INTERPOLATING PHREATIC LEVEL ALTITUDE AROUND MĂDÂRJAC VILLAGE USING GEOMORPHOMETRIC VARIABLES AS COVARIATES

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ABSTRACT

Groundwater resource mapping is important in areas like Moldavian Plateau, where groundwater scarcity is a characteristic feature, now and in the scenario of the future climate changes. We study the possibility of using a methodology to acquire ground water level data and interpolate this data, to get a snapshot of the groundwater surface. For constraining the interpolated groundwater surface under the land surface we have used the river and gully channels as 0 groundwater depth, and field measurements in village wells as groundwater surface levels. Because there are consistent proofs that the groundwater level is controlled heavily by the landforms geomorphometry, beside a spline interpolation, we have tested several statistical interpolation methods (multiple linear regression, geographically weighted regression and universal kriging), in order to include the landform control. The results show that the statistical methods of interpolation used in conjunction with geomorphometric variables (land surface altitude and channel network base level) manage to model well the conformation of the groundwater surface, explaining its spatial variation.

Keywords: phreatic level, interpolation, geomorphometric variables, Mădârjac village

INTRODUCTION

The qualitative and quantitative evaluation of water resources represents a key element in human community's development, especially in the context of a traditional rural communities using only groundwater for water consumption. The emergence of phenomena of severe drought manifested in this area in the years 2000, 2007, 2011, 2012 [1] [2], even though the area is in a quasi-natural state with a high degree of forested areas. Thus, the lack of accurate information on the characteristics of the hydraulic hydro-structures in which underground water is found (the depth at which groundwater aquifers appear, flow discharge, flow movements, geophysical characteristics of the rocks) have prompted a number of administrative measures that have had little effect in boosting the amount of water for the population.

Amid the increase in intensity of climatic phenomena, increasingly visible in recent decades, a number of problems because of the reduction in the rain water intake (in the spring season, when the most important transfer of water between the topographic surface and groundwater aquifers happens – see Fig. 3) and the increase of evaporation capacity [3][4], a thorough analysis of their effects on underground water resources according to the local geological and geomorphologic characteristics.

The lack of accurate data on the geological conditions and appropriate measurements with a high density on groundwater level, has led to only a global assessment of these resources, few studies having analysed the groundwater reserves in the area of Bârlad Plateau [5]. In the same context are also the recent scientific approaches which use the methodology of analysis proposed by the groundwater framework directive 60/2000 of the European Commission [6][7].

The main issue to be handled within the framework of such an analysis is the lack of studies and measurements of spatial distribution of underground water resources and significant reduction in recent years, of the number of hydrogeological observation points in the national monitoring system. Global assessments are based on outdated information, published in the period 1970-1980, and do not allow the meaningful study of the impact on groundwater resources.

