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CONSTRUCTING A SOIL HYDRAULIC CONDUCTIVITY MAP USING PEDOTRANSFER FUNCTIONS AND GIS

APPLICATION TO HOROIATA BASIN, ROMANIA

BY

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Abstracts: Due to the costs of laboratory or field determinations, pedotransfer functions (PTFs) are used to estimate and predict the spatial variability of hydraulic conductivity (Ks) at different scales. Our purpose was to estimate Ks, and to model its spatial variability at the scale of a small watershed. The data obtained may be further used in studies that imply Ks as parameter. Because we do not have measured data of Ks, the validation of different PTFs has been done through expert opinion and on the basis of the few measured data from the area existent in other studies. Both the validation of the test samples and the crossvalidation indicate the superiority of the spatial model obtained through universal kriging universal with 1st order polynomial spatial trend, at local level.

Key words: GIS, soil hydraulic conductivity, model, algortitm.

1. Introduction

Soil surface plays an important role as interface between the atmosphere and the unsaturated zone, separating hydrologic processes into runoff and infiltration [1]. Soil's hydrologic functioning is defined by the structure of the access routes and of the spaces available for water movement and retention. This relation has a multitude of feedbacks that modify the function according to the changes in structure, and reversely [2].

Among the most important parameters linked to soil water state and dynamics are the hydraulic ones. The most important such properties are water retention in soil, the relation between the volumetric water content θ and its potential h, the characteristics of hydraulic conductivity, and the relation between hydraulic conductivity K and the water content or potential [3]. Soil properties needed to describe or model infiltration, water movement in soil, water storage and intake by plants are the water retention curve, and soil's hydraulic conductivity (K) as a function of theta, h or T.

Hydraulic conductivity describes the easiness in water's way through soil. It is a constant of the proportionality between the water flux and the hydraulic gradient [4].

There are several field and laboratory methods for the direct measurement of hydraulic properties, but they are complex and time consuming. For this reason, and for more general applications, have been developed a series of simpler estimating techniques to obtain these relations on the basis of soil properties that are easier to measure. These are the pedotransfer functions (PTFs), statistical correlations between soil texture, soil organic matter, water potential in soil and Ks, which may offer quite correct estimations for many analyses and decisions.

The PTFs have gained recognition during the last years as approaches in translating simple soil characteristics into complicated parameters. At the beginning of PTFs development, many of them have been constructed with the help of linear regressions. Still, these have been replaced by non-linear regressions, due to the amendment in soil hydraulic properties estimations. The major disadvantage of the regression equations is that must be described a priori relations between the grain size data and the hydraulic characteristics, through well defined models of estimating soil hydraulic parameters.

2. Materials and Methods

The analysis has been conducted on a sample area from Tutovei Hills, more precisely in Horoiata basin. The region's individuality is given by the relief fragmentation under the shape of elongated hills oriented approximately north-south, separated by a network of consequent valleys.

Our objective was to construct a hydraulic conductivity map, conductivity being a parameter that enters a multitude of other calculation formulas, which estimate for example erodibility or pollutant dispersion in soils.

The database used is made up of over 140 soil profiles realized by OSPA Vaslui, taken from other authors' studies or sampled by us. The most delicate problem implied by this study was the lack of measured hydraulic conductivity values. Being difficult and costly to measure, this parameter (and not only) does not enter the range of usual determinations conducted in Romanian in the soil survey programs.

Because of this reason we appealed to the PTFs that estimate this parameter, which tough are quite numerous. In the recent literature may be found a multitude of such functions, estimated through different methods and departing from different data sets (soils with different characteristics). There are also several studies that have attempted to evaluate / compare such functions. Thus for example Oliver and Webster (1990) appreciated that Cosby's (1984) method gives good results. Vereecken (1995) [5] evaluated the performance of 11 different theoretical models for predicting unsaturated hydraulic conductivity. Among the methods elaborated by Brackensiek, Saxton, Cosby and Vereecken, Tietje O. & Hennings V. (1996) [6] appreciate as best being that of Cosby. The variability of Cosby's method leads to a standard deviation of Ks of 2.7 for sand, 5.6 for silt and 3.5 for clay. Wagner B. et al. (2001) [7] have evaluated 8 known and accepted PTF's for the evaluation of Ks. Gijsman et al. (2002) have also conducted an analysis of eight modern estimation methods, noticing a significant discrepancy between them. They concluded that the method elaborated by Saxton et al. (1986) is the best. Borgensen and Schaap (2005) [8] appreciate that the predictions of the Rosetta model give high errors due to a weak performance at 10 and 100kPa. Matula et al. (2007) [9] consider that the equations of Wosten (1997) give acceptable results. Among the latest studies of this type is that of Manyame et al. (2007) [10], who have determined the prediction ability of three functions: Campbell, van Genuchten and Vauclin, and concluded that the first performed better.

