Design and Development of an OGC Web Processing Service as a Framework for Applying Ordinary Kriging in Groundwater Management

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ABSTRACT: This work refers to the design and implementation of a geoprocessing service on the Web (Web Processing Service - WPS), according to the Open Geospatial Consortium (OGC) WPS standard and in order to give to the users of the service the ability to perform Kriging interpolation on the fly. The fundamentals of Kriging interpolation are initially analyzed and then we present a) the integration to the service of the open source implementation Gstat, as it is used for Kriging interpolation and b) the modifications required for performing the method on data derived from measurements of groundwater resources that have been recorded at selected areas of Greece. After their processing, those data are stored in geospatial databases. Data retrieval from their databases as well as Kriging execution are performed using a web client application, which has been implemented with the dual purpose of presenting the data on the map and demonstrating the execution of service's methods, using as input (a) the recorded groundwater data and/or (b) relevant data that are additionally provided by the user. The development of both Kriging interpolation and the web client is based solely on open source software.

Keywords: Statistical Geoprocessing, Kriging interpolation, Web Processing Service, WPS, Web Client Application, Groundwater Management

ΠΕΡΙΛΗΨΗ: Η παρούσα εργασία αναφέρεται στη σχεδίαση και υλοποίηση υπηρεσίας γεωεπεξεργασίας στον Ιστό (Web Processing Service - WPS) κατά τα πρότυπα της Open Geospatial Consortium (OGC) WPS, ώστε να παρέχεται στους χρήστες της υπηρεσίας η δυνατότητα εκτέλεσης της διεργασίας παρεμβολής Kriging από το διαδίκτυο, σε πραγματικό χρόνο. Το κύριο πλεονέκτημα της χρήσης απομακρυσμένων υπηρεσιών του ιστού σε σχέση με τοπικά εγκατεστημένο λογισμικό που παρέχει τις ίδιες δυνατότητες είναι (α) η δυνατότητα που δίνεται στους χρήστες να εκτελούν τις μεθόδους της υπηρεσίας γνωρίζοντας μόνο τον τρόπο κλήσης και τα απαιτούμενα δεδομένα στην είσοδο, (β) η εξάλειψη της ανάγκης για σταθερές ενημερώσεις λογισμικού που απαιτεί η χρήση τοπικά εγκατεστημένου λογισμικού και (γ) η δυνατότητα εκτέλεσης αλγορίθμων με μεγάλες απαιτήσεις σε μνήμη και υπολογιστική ισχύ, στο «σύννεφο» (cloud). Αφού αναλυθούν αρχικά οι βασικές αρχές της παρεμβολής Kriging, παρουσιάζεται στη συνέχεια η ενσωμάτωση στην υπηρεσία της υλοποίησης παρεμβολής Kriging ανοιχτού κώδικα Gstat καθώς και οι τροποποιήσεις που απαιτούνται για την εφαρμογή της μεθόδου σε δεδομένα που έχουν προκύψει από μετρήσεις υπόγειων υδάτινων αποθεμάτων σε επιλεγμένα σημεία στον Ελλαδικό χώρο. Τα δεδομένα αυτά, μετά την επεξεργασία τους, αποθηκεύονται σε γεωχωρικές βάσεις δεδομένων. Η ανάσυρση των δεδομένων από τη βάση και η εκτέλεση της παρεμβολής Kriging από το χρήστη, γίνεται με τη βοήθεια κατάλληλης εφαρμογής πελάτη στον Ιστό (web client application), η οποία υλοποιήθηκε με το διπλό στόχο της παρουσίασης των δεδομένων πάνω στο χάρτη από τη μια και την επίδειξη εφαρμογής των μεθόδων της υπηρεσίας από την άλλη, με είσοδο τα δεδομένα αυτά και επιπλέον δεδομένα του χρήστη. Η ανάπτυξη της παρεμβολής Kriging ως μέρος της υπηρεσίας, καθώς και της εφαρμογής πελάτη που τη συνοδεύει, βασίστηκε αποκλειστικά σε λογισμικό ανοιχτού κώδικα και πιο συγκεκριμένα στην ενημέρωση της υλοποίησης 52 North WPS με την προσθήκη της μεθόδου παρεμβολής Kriging και την τροποποίηση του λογισμικού 52 North WPS OpenLayers Client, αντίστοιχα.

