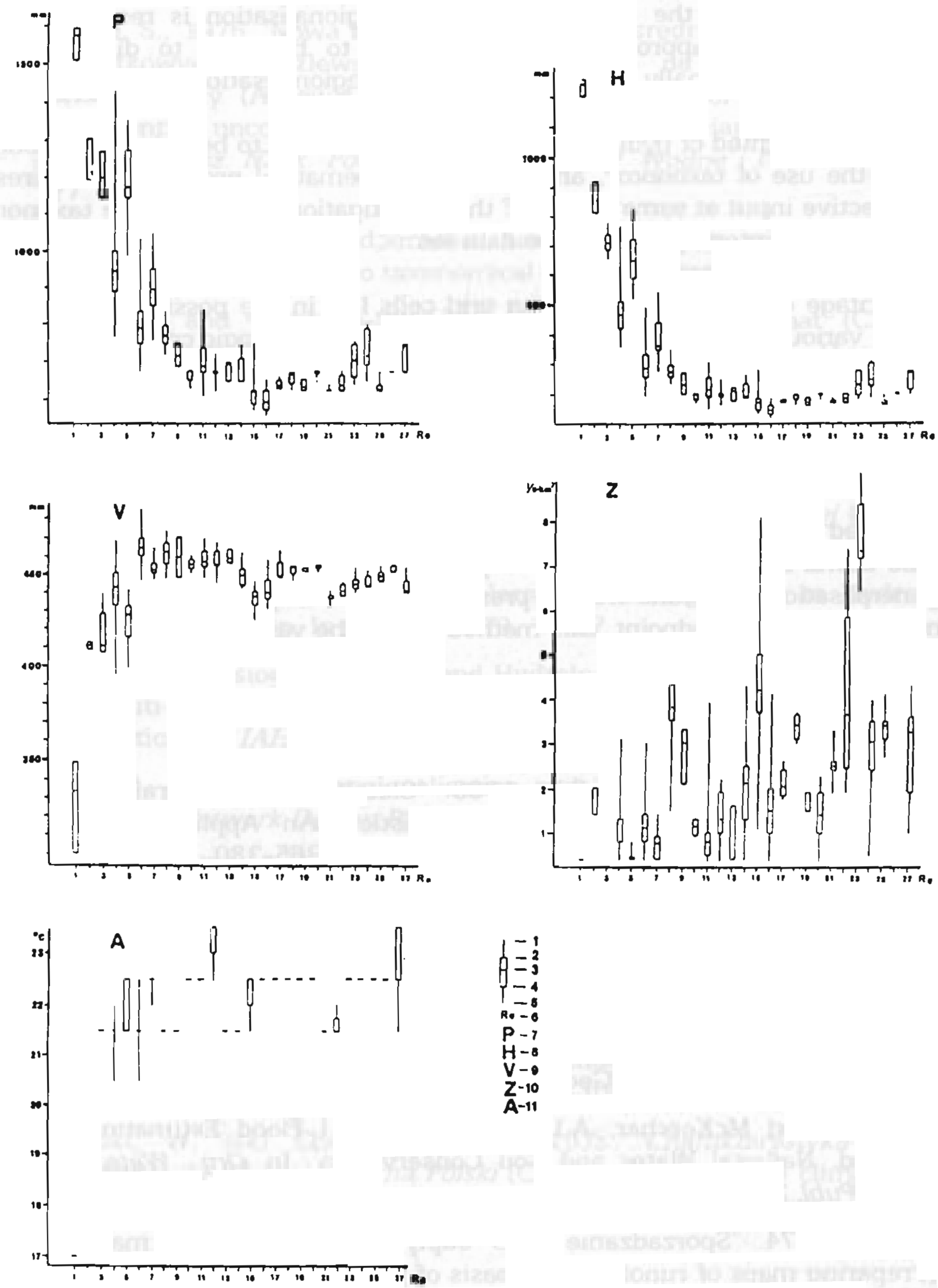

Figure 6: Statistics of Hydrologic Regions in the Upper Vistula Basin
(values: 1 – maximum, 2 – upper quartile, 3 – average, 4 – lower quartile, 5 – minimum, 6 - region, 7 – precipitation, 8 – runoff, 9 – evaporation, 10 – groundwater resources, 11 – amplitude of mean monthly air temperature)

Conclusions

One must first define the purpose for which regionalisation is required, then decide on the most appropriate characteristics to be used to discriminante between regions, and finally select an appropriate regionalisation method.

The method presented of hydrologic regionalisation seems to be objective enough. But even the use of taxonomy, an objective mathematical procedure, requires a little subjective input at some stages of the investigation. However, the taxonomy greatly facilitates interpretation of the data set.

The advantage of the procedure using grid cells lies in the possibility of storing and using various data for the investigated area. The hydrologic criterion seems to be the best one. Different data sets might have produced a different system of regions or caused significant changes in the location of regional boundaries. The effectiveness of the regionalisation should be assessed by statistical measures and on the basis of the purpose of the procedure.

It is believed that the simple hydrological regionalisation presented in this paper could be useful in various branches of hydrology, including network planning and the generalisation of results from representative and experimental basins. From the methodological standpoint, this method should be valid for all terrains in the world.

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