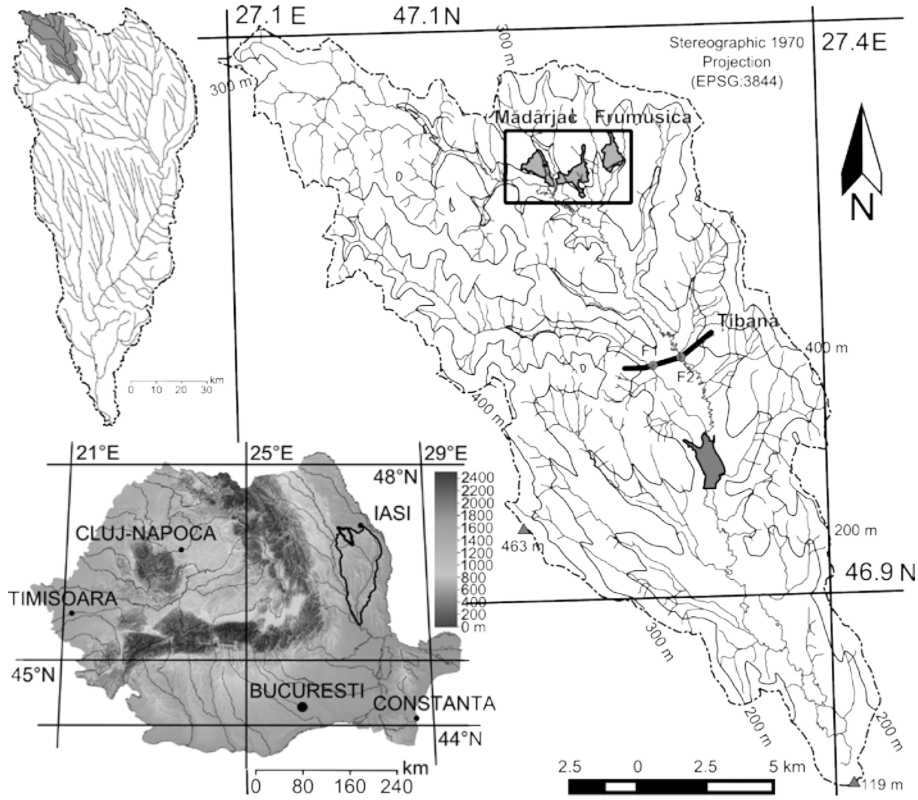

Figure 1 Geographic position of the studied area

Taking into account that the position of the hydrogeologic monitoring stations, located mostly along the hydrographic network, additional information is needed on the distribution of groundwater level on hillslopes and ridges, which are under-investigated, and where the majority of the localities are situated. In this context, to model the groundwater level according to certain geomorphometric variables, a test area was chosen in the northern part of Șacovăț basin, which drains the central part of Central Moldavian plateau (Fig. 1). Within this study area (Mădârjac municipality) were made a series of measurements on groundwater levels in domestic wells on 23 September 2014.

STUDY AREA

In the studied area we can distinguish a main groundwater hydro-structure which is recharged from rainfall and snowmelt and connects with the river channel network. In areas affected by landslides a secondary hydro-structure appear inside landslide masses and hillslope deposits, which induce changes in the groundwater level on ridges and plateaus, as is the case in the northern area of the area of study.

Local hydrogeological conditions are characterized by the presence of fine clayey and sandy deposits at the surface of the hillslopes, with loamy deposits on ridges, while sands and compact clays appear as underlying rocks. The alluvial fill can be depicted in Fig. 2, where two hydrogeological boreholes (Țibana, F1 and F2), located 6 miles downstream, are monitored by the Prut-Bârlad Water Administration. The thickness of the aquifer deposits is 7 to 8 m, and in some cases the aquifer is confined. Confined aquifers appear under the phreatic layer. The filtering coefficient oscillate between 1.2 and 1.4 m^3/day, the radius of influence between 110 and 112 m and the coefficient of transmissivity between 9.5 and 9,6 m^2/day [8]

