**Computer Technology of Determination of AREA of Submerged Territory
According to Digital Elevation Model**

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KEY WORDS: DEM, Accuracy, Floods, Tecniques.

ABSTRACT

The purpose of our research was to ascertain a relation between the accuracy of relief form recovery and the sampling interval of created DEM. Two aspects of the problem of studying the accuracy of relief recovery were selected: the construction of regular DEM and the recovery of contour lines using created DEM. As a result of our experimental works, we received the standard deviations of marks of DEM created by cartometric methods in relation to test grid based on the map. The estimation of constructed contour lines was performed by the visual comparison of the given map of contour lines to the map built on DEM.

1. INTRODUCTION

A terrain relief is one of the main elements for solving the whole series of the engineering works. Planning related to construction of roads, motorways, reservoirs, reclamation systems, water supplies and so on is performed on the basis of information on the terrestrial relief. There is growing amount of works in which the final goal is data acquisition for shift and erosion processes. Determination of area of submerged and flooded territories belongs to the separate group of works.

We have developed the computer technology of determination of area of submerged territory based on a digital elevation model.

2. TECHNOLOGY OF DETERMINATION OF SUBMERGED AREA

On the basis of DEM creation is output information obtained by the cartometric method based on the scanning a map, although other methods of obtaining information can be used.
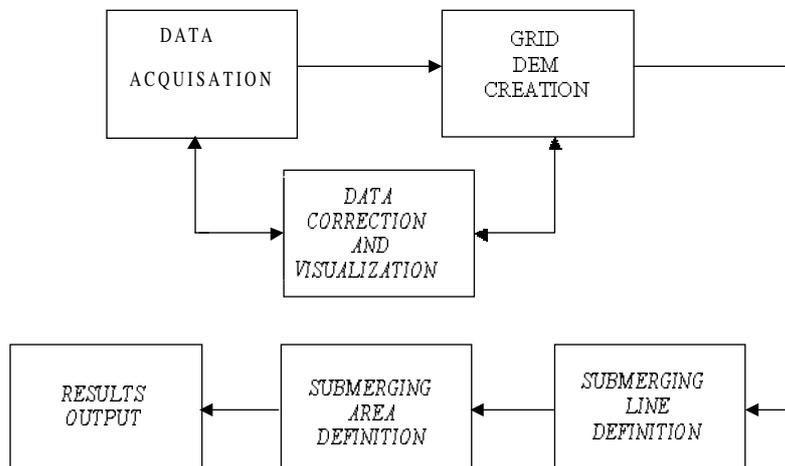

Figure 1. Flowchart of technology of determination of submerged area

The technology includes the next basic processes: digitalization of a cartographic material; building a regular model of the elevation; determination of line of submerged; representation of the results. The plot of general technological scheme is shown in Figure 1.

Basing on the performed analyses of the different methods of output data collection for relief it has been established that stream digitizing or scanning contour data from map in combination with point data is the most preferable.

From previous research it has been found that Kriging's method using the search for the nearest points in quadrants has several advantages in comparison with other methods of approximation such as weighted average, polynomial or multiquadric.

The accuracy of the area determination depends on the accuracy of finding the submerging line in turn this accuracy impacts the choice of sampling interval determination for regular DEM creation.

3. DETERMINATION OF OPTIMAL SAMPLING INTERVAL USING SPECTRAL ANALYSIS

According to Shannon sampling theorem (Pavlidis,1982) any continuous band limited function defined on the interval [a,b] can be restored from a set of sampled values. The accuracy of recovered form of the relief depends on the sampling interval.
Optimization of choosing interval can be carried out basing on correlation and spectral analyses of the relief. Assuming that the relief is a random function and after eliminating trend the statistical characteristics of the function is described by a correlation function.

The degree of dependency between oscillations of relief impacts a number of points that define the sampled function. If dependency increases the number of the points can be decreased and vice versa.

A spectral density serves for description of the frequency structure. The principal relations of spectral theory are given in

$$K(\tau) = 2\int_0^\infty S(w)\cos\tau w\, dw, \tag{1}$$

$$S(w) = \frac{1}{\pi}\int_0^\infty K(\tau)\cos w\tau\, d\tau, \tag{2}$$

where $K(\tau)$ is the autocorrelation function; $S(w)$ is the function of spectral density, w is round frequency.

