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DETERMINING SPATIAL ANISOTROPY USING GEOGRAPHIC INFORMATION SYSTEM

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Earth related data are often autocorrelated. The degree of autocorrelation of spatial continuity varies with geographic direction. If the spatial dependence is clearly continuous in one particular direction, then anisotropy is present in a data set. Anisotropy reveals the spatial structure of studied phenomena such as air pollution, mineralization, insect behavior, etc. The purpose of this article is to develop an efficient, and relatively easy-to use method for determining and measuring spatial anisotropy and isotropy by utilizing the Arc/Info Geographic Information System. Procedures and methods are tested on the Rio Grande data set. The axes of anisotropy are measured anis, the index of anisotropy is being calculated, and the directions of spatial continuity are expressed in degrees of azimuth. Prevailing variogram models, spherical and gaussian, have been determined and graphed without leaving the GIS environment. Practical applications of this method are in mining, optimal sampling strategies, variogram analysis, in the search window strategies, insect outbreaks mapping, underground or surface water pollution monitoring, environmental impact assesment and in many other natural resource management oriented studies.

Key words: spatial anisotropy, spatial isotropy, geographic information system

INTRODUCTION

For the last two of decades, Geographic Information Systems have contributed significantly to the development of spatial analysis and computerized mapping. Anisotropy is one of the important parameters of spatial structure. It indicates spatial

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dependance and also spatial continuity of a variety of geographic phenomena. Since the earth related data are often autocorrelated, variogram or covariance function are capable of expressing the spatial behavior of studied geographic phenomenon. Anisotropic ellipse is therefore, a structural spatial feature which indicates the shape, length and direction of spatial dependance of studied phenomena. If certain spatial feature has no particular trend the isotropy is present in a spatial data set.

The purpose of this study is to develop an efficient method for determining spatial anisotropy or isotropy using Geographic Information System and to introduce this work to a large audience of geographers. Anisotropy has been analyzed primarily by geostaticians and mining engineneers (Isaak and Shrivastava 1989). In this study an attempt was made to determine anisotropy as an independent geographical feature. As such it was described and quantitatively estimated. The usage of Geographic Information System in determining of spatial continuity is a recent approach and until now it has not been applied to structural spatial modeling.

GEOSTATISTICAL CONCEPTS

Samples taken in the field are often viewed in geostatistics as random variables. Their spatial variation can be measured by a covariance function or variogram. Covariance is the numerator of widely used correlation coefficient for the two variables at hand.

$$C = \frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) \qquad (1)$$

where: C is covariance, x_i is the first variable, y_i is the second variable, $\bar{x}$, $\bar{y}$ are arithmetic means of x_i, y_i and n is the number of variables. Since the measurements taken in close proximity are likely to behave similarly, the degree to which they both vary is likely to be high. This indicates that the covariance function decreases with increasing distance. Similarly, correlation is decreasing function of the distance. Some authors used covariance function to determine anisotropy (Isaaks, Shrivastava 1989).

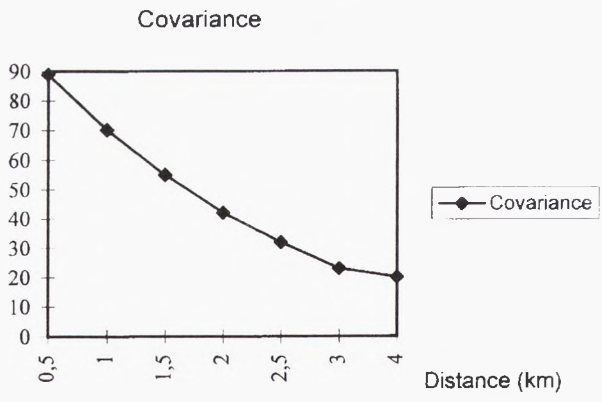

Fig. 1. Covariance function.