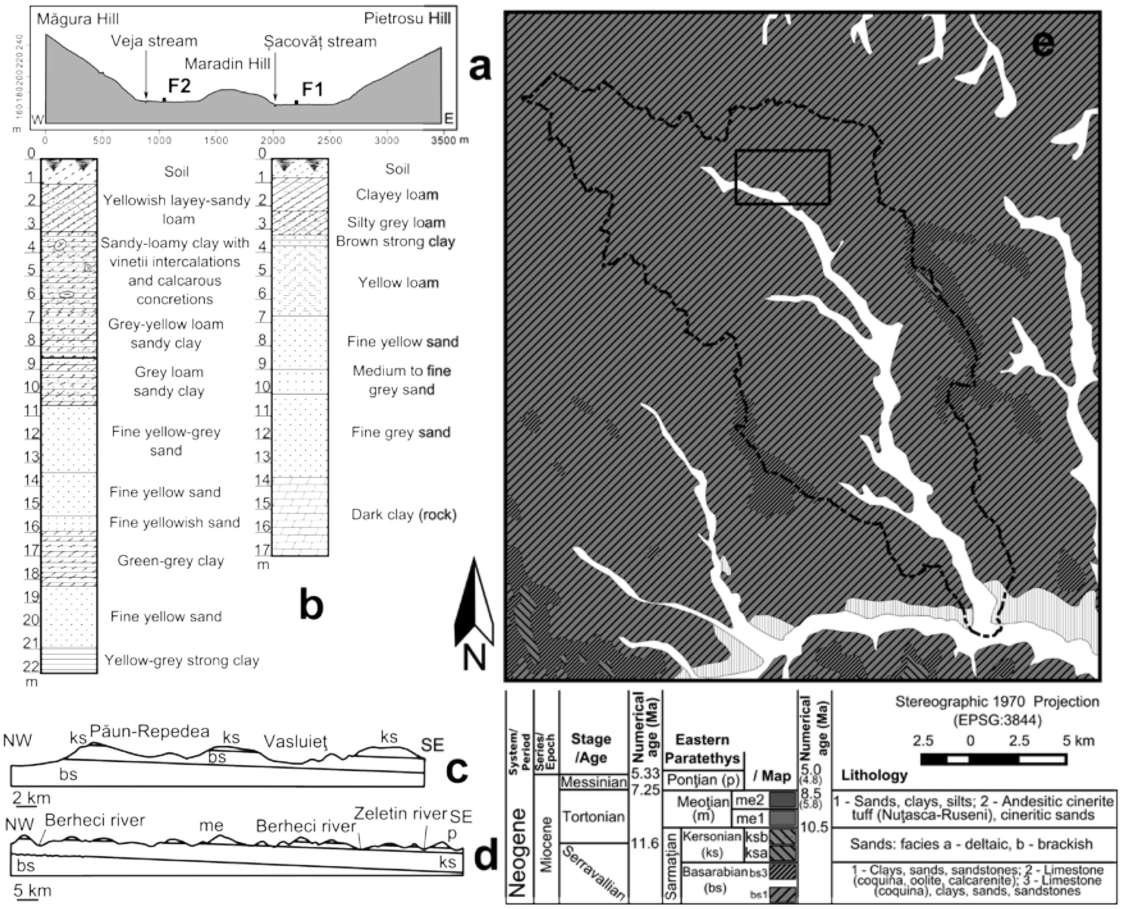

Figure 2 Geology of the studied area: a – topographic profile with the position of the two wells; the position of the topographic profile is indicated in Fig. 1 as a thick black line; b – the lithology of the deposits from the two wells; c and d are geologic cross-sections trough the surroundings of the studied area; e – geological map of the studied area.

Specific flow rates vary between 0.07 and 1.1 l/s/m^2 and hydrostatic level is set at medium depths ranging between 1.2 and 1.7 m annually (Fig. 3). Mean monthly groundwater level presents maximum values during September to November and minimum values in March to April. The amplitude of the groundwater level variation between two consecutive months can reach up to 200 cm (Fig. 3 and 4).