The function $K(\tau)$ and $S(w)$ form Fourier transform pair. Using the sampling theorem terrain relief can be represented with required accuracy in the case when picket points will be located through interval

$$\tau_0 = \frac{1}{2f_c}, \tag{3}$$

where f_c is boundary frequency; $\frac{1}{2f_c}$ is the shortest period in realization.

The boundary frequency f_c is related to the boundary round frequency w_c by relation

$$w_c = 2\pi f_d, \tag{4}$$

then optimal interval

$$\tau_0 = \frac{\pi}{w_c} \, .$$

(5)

While studying problem the relief recovery we use the fact that little oscillation of relief corresponds to the high-frequency of its Fourier transform, so the limit little value of the amplitude error can be given and the value of amplitude of spectrum S_c can be defined:

$$S_c = \Delta N \tau,$$

(6)

where Δ - permissible small amplitude error; N – number of points; τ – interval between points.

We define boundary frequency w_c by given permissible value of spectrum and optimal sampling interval by the expression (5).

4. EXPERIMENTS AND RESULTS

Some experimental works of selection of optimal sampling interval using the spectral theory and determination of the area of submerged territory are presented in this section in order to evaluate the potential of suggested technology.

Therefore we chose 3 test areas on the maps. The characteristics of test areas and accuracy of regular DEM creation are given in the Table 1.

Average standard deviation of DEM point determination is produced from the differences between grid interpolated on the map and calculated DEM.

Input data for DEM creation is generated by scanning contour data with 1-mm map spacing. Information about characteristic points of relief and additional points at the flat area of map is recorded in the individual file. Regular DEM is created by Kriging method using Surfer program.

№№ Test area	Map scale	Area size, cm×cm	Cross section, m	Slope in degrees	Spacing between DEM nodes, cm	Number of points for estimation of accuracy	Standard error of DEM creation, m
I	1:2000	16x34	1	0-20	1	544	0,28
II	1:5000	21x33	1	0-30	1	693	0,33
III	1:10000	10x10	2,5	0-12	1	121	0,55

Table 1. Characteristics of test area and the accuracy of DEM creation

Two aspects of the problem of studying the accuracy of relief recovery were selected: the construction of regular DEM and the recovery of contour lines using created DEM.

If a great deal of papers the questions of the regular DEM creation are devoted to the second topic is described less completely. The accuracy of the area determination depends on the accuracy of the plotting contour line.

We define characteristics of accuracy these two cases differently. The average standard deviation of DEM determination is received basing on height differences between the correct DEM and reconstructed DEM.

The accuracy of the contour line creation is easily to estimate by visual comparison of contour line on the scanning map and line created using DEM. On one hand, from grid spacing depends the accuracy of reconstruction of contour lines. On the other hand, it impacts volume of stored information.

To determine optimal sampling interval we calculate discrete value of correlation function from the differences between heights of test grid and heights calculated using DEM and than we define the value of spectral density by Eq. (1). The nature of variogram is related to correlation function so that it is reasonable to use the definition of spectrum, because one's nonnegative.

The techniques of variogram creation are described in Davis (1973). The plot of variogramms and spectrums functions is given in Fig. 2. The value grid spacing is shown in the x - axes and the value semi-dispersion of $\gamma(\tau)$ is marked in the y - axes.

The permissible spectrum of amplitude S_c for area I at $\Delta^2 = 0,01m^2$; $N = 160$; $\tau = 1mm$, it is defined as Ivancov (1972): $S_c = 0.01 \cdot 160 \cdot 1 = 1,6m^2 \cdot mm$. For the given boundary value of spectrum $S = 0,1m^2 \cdot mm$ from graphics (Fig. 2b) the boundary frequency is defined $\dfrac{w_c \Delta t}{2} = \dfrac{\pi}{6}$, that is $w_c = \dfrac{2\pi}{6\Delta t}$. Therefore, the optimal interval τ_0 is equal to:

$$\tau_0 = \frac{\pi}{w_c} = \frac{6\pi\Delta t}{2\pi} = 3\Delta t \text{ and } \tau_0 = 3mm.$$

For area II, it is: $S_c = 0.01 \cdot 210 \cdot 1 = 2,1m^2 \cdot mm$. For the boundary spectrum $S = 0,1m^2 \cdot mm$ (Fig. 2d), we have that
$$w_c = \frac{11\pi}{12}, \quad \tau_0 \approx 0,5mm.$$

For area III, it yields $S_c = 0.09 \cdot 110 \cdot 1 = 9,9m^2 \cdot mm$. For the boundary spectrum $S = 0,1m^2 \cdot mm$ (Fig. 2f), we have that
$$w_c = \frac{\pi}{6}, \quad \tau_0 = 3mm.$$

The most complex form of the relief is site of the map of 1:2000-scale (area I), it consists of parts with quiet slope ($\alpha < 5^o$), steep slope crossing by gullies ($\alpha > 10^o$) and flat parts near the river bed with the quite remarkable form of microrelief ($\alpha < 1^o$).