Variogram, on the other hand, indicates the opposite trends than the covariance function since the difference between two samples increases with the distance. The variogram (Figure 2) is an increasing function of the distance.

$$y = 1/(2n) \left\{ \sum_{i=1}^{n} [z_i(u) - z_i(u+h)]^2 \right\} \tag{2}$$

where: y is the variogram value, z_i is the sample value at location u $z_i(u+h)$ is the sample value h distant apart from z_i and n is the number of pairs. Both functions (variogram and covariance) are related as follows: $y(h) = C(0) - C(h)$ for the second order stationary process. In essence stationarity is the independence of univariate or multivariate probability laws from the location u, e.g. all pairs of points have the same joint probability distribution.

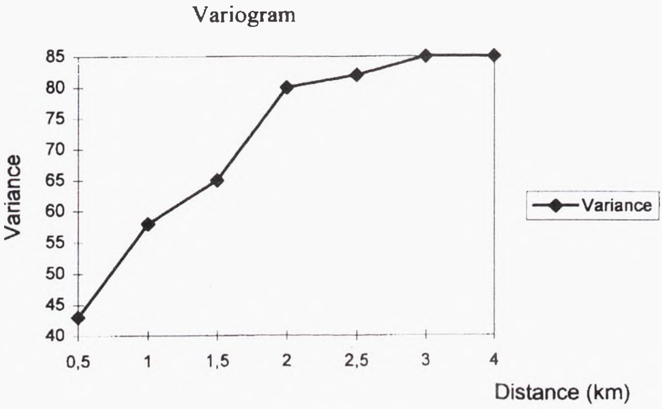

Fig. 2. Variogram.

ANISOTROPY AND ISOTROPY OF SPATIAL STRUCTURES

Figure 1 and Figure 2 indicate that the value of covariance function and variogram depends on magnitude of distance. However, the spatial features often vary with the geographic direction. Hence, the spatial correlation can have significantly larger continuity in one particular direction and smaller continuity in the other direction.

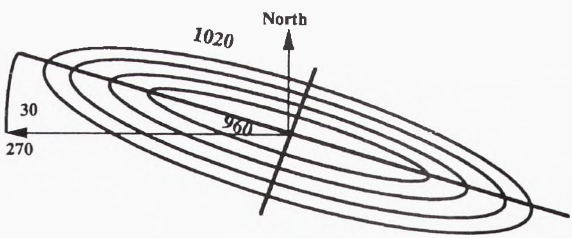

Fig. 3. Two dimensional anisotropical structure.

This results in a spatial structure with two or three different axis of anisotropy (Figure 3). If there is no significant spatial relationship in any direction, an isotropic spatial structure will develop similarly to Figure 4.

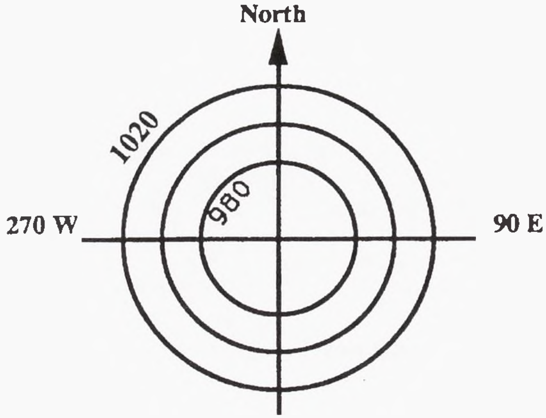

Fig. 4. Isotropic structure. The spatial relationship is independent from the direction.

The purpose of this article is to determine, measure and quantify the axis of spatial anisotropy using Geographic Information System. Anis, the index of anisotropy is obtained by dividing the minimum length of anisotropy by the maximum length. This elongation ratio provides an important information about the spatial structure. The smaller the ratio, the stronger the spatial dependence is in one particular direction. As the Figure 5 indicates spatial continuity was expressed by semivariogram values. For practical applications are both terms (variogram and semivariogram) interchangeable. The variogram model is expressed in equation (1). As the prefix "semi" indicates semivariogram or semivariance is half of the variogram. The later term (variogram) is used in geostatistics more frequently due to its traditional usage in mining and geology. On contrary, in statistics the covariance function is used more frequently than variogram (Cressie 1993). Upper part of Figure 5 shows higher density of semivariance isolines. This supports three dimensional visualization of spatial continuity features in this area. Some of these isolines were deleted in the lower part of this figure. The axis of anisotropy and semivariance values were also drawn.