Λέξεις Κλειδιά: Γεωστατιστική Επεξεργασία, Παρεμβολή Kriging, Υπηρεσία Γεωεπεξεργασίας στον Ιστό, Εφαρμογή Πελάτη στον Ιστό, Διαχείριση Υπόγειων Υδάτινων Αποθεμάτων

I. INTRODUCTION

The representation of spatial distribution of groundwater characteristics is of great importance in measuring groundwater quality and quantity. One of the approaches, which have been used in determining the spatial distribution of groundwater parameters, is the geostatistical approach. Geostatistical methods have been applied in different branches of science, such as Earth science, Hydrogeology, Soil science, Mining and Hydrometeorology [1]. These methods are coupled with GIS capabilities for characterizing the space structure and spatially interpolating vector (point) measurements to create spatial, raster layers of measured values.

Commonly used methods applied in spatial interpolation include Kriging variants (e.g. Simple, Ordinary, Universal and Block Kriging) and Inverse Weighted Distance (IWD). Kriging is regarded as the best linear unbiased estimator. Its

main advantage compared to deterministic approaches, such as IWD, is that for each predicted value the variance of prediction (or prediction error) is also computed and may be used to quantify the quality (or accuracy) of interpolation.

Before using the interpolation techniques, groundwater data can be explored by well known (geo)statistical tools, provided by either ArcGIS or open source geostatistical software. Exploratory statistical techniques that are commonly employed in (not only) groundwater management are [2]-[4]:

- Histograms.
- Normal QQPlot, which it is used to check how close the distribution of a dataset is to the normal distribution.
- Voronoi map, to analyze the spatial variability and stationarity of a dataset.
- Trend analysis, to determine the global trend in dataset.
- Semivariogram, to examine the spatial autocorrelation in dataset.

Conserning open source software, Kriging is provided by a number of geoprocessing libraries ([5]-[7]) and applications ([8]-[10]). Among them, Gstat [10] is a program dedicated to multivariable geostatistical modeling, prediction and simulation. It consists of a broad range of functionalities, which permit the efficient development of Kriging interpolation techniques. It was originally (1997) developed in ANSI C but, since 2003, its functionality is available as an R [11] package as well [12].

As a common practice, geoprocessing algorithms are organized in libraries, which are included as plugins in desktop GIS programs. Referring to the best-known example, sextante [7] functionality is offered this way to QuantumGIS[1], gvSIG[2] and, recently, even to ArcGIS[3] users. The publication of the Web Processing Service (WPS) standard by the Open Geospatial Consortium (OGC) [13] in order to unify the description of geoprocessing algorithms offered online on the Web (e.g. [14]), has led in the recent years to the development of open source software, such as the 52 North WPS implementation, which allow the integration of algorithms in Web services, following the OGC-WPS standard. Although WPS processes may be called either by desktop or web GIS clients, the main advantages of using remote web services and their web clients when compared to locally installed software that provides the same capabilities are (a) the ability of allowing users to perform the methods of the service knowing only (i) the input data/parameters and (ii) how to call them, (b) the elimination of the need for constant software updates that are required by the locally installed software and (c) the possibility of distributed execution of space or/and time demanding algorithms (spatial interpolation known to be one of them) in the cloud [15].

In this work, the design and implementation of a OGC-WPS service is presented for giving the ability to users to perform Ordinary Kriging interpolation on the fly. The development of the service is based on the 52 North WPS implementation[4] of the OGC-WPS 1.0.0 standard. The implementation has been extended in order to provide to clients the Ordinary Kriging process of the R-Gstat package [12]. As the process is indented to be applied on groundwater data, stored in postgreSQL[5] databases, a javascript web client has been built for uploading those data on the map and demonstrating the execution of the process. Once again, development of client is based on the (extensive) modification of the open source 52 North WPS Openlayers Client[6].