The selection of sampling interval, i.e. appropriate size of the grid, defines residual errors of the recovered contour lines.

The windows for area I with test contour line000 (plotted points) and contour line reconstructed by DEM built with sampling intervals 1cm and optimal interval are shown in Fig. 3.

It is observed the considerable deviation test of contour lines from lines created using DEM with sampling interval at 1 cm. (Fig. 3a) so some part of relief form is smoothed. At the flat area, solid contour lines are depicted as closed discontinuous figure. It is noted that an additional data as characteristic points does not allow plotting contour lines with required accuracy.

The sampling interval equal to 3 mm permits to reliably plot contour lines on slopes and on flat areas complex microforms are not exactly recovered (Fig. 3b). Decreasing sampling interval to 1.5mm almost does not change preceeding picture, but somehow enchances contour lines in flat areas with complex microforms.
The given way contour lines of reconstruction by DEM has high requirements for accuracy of plotting contour lines. Selection of the cartographic materials for the DEM creation is related to accuracy of determination of the submerged area that is limited by type of lands: 1) a truck garden, a plough-land; 2) a hayfield, a pasture; 3) a forest, scrubs; 4) a marsh.

For determination of the submerged area three sites of the different forms and sizes on the area I are selected. The determined area is evaluated by test mesh with a mesh size of $1 \times 1 \, mm^2$ each. The received results are given in Table 2.

Area S, ha	S_{mesh}, ha	S_{DEM}, ha	ΔS_{mesh}, ha	ΔS, ha	% from S_{mesh}
I	0,599	0,610	0,004	0,011	1,8
II	0,789	0,768	0,004	0,021	2,7
III	0,100	0,085	0,002	0,015	15,0

Table 2. The accuracy of determination of the submerged area

It is worse to determine small size areas with the stretched forms of the contour lines.

On the output of system is received: regular DEM, graphic image of relief as contour lines with plotted submerging lines, quantitative values of submerged area.

5. CONCLUSIONS
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The performed experiments give the possibility to make conclusion about the expediency of the usage of the given technology of determination of the area of the submerged territory based on DEM.

The main cartographic materials for the determination of submerged area in inhabited sites can be recommended 1:1000 – 1:2000-scales topographic plans with cross section equal to 0.5-1m. For especially precise works it can be 1:500-scale plans with cross section equal to 0.25 m.