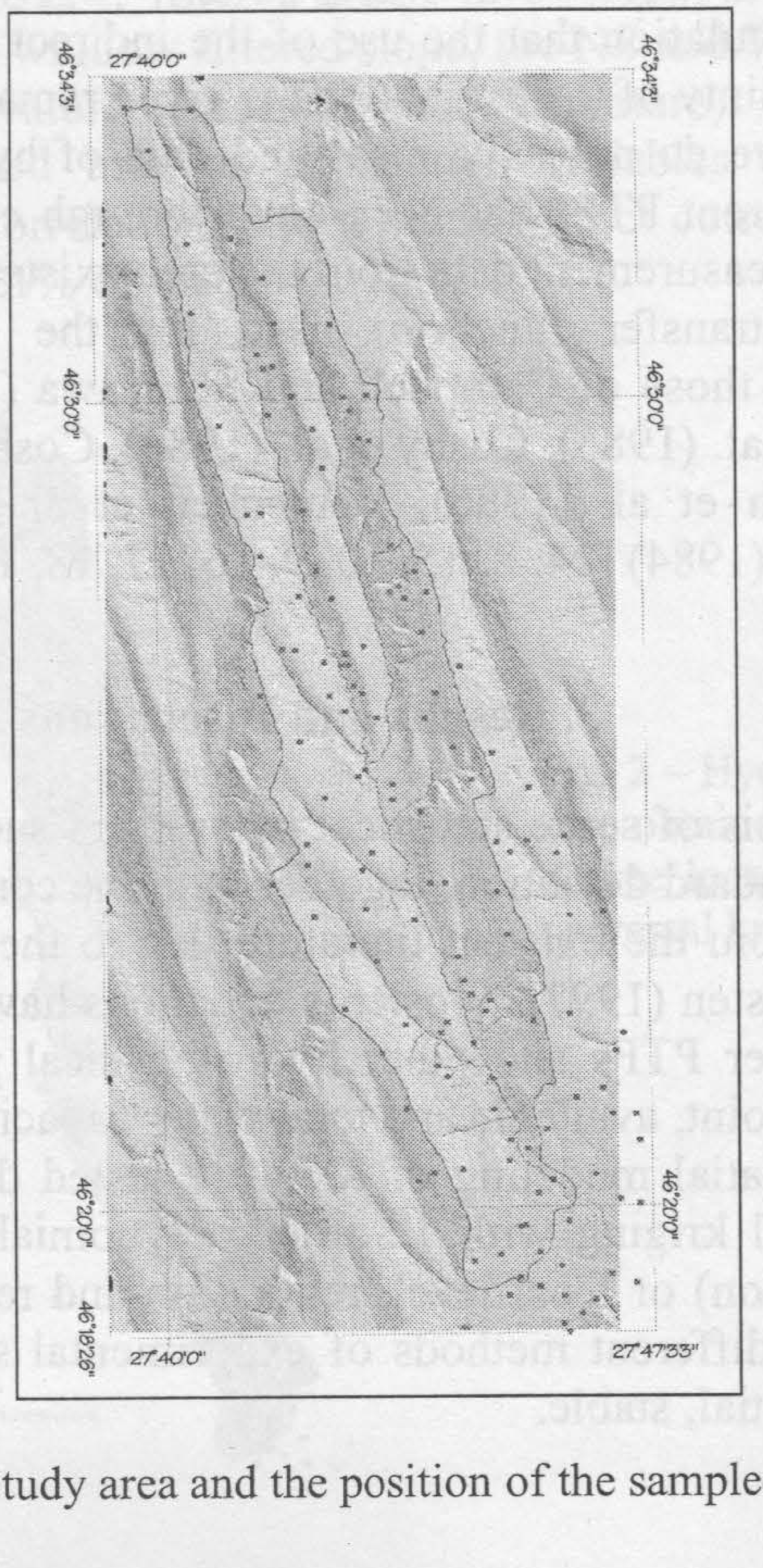

Fig. 1 – Study area and the position of the sampled profiles.

Wagner et al. (1998) [11] affirm that the prognosis capacity of the models that are based only on inputs of textural parameters is limited due to soil variability.