PROCEDURES AND RESULTS

The data set used in this work includes digitized elevation points (bench marks) from USGS 7. 5 minute maps of 1/24 000 scale. However, proposed method can be applied to variety of topics such as: sulfur dioxide air pollution, soil salinity trends in dry areas, monitoring of polluted underground water table, insects outbreaks in forests, corn protein content in agricultural production etc. The kriging function converted the irregularly spaced points (z values) to the lattice with equally spaced data cells. Kriging is a low pass algorithm which provides a minimum error variance of any unsampled value. Lattice is a special form of data representation. It is a mesh of equally spaced cells. In the center of each cell is located a point (z value) such as elevation. Three dimensional surface is usually represented in Geographic Information Systems either by TIN (triangular irregular network) or by lattice.

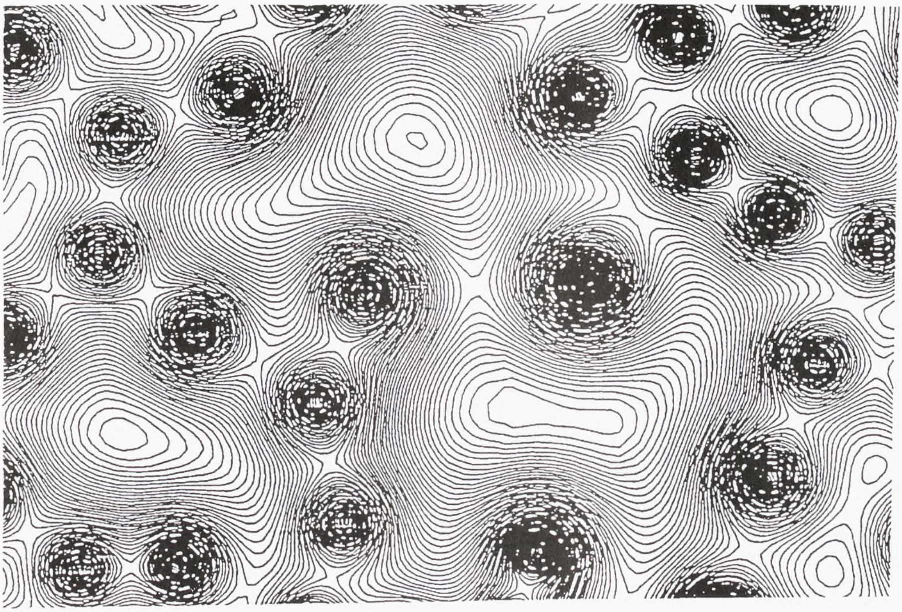

Fig. 5. Contours of semivariogram values reveal the shape, size and direction of structures.

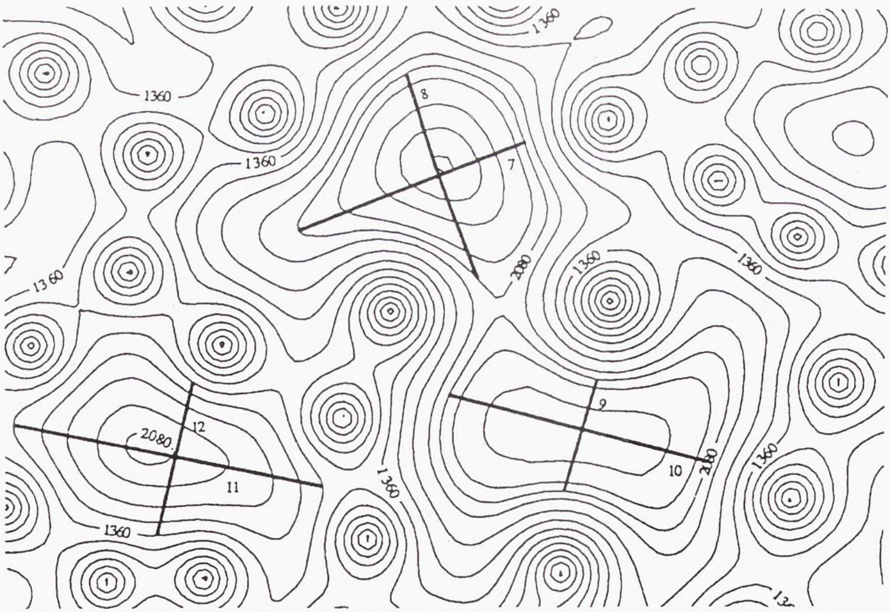

Fig. 6. Spatial structure of variogram features with axis of anisotropy.