This paper is organized as follows: in the next section, the acquisition and storage of groundwater data is described. In Section III, Ordinary Kriging is analyzed in detail, followed by the description of the design and implementation of the OGC-WPS, found in Section IV and the implementation of the web client in Section V, respectively. Finally, Section VI concludes the overall work.

II. GROUNDWATER DATA

The NCSD/IGME (Greek National Centre for Sustainable Development - Institute of Geology and Mineral Exploration) has selected seven pilot sites to dispose geospatial data, field measurements and chemical laboratory analyses. These sites have been selected based on data and facts that indicate their significance from geological, hydrological, hydro-geological and hydro-chemical aspects. Hydro-geologically, they are porous, unconfined aquifers. The geographical dispersion of the sites, depicted in Figure 1, was another factor that led to their selection: two sites are located in Central Macedonia (Mygdonia and Strymon basins), two sites are located in central Greece (Almyros and Sperchios basins), one in western Attika region (Thriassio basin), one site in Peloponnese (Argolis basin) and the last site is located in Northern part of Rhodes Island.

The datasets, which come from NCSD/IGME, refer to three main topics. The first topic refers to the description of boreholes and the second and the third ones refer to chemical analyses and water levels measurements respectively, as were carried out over the aforementioned boreholes, from 2000 to 2013. For each borehole, there are various features recorded, such as its coordinates, depth, elevation, aquifer, water district, pumping type, topology (e.g. valley, hill) and the geology of the ground upon which the borehole has been drilled.

In the topic of the chemical analyses, each groundwater sample analysis is naturally related to the borehole it was taken from. The dates of the

analysis as well as the concentration of a set of chemical compounds with known importance in measuring groundwater quality (pH, Ca, Mg, Na, etc.) were recorded. Similarly to chemical analyses, water level measurements were related to the boreholes they refer to; the date of each measurement was recorded as well.

The datasets were then organized in relational databases using the open source, PostgreSQL Database Management System (DBMS). Due to the applied restrictions of relational databases, clerical errors were detected and corrected during the organization of data in relations (tables). Another advantage of this conversion is that relational databases are well supported as a storage system of vector data by OGC Web Feature Service (OGC-WFS) providers, such as Geoserver[7].

Finally, it should be noticed that those datasets have been successfully imported as Linked Open Data in the cloud [16]-[17], using the Resource Description Framework (RDF) format and the intension of NCSD/IGME is to be publicly available.
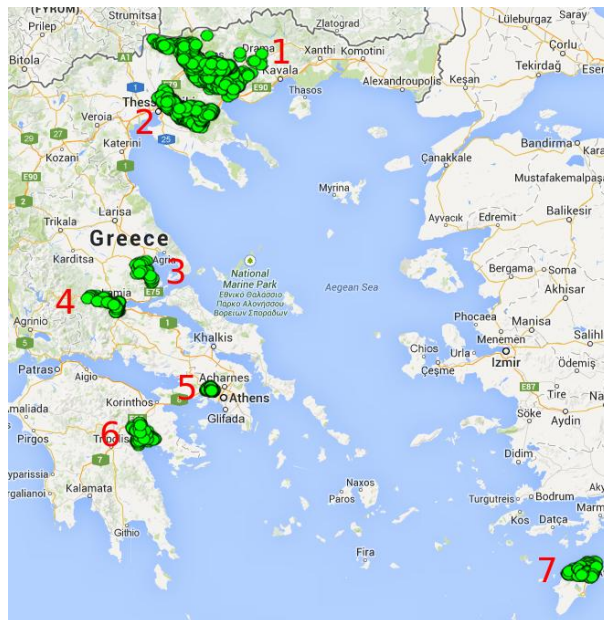
Figure 1: Borehole sites (green circles) at (1) Strymonas, (2) Mygdonia, (3) Almyros, (4) Sperchios, (5) Thriassion, (6) Argolis and (7) Rhodes.