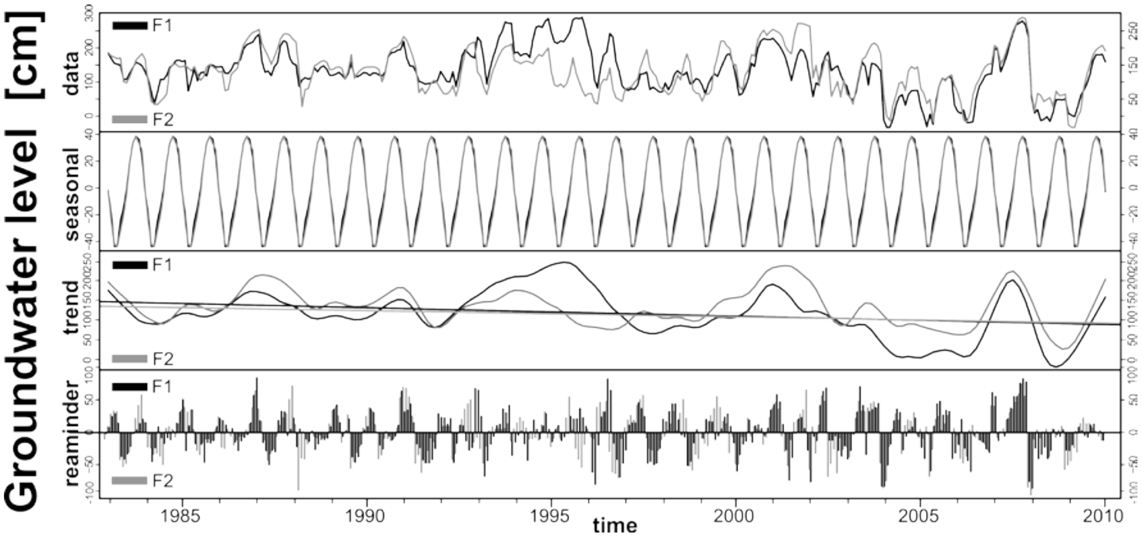

Figure 3 Mean groundwater level decomposition at the Țibana monitoring station wells (1983-2010)

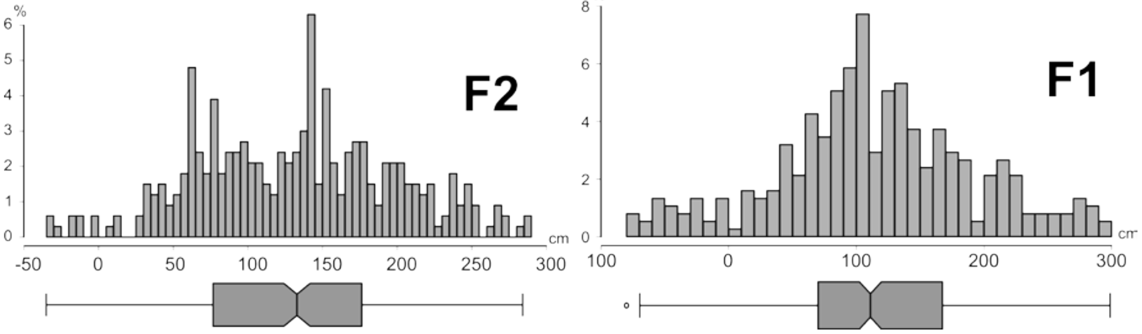

Figure 4 Descriptive statistics of mean monthly groundwater level at Țibana monitoring station wells (1983-2010)

METHDOLOGY

The data used in the interpolation (Fig. 5) consist of measurements made in 96 wells used by the villagers (measurements made on 23.09.2104) and 1352 points along the drainage network (river channel and gully channel). The points along the channel network were considered to have 0 the depth of the groundwater level, and were used to spatially constrain the groundwater level interpolation.

To supplement the modelling, a DEM, derived from LIDAR data, at 5 m resolution was used together with several geomorphometric variables, but from which only the altitude and channel network base level (computed in SAGA GIS [9]) were chosen by the stepwise multiple linear regressions.

Multilevel B Spline (MBS) was implemented using SAGA GIS v. 2.13 Multilevel B-Spline functions with 14 levels and regularization of 0.001, honor all the points. This method was used because IDW didn't get a usable surface.