The prediction of any value in unsampled locations is a result of a linear unbiased combination between the weights and sample values. The kriging algorithm assigns weights to the neighboring sample values of a point being estimated, based on the distance to this point. The kriging procedure in Arc/Info also creates predicted semivariance values for each mesh point. In order to find the mathematical model that fits these semivariance values the *semivariogram* GIS function was used. This procedure can be repeated until the best fit is determined. Arc/Info uses gaussian, exponential, spherical and linear models to fit semivariance values. Kriging is an intensive process and the speed of execution depends primarily on the cell resolution and the number of input points that interpolate values in unsampled locations. In this study, the 12 nearest input sample points were used and the size of each cell was 80 meters. The study area was 24.5 x 26 km. The lattice was created with the help of the kriging function and the *latticecontour* command generated the isolines from semivariogram values. A separate axis layer was developed interactively and *arccogo* function was used to calculate the azimuth of each axis. The direction of spatial dependence determined by the azimuth values is a beneficial result with many practical applications.

Engineers or ecologists will be able to take further steps in their environment knowing that the spatial phenomena of their interest takes on certain direction. For example, figure 6 indicates that the spatial structure with axis 7 and 8 does not have a significant anisotropic shape. Both axes have almost the same length 2431.8 and 2159.8 meters, therefore, anis, the coefficient of anisotropy, is close to one (0.88) which indicates that there is no particular direction of spatially correlated values.

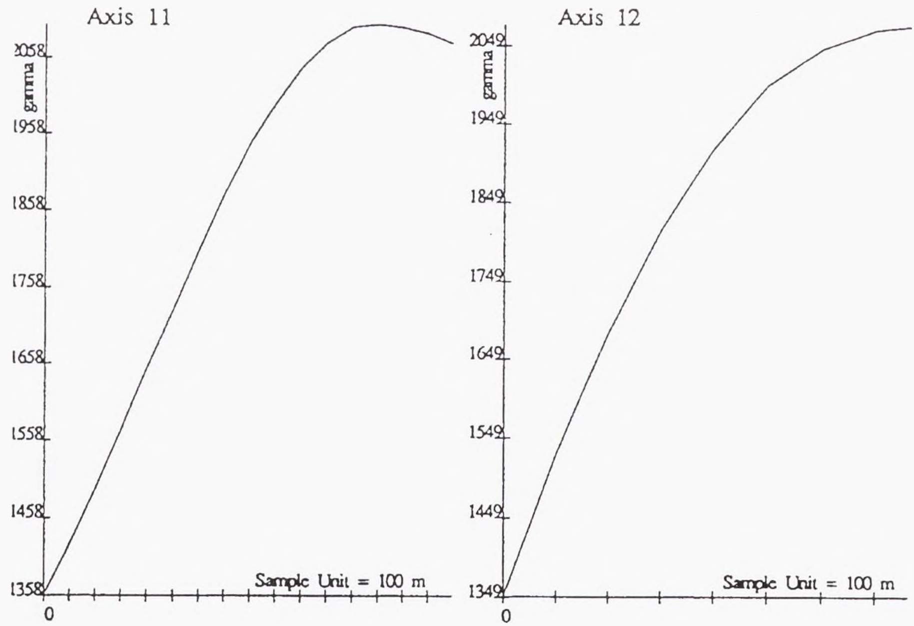

Fig. 7a and 7b Spherical variograms.