III. KRIGING INTERPOLATION

A. Preliminaries

Kriging is a geostatistical method, which relies on the fact that as distance between points increases, their similarity, defined by the covariance or correlation between points, decreases. Kriging predicts the unknown value $Z(\mathbf{x}_0)$ at a location in question $\mathbf{x}_0$ based on the data values in a neighborhood of this location. Similarly to the other well known interpolation techniques, the calculation of the unknown value is based on the

weighted sum of the locations with known values in the neighborhood of point $\mathbf{x}_0$:

$$Z(\mathbf{x}_0) = \sum_{i=1}^{N(\mathbf{x}_0)} w_i Z(\mathbf{x}_i) \quad (1)$$

where weight w_i is the contribution of value $Z(\mathbf{x}_i)$ and $N(\mathbf{x}_0)$ is the number of neighbors involved in predicting the unknown value. Unlike the deterministic interpolation methods, in Kriging the input data values are considered to be the realization $z(\mathbf{x})$ of a random field $Z(\mathbf{x})$ which consists of a trend $m(\mathbf{x})$ and a residual $R(\mathbf{x})$:

$$Z(\mathbf{x})=m(\mathbf{x})+R(\mathbf{x})$$

or

$$R(\mathbf{x})=Z(\mathbf{x})-m(\mathbf{x})$$

Kriging estimates the residual $R(\mathbf{x})$ as the weighted sum of the residuals at adjacent positions around the location point $\mathbf{x}$. Weights w_i of Eq. (1) are derived from the covariance or the semivariance of known values and thus, semivariance modeling, described in Section B below, should statistically characterize the residual component.

The three basic variations of Kriging, namely Simple, Ordinary and Universal (or with trend), arise from the assumptions made about the trend component of input data as being known and constant (Simple), unknown and locally constant (Ordinary) and spatially or functionally varying (Universal Kriging), respectively. Both Simple and Ordinary techniques may be considered sub-cases of Universal Kriging. In addition, if the trend of Universal Kriging is not a function of spatial coordinates, then other known Kriging interpolation variants arise, such as Kriging with External Drift. Finally, if prediction refers to the average of the measured values in a particular area rather than to single points, we have the so-called Block Kriging.

B. Ordinary Kriging Method Analysis

Kriging interpolation consists of two steps, namely:
  1) covariance, or semivariance modeling based on the set of locations with known values and
  2) prediction of values for a number of points in question.

Both steps are analyzed in detail in the following two paragraphs.

As already mentioned in Section I, often, pre-processing, statistical data analysis steps are taken before performing Kriging, for checking data consistency, removing outliers and identifying statistical distribution. Data normalization may also be performed on data before Kriging.

Semivariance Modeling. Kriging uses semivariance to express the degree of relationship between points on a surface. The empirical semivariance is half the variance of the differences

between all possible points placed a constant distance (lag) h apart:

$$g(h) = \frac{\sum\limits_{i=1}^{N(h)} \left(z(\mathbf{x}_i) - z(\mathbf{x}_i + \mathbf{h}) \right)^2}{2N(h)} \quad (2)$$

where $z(\mathbf{x}_i)$ is the value of the variable Z at location $\mathbf{x}_i$, $h = |\mathbf{h}|$ is the lag, and $N(h)$ is the number of pairs of sample points separated by h.

Semivariogram plots (empirical) semivariance values against lags h (Figure 2). In practice, instead of the often noisy semivariance measurements which are obtained using Eq. (2) on the points with known values, a semivariance model, or function of the three parameters, *Range*, *Sill* and *Nugget* defined below and depicted in Figure 3, is used to compute the semivariance of point pairs according to their distance.
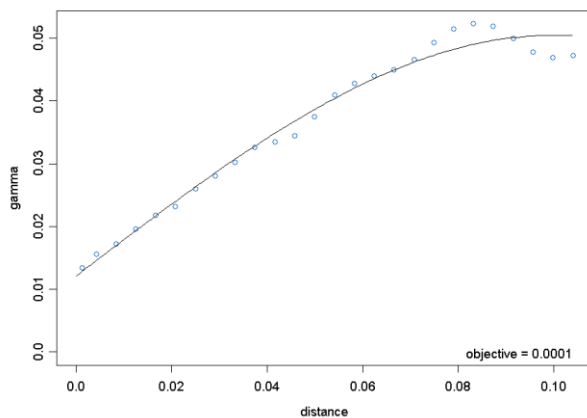

Figure 2: Empirical semivariance (cyrcles) and semivariance model (curve).

