UNIVERSITY OF SZEGED
Faculty of Science
Doctoral School of Earth Sciences

THE APPLICATION OF MODERN GEOMATHEMATICAL METHODS IN PRACTICAL HYDROGEOLOGY

Ph.D. Thesis Book

JÓZSEF KOVÁCS

2007, Szeged

Preliminaries of the research work implemented

The majority of models used in practical hydrogeology today are deterministic in nature despite the fact that they are created using an array of variables used as samples. As it is known, statistics and modeling results calculated from a set of variables will yield different outcome during a repeated sampling process, as we are talking about random variables. Sensitivity analysis is one tool in deterministic modeling to overcome the mentioned problem. Nevertheless, this does not remove the uncertainties of the applied model. Another important feature many analyst face more and more often these days is that they are dealing with an ever increasing array of data. This naturally calls for the understanding of the inner characteristics of the data set before subjecting them to analysis. With this information at hand, there is no surprise that the method of time-series analysis is gradually gaining importance in all fields of the geosciences, including hydrogeology as well.

Time-series analysis has a long history looking back almost a century. Initially they were restricted to the prediction of the trend and periods in the analyzed data set. Later on, after about 50 years intensive theoretical research initiated in connection with this technique yielding probably the most important contribution to the field by P. Box and G. M. Jenkins. They were the first to apply AR (auto regression) and MA (moving average) processes to model phenomena, which are not constant with the pass of time. There is an intensive development in recent research implemented in connection with time-series analysis as well. As a result several new research areas emerged linked closely to the methods applied in the field, not to mention the transformation of the traditional, available techniques and methods of time-series analysis.

Material and methods

During the preparation of the thesis, I heavily relied on the literature, both Hungarian and foreign, dealing with the geology of the study areas, as well as the application of time-series analysis in hydrogeology. Data regarding water levels, water pumping, by the courtesy of VITUKI Ltd., as well as the meteorological parameters of the study areas, plus the outcome of research work implemented under my supervision at the ELTE University of Budapest were also utilized in my work.

The foreign and Hungarian applications of time-series analysis to my study field were carefully examined. A technique not yet applied in geomathematics before was chosen for further testing and utilization in an setting, which forms an interface between the fields of Geology, Hydrogeology and Mathematics.

From the well-known methods of time-series analysis, the chosen technique utilized in my thesis work was that of dynamic factor analysis applied to solving hydrogeological problems. This technique has a background history of almost 30 years. This is the first time that this technique was applied in the geosciences and was tested in different hydrogeological settings in my thesis work.

Predictions were implemented using a modern form of the traditional performance density predictions, the Lomb-Scargle period prediction method, primarily used by astronomers. The application of this method is very scarce in the geosciences, with the only exception of some paleoclimatic studies, at the national and international level as well. The third method I applied during my research work was wavelet spectrum analysis, frequently utilized in the fields of hydrology and hydrogeology as well world-wide. No domestic utilization of this method is known, as far as I am concerned. Although it's outcome the time-frequency map is much more informative than the results of other applied methods.

New scientific results

Dynamic factor analysis has been introduced to the geosciences for the first time as part of my thesis. Data deriving from groundwater observation wells can be regarded as records of time-dependent random phenomena. Thus the hydrographs prepared for the individual wells are considered to represent stochastic processes. The processes linked to the individual wells, however are by no means individual processes but rather must be taken as the local realizations of the same natural phenomenon among different settings. No wonder that these processes should be handled collectively, as components of a phenomenon of multidimensional nature, which components are naturally interlinked from the point of the probability theory. This interrelatedness on the other hand must reflect some spatial structure. Thus there is every reason to believe that the processes observed at different loci are the outcome or governed by the same latent forces, infiltration, water discharge. Only the intensity of these influences or forces varies from location to location. In the light of this information our first goal was to identify these background forces or influences, then predict their spatial variation. The following are all new results in this effort:

1.1 The time-series of filtered karst water monitoring wells of the SW part of the Transdanubian Mid-Mountains were scrutinized for a period of 1970-1990. The observed first dynamic component corresponded to the water discharge from the area, while the second component corresponded to the rate of infiltration as shown by our results.

1.2. During a similar time-series analysis for the area of the Szigetköz, data deriving from the groundwater observation wells of this study area had to be divided into two parts and analyzed separately due to the possible modifying effects of the artificial diversion of the river Danube. The two studied cases corresponded to a stage before and after the diversion of the Danube. In the first case, the first dynamic component corresponded to the influences of the active Danube river on the groundwater table. The remaining background components could not have been identified in this period. In the second case, representing the period after diversion, the first component corresponded to the influences of the diverted Danube, the second component to the average annual rainfall, while the third component corresponded to the influences exerted by the Danube diverted back to its original channel. As shown by these results the background forces influencing the groundwater table in the Szigetköz were significantly altered after the Danube was diverted from the area. The precipitation as a background factor suddenly gained larger importance after the diversion. Plus a dual behavior is observable regarding the influences of the diverted Danube river, as it was expectable after the construction of a dam.

1.3. The loadings of the newly gained dynamic components can be regarded as representing the strength of the identified local background influences yielding comprehensive hydrogeological parameters for the study area. In case of the Szigetköz, the most intensive discharge areas from the Danube were spatially displaced as a result of the construction of the dam. .