As it can be noticed, different authors indicate a certain PTF as performing better, fact that can only mean that each of the equations gives good results only if applied to areas with similar conditions or to soils with similar properties as those used in the deriving of the functions.

As Nemes A. et al. (2003) [12] appreciate, new approaches for the development of PTFs are continuously introduced, yet their applicability to other locations than those from where the data have been collected is rare. The authors say that the PTFs derived from international soil databases may be an alternative, yet a comparison test with the nationally-derived ones is always useful.

A limitation of the majority of the studies that evaluate FTPs is that the main estimation errors sources remain unclear. In these studies, it is not clear if the differences between the datasets used for the deriving of the FTPs (dimension, origin, validity) or the differences in the developing algorithms lead to a function to be better than other. They suggest that having a smaller set of relevant data may be better than using a larger but more general database. In this idea, [13] postulation that the use of the indirect methods is acceptable as long as the uncertainty of the estimations is given remains very truthful.

Because we do not have measured data of hydraulic conductivity, the validation of different PTFs has been done through expert opinion and on the basis of the few measurement data from the area existent in other studies.

The pedotransfer functions used for the estimation of hydraulic conductivity were those of Campbell and Shiozawa (1994), Dane and Puckett (1991), Puckett et al. (1985), Cosby et al. (1984), Cosby et al. (1984), Saxton et al. (1986), Saxton et al. (1986), Vereecken et al. (1990), Wosten (1997), Brackensiek et al. (1984) [14, 8, 15, 10, 9, 16, 17, 18, 19, 5, 11].

3. Results and Discussions

The analysis of some statistical parameters such as average, minimum, maximum and standard deviation, together with the comparison of the evaluated data with those from the existent literature, led to the choice as Ks estimating PTF of that of Wosten (1997). Wosten's equations have predicted with a higher accuracy than other PTFs and other hydro-physical parameters such as field capacity, wilting point, available and total water capacity.

For the spatial modeling of Ks were tested different kriging variants: ordinary, universal kriging with 1st order polynomial spatial trend applied at global (whole region) or local level, regression and regression-kriging models. Also were tested different methods of experimental semivariograms: circular, spherical, exponential, stable.

Table 1
Statistical Results for the Used Methods

Independent sample validation			
Statistical quality parameters	Universal kriging, 1st degree global polynomial trend	Universal kriging, 1st degree local polynomial trend	Regression kriging
R^2	0.649	0.677	0.461
Slope of correlation line	0.511	0.558	0.386
Mean error	– 8.686	– 9.520	– 9.969
RMSE	29.962	28.902	30.238
Crossvalidation			
R^2	0.412	0.478	0.353
Slope of correlation line	0.384	0.479	0.312
Mean error	– 0.340	– 1.359	– 0.327
RMSE	29.269	27.542	27.148

For the regression model were tested as potential predictors the rectangular coordinates, DEM, filtered DEM in 500X500m moving window, slope, 100x100m moving window filtered slope, the NS and WE components of exposition, surface curvature (profile, plan curvature). The progressive regression model obtained uses as explicative variables the Y coordinate (variation NS) (inverse correlation) and altitude (direct correlation), but has a low explanation degree (21% of the Ks variance).