In theory, the semivariance value at the origin (h = 0) should be zero. If it is significantly different from zero for distances very close to zero, then this minimum semivariance value is referred to as the *Nugget* (Figure 3). As points are compared to other increasingly distant points, the semivariance increases. Beyond some distance, called *Range*, the values of any points on the surface are statistically uncorrelated. The semivariance value at *h=Range* is called *Sill*, while *Partial Sill* is defined as follows:
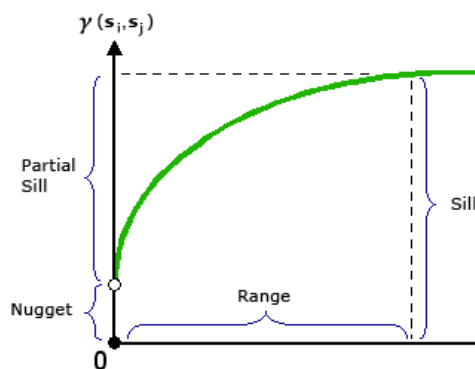
$$PartialSill = Sill-Nugget$$

Figure 3: Semivariogram anatomy defined by *Range, Nugget* and *Sill* (from ArcGIS Help 10.1: Semivariogram and covariance functions).

Prediction. Prediction in Ordinary Kriging may involve the overall set, or a subset of points with known values. In the first case we have global prediction. In the second case, a subset of points with known values is defined in an area of an acceptable, user-given radius (*SearchRadius*) around the point in question and only this subject is used for prediction (local neighborhood prediction). Furthermore, if the cardinality of this subset is less than a user-given value *MinNum*, no prediction is made ("bulls eyes" effect) and if exceeds a user-given value *MaxNum*, then only the MaxNum points, which are closest to the point in question will be used in prediction. Furthermore, MaxNum can be used on its own, without using search radius at all.

The steps taken to predict the unknown value at a specific location $\mathbf{x}_0$, given the set of points with known values, are as follows:

1) First, distances between point $\mathbf{x}_0$ and each point with known value are computed.

2) Based on those distances, semivariance values between $\mathbf{x}_0$ and each one of the points with known values are computed, using the semivariance model.

3) Given the semivariance values, a series of linear equations is solved in order to get the predicted value for the location in question.

In case of using local neighborhood prediction, the steps above involve only the points that are placed in the local neighborhood of $\mathbf{x}_0$, as it is depicted in Figure 4. In most cases, interpolation refers to the prediction of values in locations of a grid that includes the points with known values (Figure 5). The parameters for grid construction, namely *grid extent* in each dimension and *grid cell size* may be given by the user or, grid extent for example, could be extracted automatically from the locations of points with known values, as it is depicted in Figure 5.
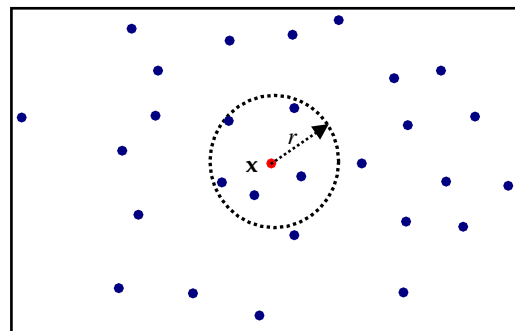