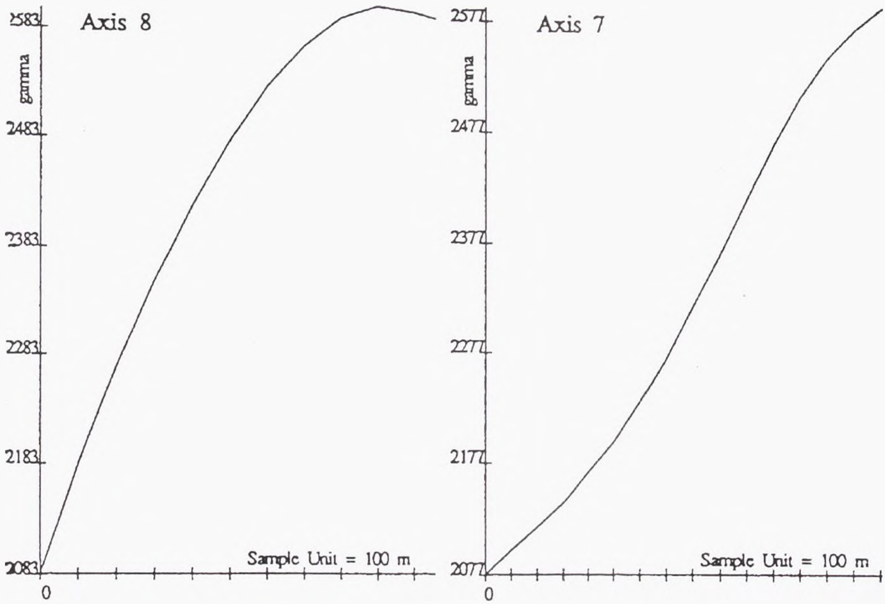

Fig. 7c and 7d. Spherical and Gaussian variogram models.

The two remaining test structures are more anisotropic. The first one with axis 9 and 10 has a significantly lower anisotropy (0.43) than the previous isotropical structure. The anisotropy index of the second feature (axis 11 and 12) is slightly higher, 0.506, indicating a transitional stage between an ideally isotropical shape, circle, and extremely elongated feature with anis index close to 0. The maximum length of correlated values occurs along the longer axis, and minimum spatial continuity is determined along the length of the small axis which is perpendicular to the previous one. Both intersect at the centroids of each structure. Determination of the overall shape of spatial structures is not fully explored until the direction of spatial continuity is calculated. Azimuth values obtained with the help of arccogo indicate that prevailing direction of all structures is between N 68.98° and N 162.18°. The axis of minimum continuity lies between N 162.18° and N 196.49°.

All parameters of anisotropy, anis, length, and direction of spatial continuity play an important role in variogram modeling. Since the spatial features in this study were obtained from the contouring of semivariance values, the cross sectional profiles along axis of anisotropy should reflect the models of spatial dependence by plotting the distance on the x axis and semivariance on the y coordinate. *Surfacesextion* ARC/Info function was used to interpolate and write surface profiles' coordinates to an info file. The info file contains section line profile information with the samples recorded at every interval of the chosen sample distance. Graphic subroutines in Arcplot module draw profile graphs along the axis of anisotropy, from the section line profile coordinates stored in the info file.

As Figures 7a through 7d indicate there are two basic models of spatial continuity: 1) spherical 7a, 7b, and 7c. 2) Gaussian, Figure 7d, along the axis of number seven. The spherical model is one of the most commonly used variogram models in geostatistics and has linear behavior at small distances near the origin. Gaussian model, on the other hand, reflects extremely continuous phenomena (Isaaks, Shrivastava 1989). The distinguishing feature of this model is its parabolic behavior near the origin. Figure 7b (variogram along axis number 12) indicate a short - range variation. The model reaches the sill within a relatively small distance, indicating the minimum spatial continuity at N 192.87°. The distance units on each graph represents 100 meters.

CONCLUSION

The determination of spatial anisotropy and isotropy has several practical applications. For example, mining and ore prospecting utilizes spatial information concerning rock mineralization. The knowledge about the direction of spatial dependence and continuity helps to establish the correct mining strategy. Proposed applications in the natural resource management work: Mapping of industrial air pollution or underground water pollution, directional dependence of soil properties, detection and mapping of geomorphologic features such as erosion-denudational surfaces, insects outbreaks and plant disease analysis, evaluation of the corn protein content and other agricultural product etc. If the spatial structure is isotropic then an omnidirectional variogram is sufficient for developing a stochastic model from data samples. On contrary, significant anisotropy in one or more directions signalizes that the model development will be more complex and variograms should be constructed for all prevailing directions. The proposed method will be useful for determining the optimal sampling strategies. The anisotropy axis is measured interactively from the variogram surface and therefore its length determines the maximum lag of spatial dependence. Beyond this distance variables are not correlated any more and further sampling will not improve the final estimate (Atkinson, Harrison 1993).