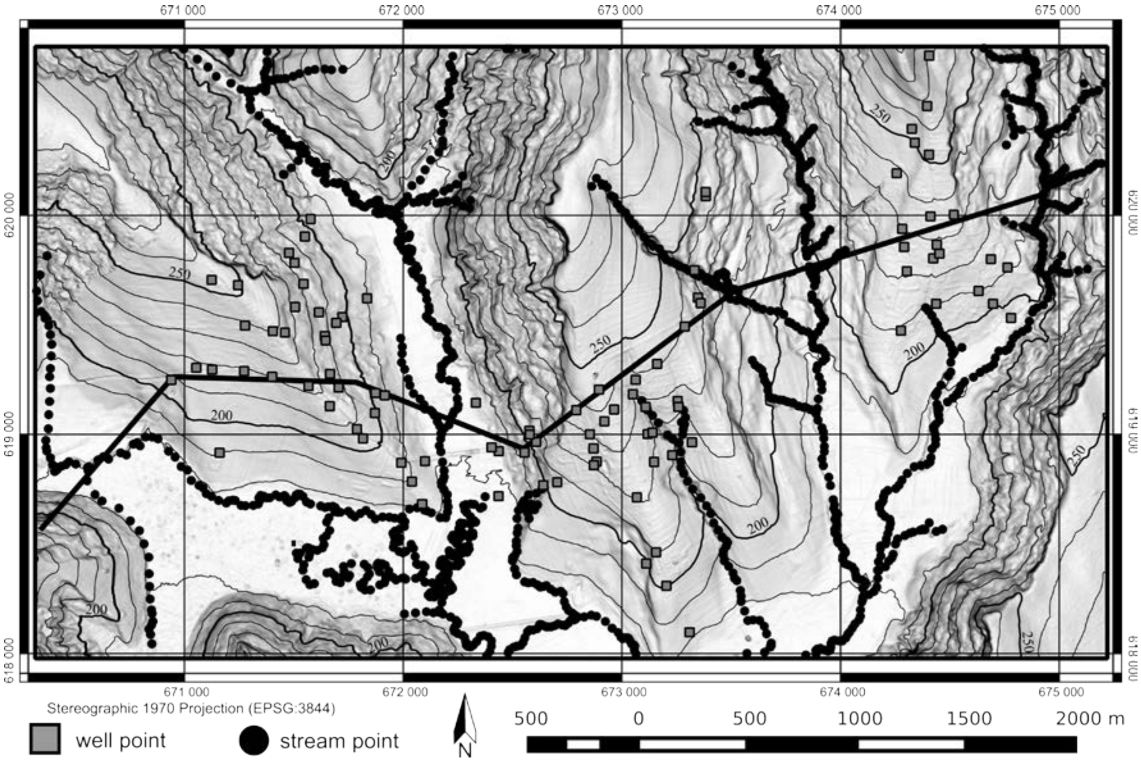

Figure 5 Distribution of the well and stream points used in the interpolation

Linear multiple regression (LMR) was implemented using SAGA GIS v. 2.13 Multiple Regression Analysis (Points/Grids) function, with k-fold cross-validation and 10 samples out.

Geographically weighted regression (GWR) was implemented using SAGA GIS v. 2.13 GWR Gridding (Points/Grids) function, with model resolution same as predictors (5 m), without distance weighting function, search range global, maximum 1000 neighborhood points used and search direction by quadrants.

Universal kriging (UK) was implemented using SAGA GIS v. 2.13 Universal Kriging function, with global search, while the cross-variation was implemented in R [10] using *gstat* package [11]. The usual (Gaussian, spherical, exponential) kriging models were tested and also the absence of anisotropy was assessed.

RESULTS AND DISCUSSIONS

In Table 1 the descriptive statistics regarding the errors of the interpolation methods and their cross-validation errors are represented. For the MBS and GWR methods cross-validation wasn't applied. We can see that all the methods of interpolation perform well, but the linear multiple regressions, which are sensitive to outliers, have the greatest mean error. Because the multilevel b-spline honor the interpolation points, the mean error does not have any relevance, and only the external validation is performed.

In Fig. 6 the resulted groundwater level depths are represented. What can be outlined is that MBS and GWR do not perform well outside the area with data, while MLR and UK performs well in this area. In this figure also the residuals are represented as colored and scaled circles, according to the residual value. All the methods give low residuals on the stream channels points. MLR residuals show that the groundwater surface is too high than the measured values in the western part and too low in the eastern, showing that this method actually has a trend included. UK residuals show a clear undershoots of the surface along the changes of slope. GWR residuals show the most fitted surface.