Figure 4: Local neighborhood prediction for the red point in question ($\mathbf{x}_0$), using the five blue points with known values, which are placed in SearchRadius equal to *r* from $\mathbf{x}_0$. The same result would have been obtained for $\mathbf{x}_0$ if we had set MaxNum=5, without using the SearchRadius at all. By contrary, if we had set SearchRadius=r and MinNum=6, no prediction would have been made for $\mathbf{x}_0$.
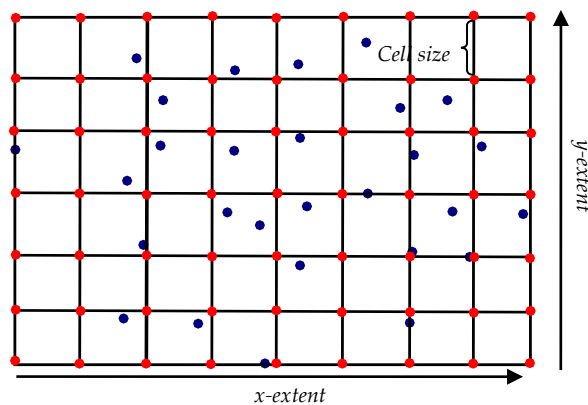
Figure 5: Prediction for the unknown locations of the grid (red points) with user-defined cell size and automatically computed extent by the locations of input (blue) points with known values.

It is evident from the description of the mathematical and computational requirements of Kriging that processing cannot easily take place in ordinary computing infrastructures especially when dealing with big datasets that cover a large spatial area. Thus providing to users the ability to run this service on the web and retrieve the results, open up the ability to do Kriging to almost everybody.

IV. WEB (GEO)PROCESSING SERVICE

A. Open Geospatial Consortium Web Processing Service

Web services are defined as software systems that allow the interaction between machines over a network. In such systems, there is often a machine readable description of the operations offered by the service and the other systems communicate with the service using messages formatted in markup languages such as XML.

Web Processing Service is an Open Geospatial Consortium (OGC) standard, which provides rules for standardizing the implementation of geographic calculations ("processes") as a web service. More specifically, the standard defines three operations:

- *GetCapabilities* that returns metadata describing the service capabilities,
- *DescribeProcess* that returns a description of a process including its inputs and outputs and
- *Execute*, which returns the output(s) of a process.

In practice, WPS operations are invoked by submitting XML to the URL of the service. When requesting an Execute operation, the HTTP request identifies the inputs, the name of process to be executed, and the form of output to be provided after execution. Data are often embedded in process execution input/output XML, although references to web-accessible data inputs/outputs are supported as well.

B. Servers and OGC-WPS implementation

WPS Ordinary Kriging process has been implemented using only open source software written in Java. The basic components of the overall system at server side (Figure 6) are the Web Java Server and a WPS Java Container (implementation) installed in server's workspace, which provides the necessary functionality to handle responses to clients' requests for WPS processes' description/execution, according to the OGC-WPS standard. This way, developers are free to implement and publish web processes without having to worry about client/server interface and WPS processes' input/output issues.

Kriging process has been implemented as a Java class using Apache Tomcat[8] Web Java Server and the 52 North WPS 3.1.1 implementation of OGC-WPS 1.0.0 standard. Ordinary Kriging is applied on input data using R Gstat package. The key features of the package in relation to Ordinary Kriging are (a) the ability of performing global or local neighborhood prediction, on projected or non-projected input data (using great-circle distances in the second case) and (b) the implementation of a fast neighborhood search algorithm.

The interconnection between the Java module located at the WPS Container and R is handled by the TCP/IP server Rserve [18]. Rserve forwards to R the Java-R Interface (JRI) [19] instructions of the Java Kriging module and sends back to the module the returned output of each R instruction (if such an output exists).

C. Ordinary Kriging process implementation

The input of the process is handled by the WPS Container and consists of:

1) The input vector data (**INPUT_LAYER**) in the form of

$$[x, y, feature_1, feature_2, …, feature_M]$$

tuples, where **x**=(x,y) are the locations of vectors.

2) The **FIELD** (feature$_j$ of **INPUT_LAYER**) upon which Ordinary Kriging will be applied. It has to be a feature with arithmetic (real or integer) values.

3) The semivariance **VARIOGRAM_MODEL** that will be used. Its value is a three letters (short) description of one of the models that are supported by Gstat (Table 1).