2. Based on the initial findings of period time predictions implemented, it can be concluded that the classical spectral analysis is very often not applicable for the investigation of hydrogeological time-series, as they assume equal sampling. The problem of unequal sampling time can be easily solved by the utilization of the Lomb-Scargle periodogram. Another great advantage of this method, often not mentioned in the literature, is that it handles one of the greatest drawbacks of performance spectrum predictions, hypothesis testing. It is very important to settle that from the observed spectral peaks, which are significant from the side of the studied phenomenon and which are not. An advance knowledge of the distribution of variables necessary for the calculation of the confidence intervals is an attractive feature of the Lomb-Scargle method. Thus the periods present in a signal can be exactly determined. The following are all new results using the referred method:

2.1. Realizations of time-series in hydrogeology are very often following a trend, and not stationary. The prediction of this trend generally takes place using polynoms of various order. Some of the period length values predicted for the remnants can disappear, while new ones can also turn up. What is the order of trend to be removed to best capture reality regarding period length? This can be easily settled by a homogeneity test.

When predictions are implemented for statistically large enough time-series samples, and the observed trend is removed using polynoms of various order, then only those significant periods are considered as valid, which yield similar results regardless of what order of polynomial trend removal was applied.

2.2. In case of the analysis of groundwater time-series from the area of the Kisalföld, an annual periodicity could have been identified for each and every case. Plus after the removal of several polynomial trends, further 9.8–10.3 and 7.2–7.4, 5.1–5.2 year cycles could have been identified at a significance of 0.05 and 0.001.

3. Wavelet analysis, in contrast to the traditional Fourier method, yields a time-frequency map. Furthermore, the application of the Fourier method is not suitable for non-stationary or transient sample performance preditictions. Conversely, the wavelet method is localized both temporally (spatially) and regarding scale (frequency), yielding a time-frequency resolution. Thus the temporally altering parameters of the studied signal can be captured.

   Using this method a gradual restructuring of the oscillating components was determined for the area of the Kisalföld, where the annual fluctuations in the groundwater table are very often missing in several time intervals as shown by our results.

Possible practical utilization of the findings

The final results of the application of dynamic factor analysis in hydrogeology are very promising in practical utilization. The components were predicted from the water fluctuation data of the saturated zone, the individual components can be regarded as corresponding to single "clear processes without any disturbing factor. In case of the study area of the Transdanubian Mid-Mountains the temporal aspect of infiltration could have been well-studied. Thus the application of this method is suitable for choosing the best calculation method for the estimation of the rate of infiltration, making predictions of water supply more accurate. The loadings of the individual components clearly correspond to the strength of the identified background factor. The received components represent such complex parameters, which can be adequately used to capture the general geological and hydrogeological features of a study area, important in estimating reservoir vulnerability. This way there is a direct link between the loadings of the received components and the degree of vulnerability, as was shown in the example of case studies from the Szigetköz.

Publications related to the thesis work

Márkus L. – Kovács J. , – Urfer W. – Berke, O., 1997.: Investigation of latent dynamic characteristics of space-time phenomena in ecology, Forschungsbericht (Research Report), 97/5, Dortmund University Press, pp.1-40.

Márkus, L. – Berke O. – Kovács J. – Urfer W., 1999.: Spatial Prediction of the Intensity of Latent Effects Governing Hydrogeological Phenomena Environmetrics Vol. 10. pp. 633-654.

Kovács J. – Szabó P.– Czéh R. – Szalai J.- Varga Gy.: Dinamikus faktoranalízis alkalmazási lehetősége a Duna-Tisza közének talajvízállás idősoraira,2002, IX. Konferencia a felszínalatti vizekről, Balatonfüred, Abstract: p. 24.

Kovács J. – Szabó P.– Czéh R. – Szalai J.- Varga Gy.: Talajvízállás adatok idősoros vizsgálatai a Duna-Tisza közén, 2002, IX. Konferencia a felszínalatti vizekről, Abstract: p. 24.

Kovács J. – Márkus L. – Halupka G., 2002.: Measuring contamination-vulnerability of aquifers by dynamic factor analysis, 8th Annual Conference of the International Association for Mathematical Geology, Berlin, Terra Nostra, Volume 2, pp.: 463 – 468.

Márkus L. – Kovács J., 2003: On the Effects of Water Extraction of Mines in Karstic Areas Mathematische Geologie Vol 7.

Kovács J. – Márkus L. – Halupka G. 2004.: Dynamic Factor Analysis for Quantifying Aquifer Vulnerability, Acta Geol. Hung. Vol. 47/1, pp. 1-17.

Kovács J. – Peres B. – Szalai J., 2004.: Periódus vizsgálati módszerek: alkalmazási feltételek, nehézségek és eredmények tiszántúli talajvízszint idősorok példáján, , IX. Konferencia a felszínalatti vizekről, Balatonfüred, Abstract.

Kovács J. – Szalai J. – Frucht É. – Koncz D., 2004: Mintavételi gyakoriság becslése térben és időben a Szigetköz talajvízszint adataira. Kézirat, ELTE TTK Alkalmazott és Környezetföldtani Tanszék, p. 29. és mellékletek

Kovács J. – Földeáki D. - Márkus L., 2005.: A talajvízjárást befolyásoló tényezők vizsgálata a Tiszántúlon, XI. Konferencia a felszínalatti vizekről, Abstract.

Kovács J. – Kovácsné Székely I, 2006.: A minta értelmezési problémái: elmélet és gyakorlat; Földtani Közlöny, Vol. 136, pp.: 139-146.

KovácsJ. – Kovácsné Székely I. – Könczöl A., 2006.: Periódus vizsgálat: Alkalmazási feltételek és nehézségek, pp. 25 – 35.

Kovács J. – Kovácsné Székely I., 2006.: A földtani adatok adatelemzésének nehézségei, Karsztfejlődés XI. konferencia kiadvány, pp.15-24.

Kovács J. - Szabó P.- Szalai J.: Talajvízállás adatok idősoros vizsgálatai a Duna - Tisza közén, Vízügyi Közlemények, megjelenés alatt.