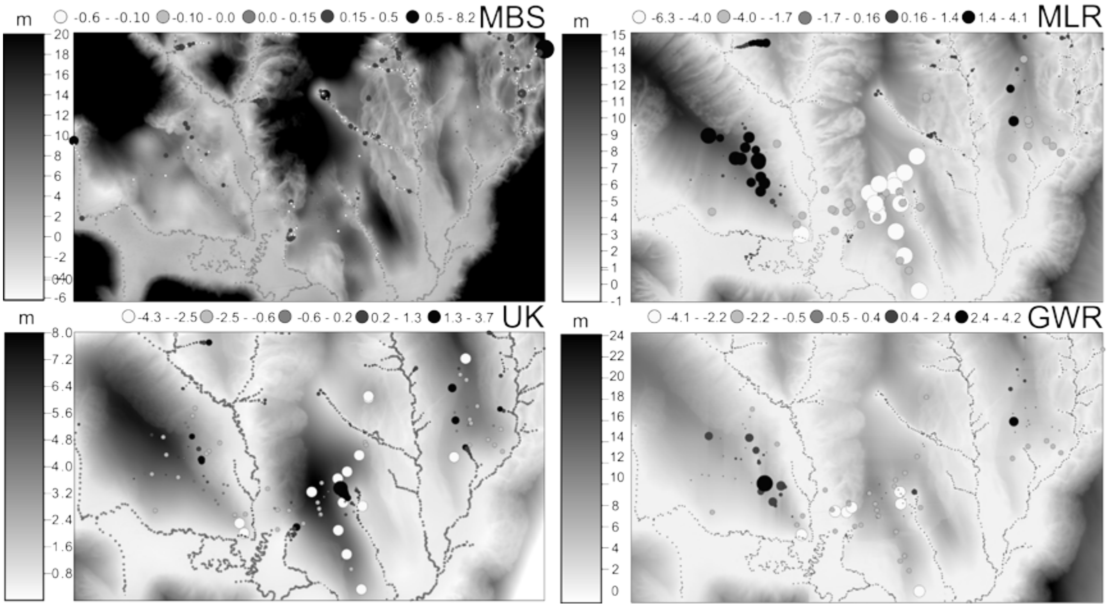

Figure 6 Results of the groundwater level interpolation expressed as the depth of the groundwater level (DEM altitude minus interpolated groundwater level)

In Fig. 7 the spread of the residuals obtained with the tested methods of interpolation versus the measured groundwater level depth are represented, together with the histogram of the residuals. The stream channels points (filled triangles) have usually small residuals around 0, for MBS spread around 0, for LMR and UK mainly over 10 and for GWR mainly under 0. The well points (filled circles) show a tendency to have bigger negative residuals as the depth of groundwater increase.

Fig. 8 shows topographic profiles along the direction indicated in Fig. 5 for all the interpolated surface and for the land surface (DEM). All the groundwater surfaces are constrained under the DEM (only MBS surface has an overshoot, in the western part, outside the interpolation values).

From the 96 well measurements, 16 were chosen to further validate the results of the interpolation, by being eliminated from the modelling. The results of this external validation are consistent with the results showed by the internal cross-validation of the interpolation methods (Table 1).