4) The **NUGGET**, **PARTIAL_SILL** and **RANGE** values. **RANGE** is measured in meters when data are projected and in kilometers (km) otherwise.

5) The **MAXIMUM_RADIUS** value, which corresponds to SearchRadius and is measured in meters for projected and in km for non projected data respectively.

6) The **MIN_NUMBER_OF_POINTS** value. Corresponds to MinNum.

7) The **MAX_NUMBER_OF_POINTS** value. Corresponds to MaxNum.

8) The **CELL_SIZE_OF_GRID** that will be used for constructing the grid with predicted values. It is measured in meters for projected and in degrees for non-projected data, respectively.
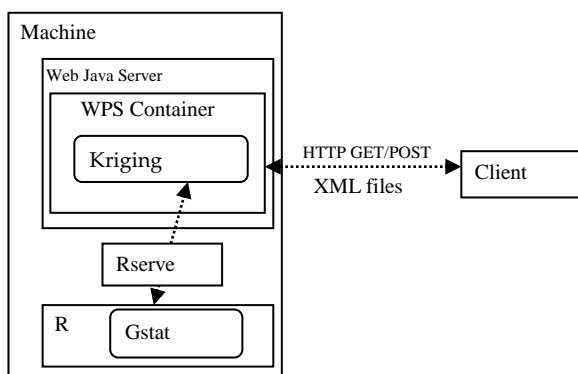

Figure 6: Server configuration of WPS Kriging implementation.

Table 1: Three letters (Short) and Long Description of models (or functions) supported by Gstat for semivariance modeling[9].

Short Description	Long Description
Nug	Nugget
Exp	Exponential
Sph	Spherical
Gau	Gaussian
Exc	Exclass-Exponential class
Mat	Matern
Ste	Matern, M. Stein's parameterization
Cir	Circular
Lin	Linear
Bes	Bessel
Pen	Pentaspherical
Hol	Hole
Log	Logarithmic
Pow	Power
Spl	Spline
Leg	Legendre
Err	Measurement error
Int	Intercept

INPUT_LAYER should not contain duplicates, i.e. there should not be two (or more) tuples for the same point, otherwise Kriging prediction solving will lead to singular matrices and a fatal error will occur in Gstat. Thus, a check is performed by the Java class on input data and if duplicates for the same input point are detected, their values are replaced by their average.

The Coordinate Reference System (CRS) of input vector data is assumed to be included in input data and if not, CRS EPSG:4326 (WGS84) is used by default. Grid extent is automatically computed by the extent of input data.

The results of Kriging are three files, accessible as temporary links. The first file includes the kriging predictions of the form

$$[x, y, predicted\_value, prediction\_variance],$$

in tab separated values (tsv) format, the second one is an image preview of Kriging predictions in PNG format and the third is a tsv file of the input data in

$$[x, y, feature_j]$$

form. The OGC-WPS output XML (i.e the response of Execute operation), which includes the three temporary links is asynchronously returned to the client by the WPS Container.

V. WEB CLIENT APPLICATION

For testing the WPS process and demonstrating its usage, a web client[10] has been implemented by modifying the open source 52 North Openlayers WPS Client. The sequence of actions in order to perform Ordinary Kriging prediction on the groundwater data, is as follows:

User Access. When the user navigates to the URL of client, (s)he sees the central html page built using styles and JavaScript (JS) libraries.

WPS Description. A panel has been developed as Openlayers control for giving the ability to the user to select input layer and parameters for Kriging (Figure 7). To construct the panel, a request is send to the WPS container issuing the description of Kriging web process in terms of data inputs and parameters required for its execution (*DescribeProcess* operation). The response to that request is the OGC-WPS XML description file for Kriging process, which, after its asynchronous arrival at the client, is parsed in order to construct the panel. Description step is executed upon loading of the main html page.