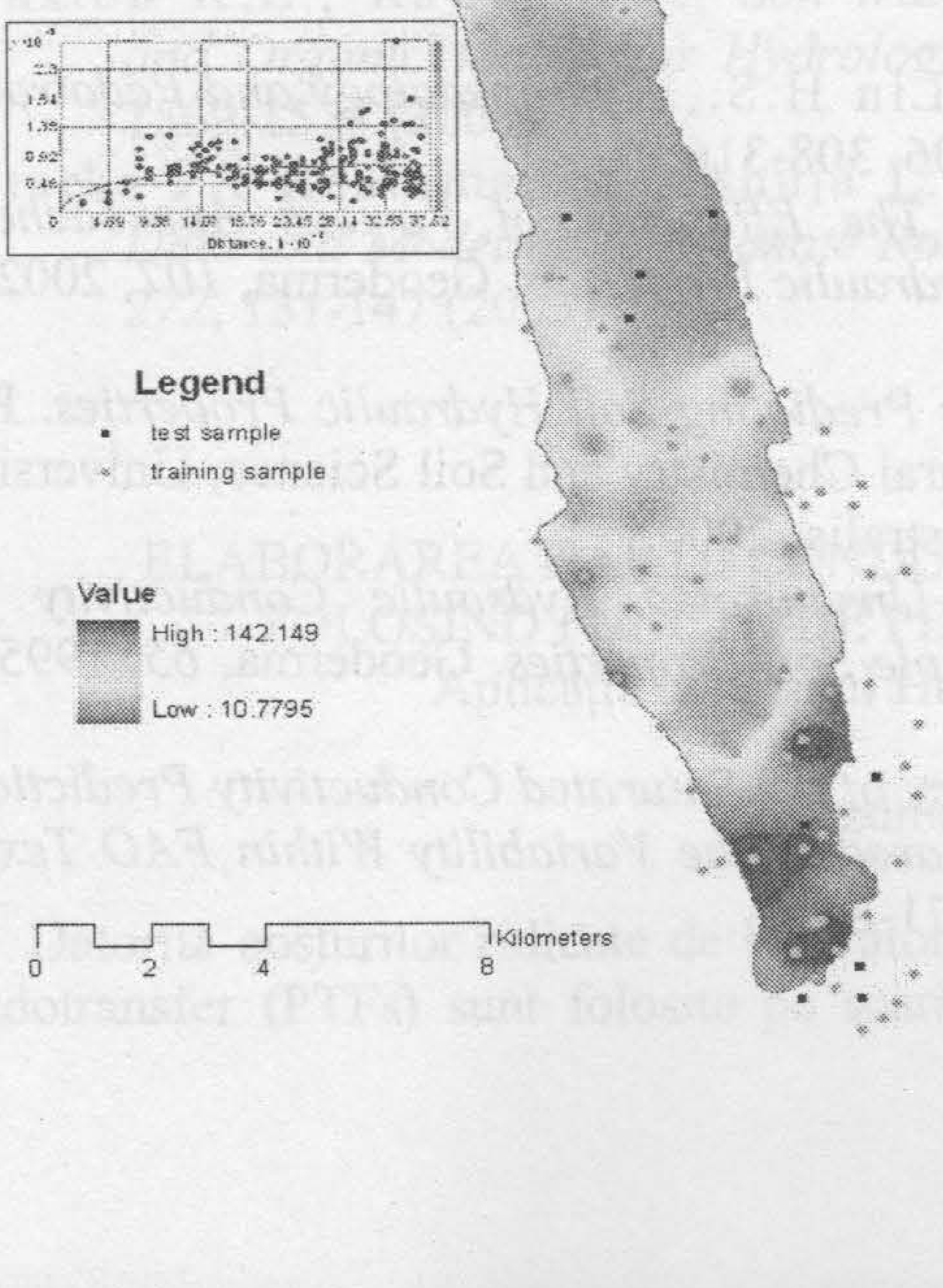

Fig. 2 – Hydraulic conductivity map obtained through 1st degree local polynomial trend universal kriging.

Validation was conducted by comparing the real values with the predicted ones for a random test sample of 10 profiles which was not included in the spatial modeling.

As can be seen from Table 1, the statistical quality parameters for both independent validation sample and crossvalidation procedure (the determination coefficient - R^2, the slope of correlation line, the mean error, the root mean square error – RMSE), indicate that the 1st degree local polynomial trend universal kriging gives the best results.

4. Conclusions

Both the validation at the test samples and the crossvalidation indicate, through the reduced values of RMSE, the higher values of the correlation coefficients and of the correlation line angle, the superiority of the spatial model obtained through universal kriging universal with 1st order polynomial spatial trend, at local level.

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ELABORAREA HĂRŢII CONDUCTIVITĂŢII HIDRAULICE FOLOSIND FUNCŢII DE PEDOTRANSFER ŞI GIS

Aplicaţie la bazinul Horoiata, România

(Rezumat)

Datorită costurilor ridicate de laborator sau de experimentare în teren, funcţiile de pedotransfer (PTFs) sunt folosite pe scară largă pentru estimarea unor parametri

complecsi de sol. Scopul studiului nostru a fost estimarea conductivității hidraulice (Ks) şi modelarea variabilității spațiale a acestui parametru la scara unui bazin hidrografic de dimensiune mică. Rezultatele obținute pot fi mai departe utilizate in studii care implică conductivitatea hidraulică. Deoarece nu am dispus de măsurători, aprecierea corectitudinii diferitelor funcții de pedotransfer testate s-a făcut pe baza verosimilității rezultatelor şi comparării acestora cu o serie de valori măsurate în zona studiată preluate din diferite studii. Atât validarea cu eşantion independent cât şi validarea încrucişată, indică superioritatea modelului spațial obținut prin kriging universal cu suprafață de tendință polinomială de ordin 1 derivată la nivel local.