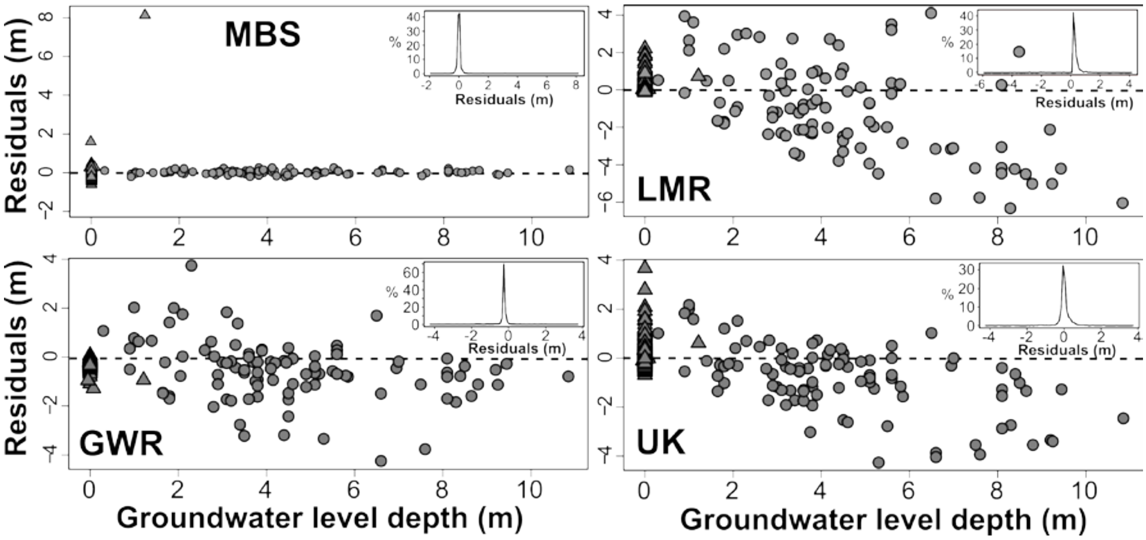

Figure 7 Residuals

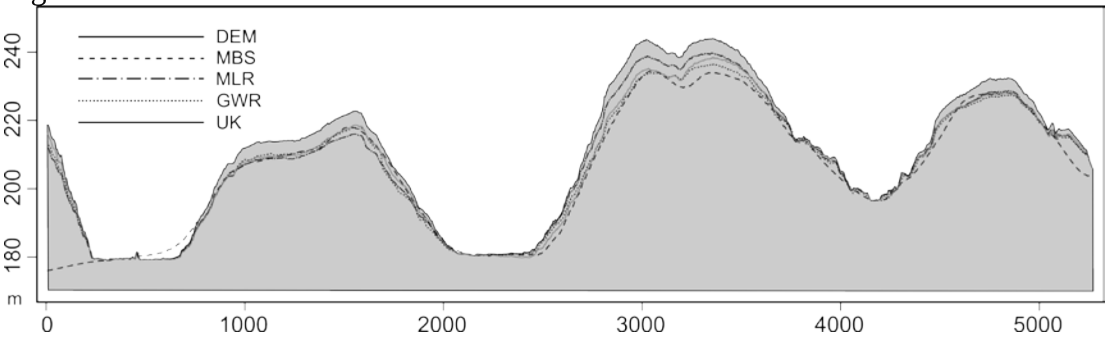

Figure 8 Topographic profile trough the DEM and all the interpolated groundwater level surfaces

Table 1 Descriptive statistics of the interpolated groundwater level

	model	R2	ME	CMSE	CRMSE	evME	evMSE	evRMSE
MBS	-	-	-	-	-	2.16	6.83	2.61
LMR	-	0.99	0.25	0.60	0.78	2.20	6.80	2.60
GWR	-	0.99	0.12	-	-	0.94	2.10	1.45
UK	gaussian	-	0.21	0.18	0.43	1.44	3.15	1.78

ME: mean error; CMSE: cross-validation mean square error; CRMSE: cross-validation root mean square error; evME: external validation mean error; evMSE: external validation mean square error; evRMSE: external validation root mean square error

CONCLUSIONS

Testing various interpolation methods on groundwater level altitude measured in domestic wells and stream channels, in areas where monitoring and legacy data regarding groundwater levels is not available, we can conclude that even simple interpolation methods can give good results, if the input data has good spatial distribution. Incorporating geomorphometric data in statistical interpolation methods will assure that the modeled surface will be confined under the DEM and will be usable in groundwater resources mapping.

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