Vector Layer Loading on Map. A JS control unit has been built for handling vector data input of Kriging (Figure 8). In current implementation, the user is given the ability to load on map groundwater data from the database using predefined, fixed or partially fixed, SQL queries. Furthermore, the user may load her(his) own data in Excel format. All data are transformed to GeoJSON[11] format and then are treated as "vector layers" of the Openlayers[12] library. In addition, a tool has been implemented which permits the selection of features in a rectangle box. Using this tool the user can create new (Openlayers vector) layers from already loaded (on map) ones. Any of the loaded layers could be used as the input layer in Kriging process.

Kriging Execution. First, the user selects one of the loaded layers as the input data layer of the process and gives Kriging specific parameters. Then, the selected Openlayers layer is transformed to a format acceptable by 52 North OGC-WPS Java implementation. The OGC-WPS input XML is then constructed, using the input data and Kriging parameters and is forwarded to the process (*Execute* operation). The output XML is parsed using JavaScript and, after all, the user is given the

ability by the user-interface to download the output files.

Figure 7: Panel for helping user to give Kriging parameters and input data.

Figure 8: Control unit for loading of vector layers on map. The user may load on map as layers (1) his own data in Excel format, (3) data of boreholes, (4) data of chemical analyses and (5) of water levels. Furthermore, the user is given the ability to create (and use as input for Kriging) new layers from already loaded ones, using a tool for selecting features in a rectangle box (2).

In what follows, an example of applying Kriging is presented. Input data come from the chemical analyses obtained for a number of chemical compounds during the "Dry" period (May-October) of 2005, for the 56 boreholes of Mygdonia basin, whose locations (in CRS EPSG:4326) are depicted in Figure 9. The parameters used for Kriging interpolation are found in Table 2. The preview png image of the result is shown in Figure 10. In that Figure, black crosses correspond to input data with known values, while the contours correspond to the borders between grid regions with different levels (classes) of predicted values. The correspondence between classes' value ranges and grid colors is captured by the legend of the plot.

VI. CONCLUSIONS

The design and implementation of an OGC-WPS service to provide Ordinary Kriging prediction has been presented. The development of the service

was based on the open source 52 North WPS implementation of the OGC-WPS 1.0.0 standard. The implementation has been extended in order to provide to clients the Ordinary Kriging process of the R-Gstat package. As the process was indented to be applied on groundwater data stored in postgreSQL databases, a javascript web client has been built for uploading those data on the map and demonstrating the execution of the process. The development of client was based on the modification of the open source 52 North WPS Openlayers Client.
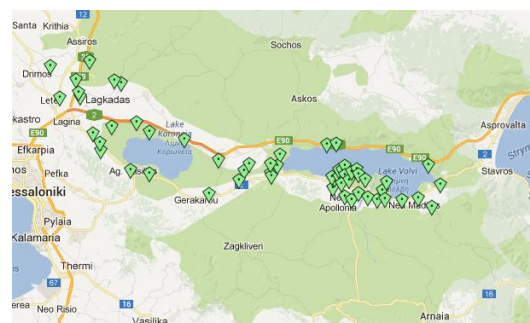

Figure 9: The 56 boreholes used for Kriging interpolation.

Table 2: Parameters of Kriging.

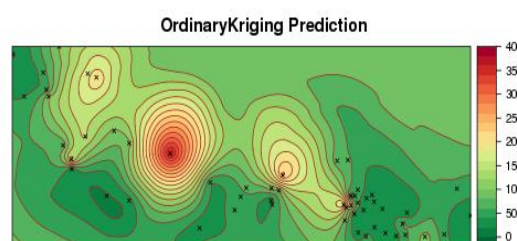| Name/ID	Value
FIELD	"Na"
VARIOGRAM_MODEL	"Sph"
NUGGET	0.0
PARTIAL_SILL	1000.0
RANGE	10.0
MAXIMUM_RADIUS	0.0
MIN_NUMBER_OF_POINTS	0
MAX_NUMBER_OF_POINTS	0
CELL_SIZE_OF_GRID	0.001

Figure 10: Preview (PNG) file returned by WPS Kriging process.

The service could be extended with the addition of additional Kriging variants and geostatistical tools. Furthermore, the distributed execution of Kriging processes could be investigated.

VII. ACKNOWLEDGEMENTS

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