The interpolation methods such as kriging consider a limited number of nearby conditioning data for CPU and memory requirements. For example doubling the number of data in the neighborhood of point or block being estimated leads to an eight fold increase in CPU time (Deutsch, Journel 1992). The proposed anisotropy analysis suggests a quick way to determine the maximum spatial continuity along the axis of anisotropy in the studied area, which in return helps to determine the radius of search window for selecting the set of neighboring sample points or blocks required for optimal weighted interpolation.

Earth related variables that are observed and studied for natural resource management and for environmental purposes often create spatial patterns that can be mode-

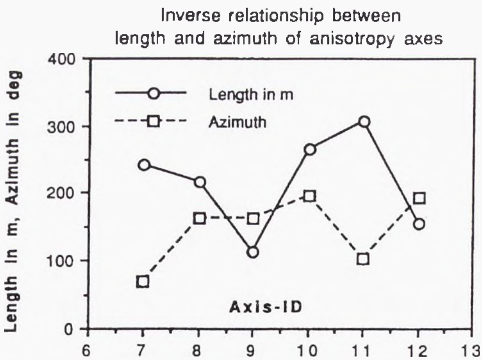

Fig. 8. Relationship between the length of anisotropy axis and their directions.

led by proper geostatistical functions. The goal of spatial analysis is to predict the behavior of spatial variables in locations for which no data exist. The analysis of spatial anisotropy provides scientists with valuable information about spatial correlation. In this paper, the spatial anisotropy is not only determined through GIS but the direction of anisotropy is calculated and the index of anisotropy is determined. The axis of anisotropy are also calculated and the profile of spatial structures is graphically displayed without leaving GIS environment.

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URČENIE PRIESTOROVEJ ANIZOTROPIE POMOCOU GEOGRAFICKÉHO INFORMAČNÉHO SYSTÉMU

Anizotropia je jedným z dôležitých parametrov priestorovej štruktúry študovaných javov. Geografické javy, ako aj ostatné javy krajinnej sféry sa vyznačujú značným stupňom autokorelácie, ktorá sa môže vyjadriť pomocou geoštatistických modelov. Variogram je kvantitatívny model priestorovej autokorelácie a priestorové zobrazenie variogramu je anizotropická elipsa alebo izotropický kruh. Anizotropia vyjadruje stupeň autokorelačného vzťahu daného javu v študovanom území a zároveň aj jeho orientáciu v priestore. Autokorelačná závislosť v prírode vyznieva pomalšie pozdĺž dlhšej osi anizotropickej elipsy a rýchlejšie pozdĺž kratšej osi tejto elipsy, ktorá ju pretína v pravom uhle. Praktický význam anizotropie, resp. izotropie je v určení rozsahu autokorelačného trendu skúmaného javu. Napríklad, rozsah a orientácia nerastných surovín v danom území, determinácia rozsahu znečistenia podzemných vôd škodlivinami a ich celkový trend šírenia v priestore, alebo štúdium priestorového správania sa hmyzu v lesnom prostredí a pod. Vzhľadom na to, že cena štatistických dát sústavne narastá, štúdium anizotropie umožňuje určiť minimálny počet sond v danom priestore pri zachovaní dostatočnej hustoty sondovania geografického javu. Predložená práca odhaľuje a meria anizotropiu, resp. izotropiu pomocou geografického informačného systému (GIS). Implementácia GIS do vedeckého výskumu je novšieho dáta a prináša rozporné stanoviská. Na jednej strane je úloha GIS vo vedeckých prácach plne podporovaná, na druhej strane kritika chápe GIS len ako technologický nástroj s grafickými funkciami. Domnievame sa, že je potrebné pokračovať aj naďalej v hľadaní ciest, ktoré plne využijú moderné technické prostriedky vo vedeckom výskume. Určovanie anizotropie pomocou GIS je pokusom ako prepojiť modernú technológiu a vedecký výskum s praktickým zameraním.