REFERENCES

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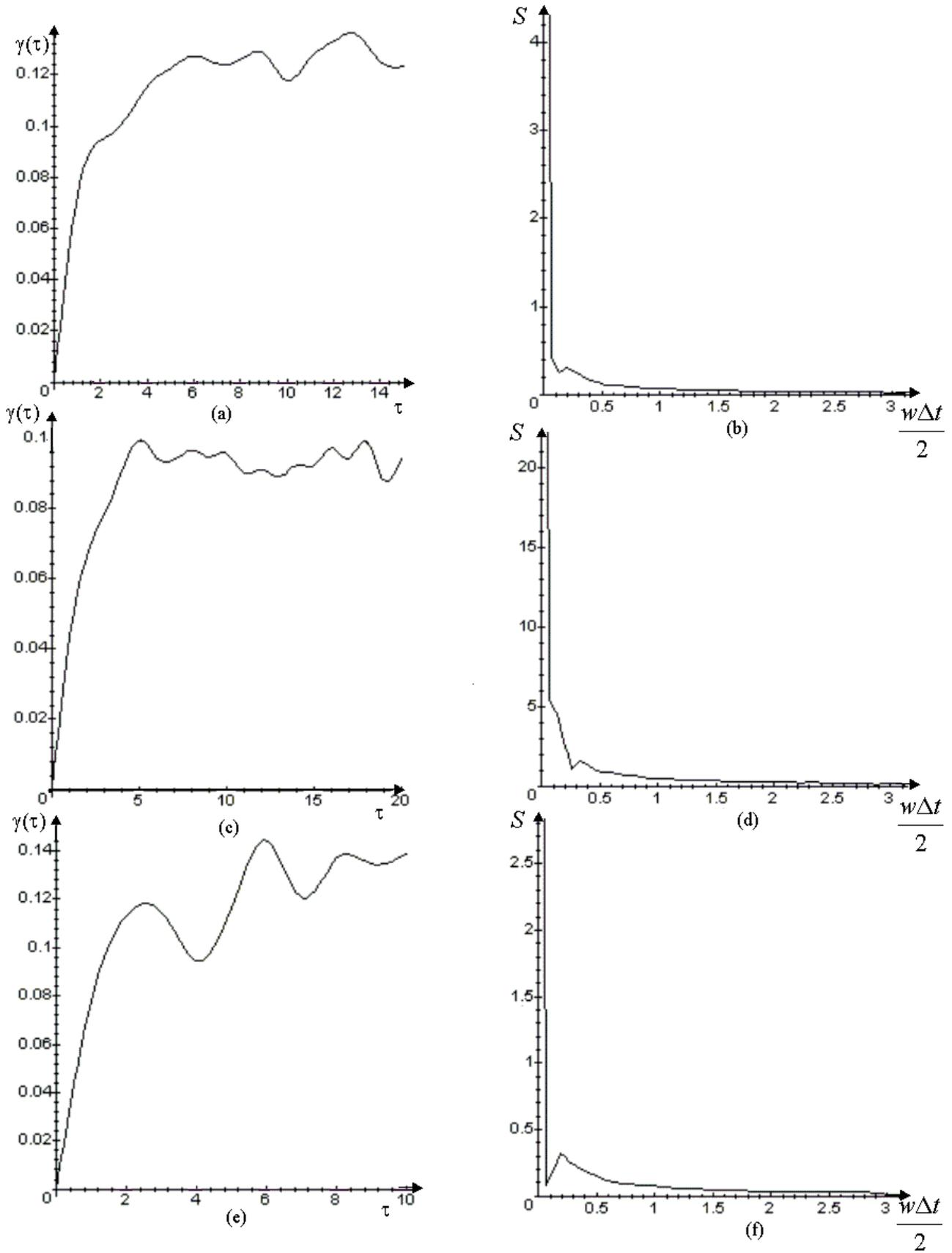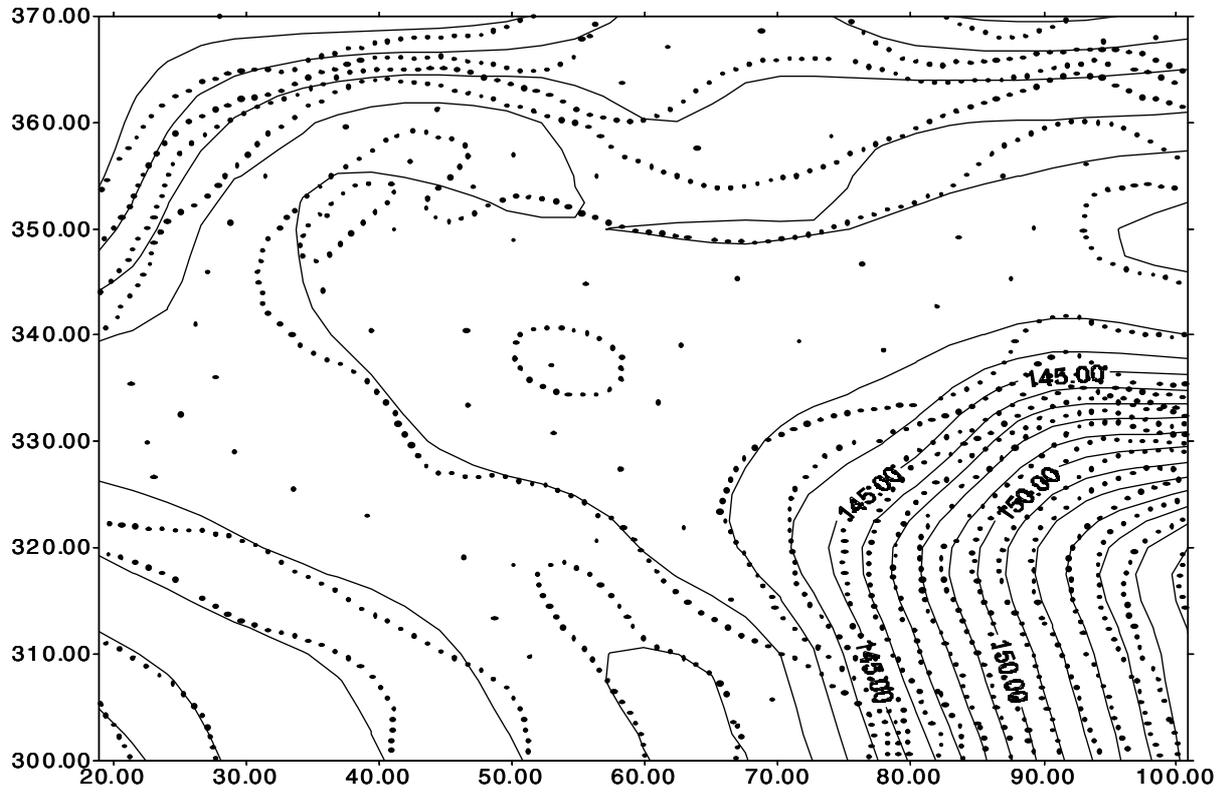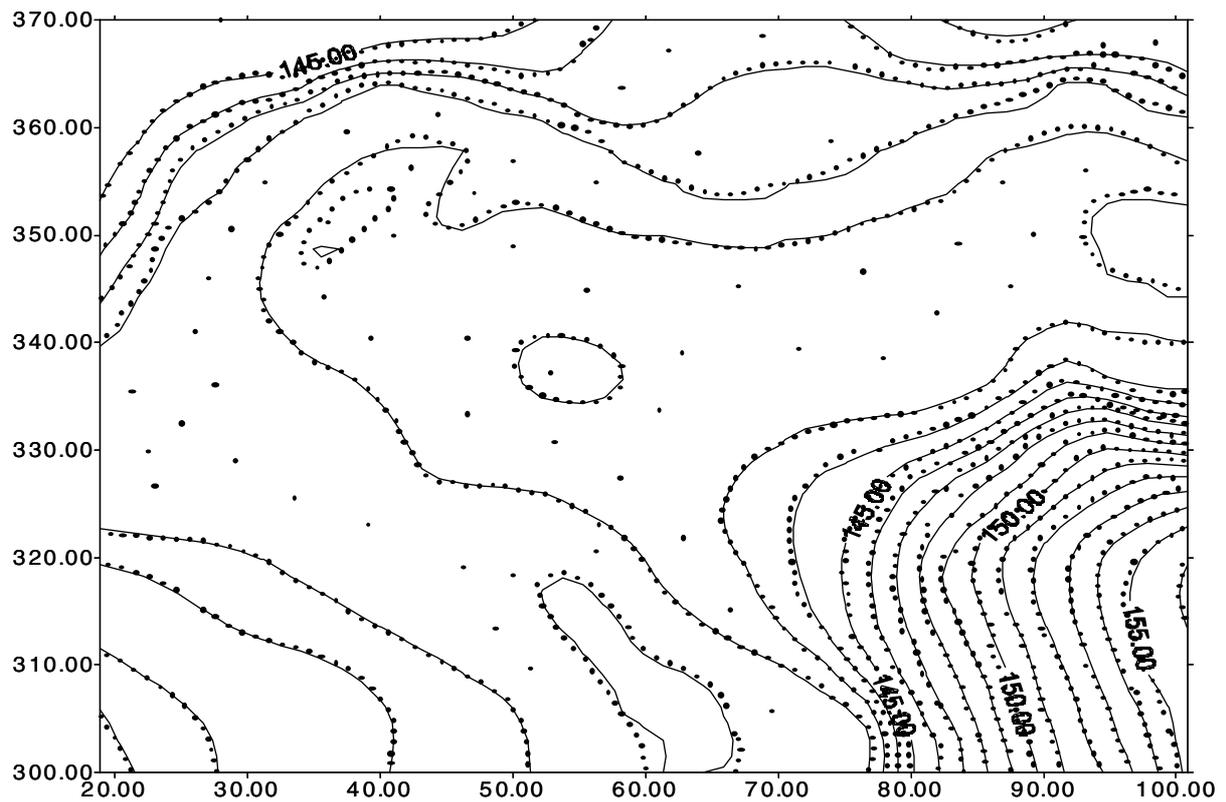Ivancov A., 1972. Osnovy teoriy tochnosty izmerytelnykh ustrojstv. M., Izdatelstvo standartov.

Figure 2. The graphics of variogram and their spectrum.

(a)

(b)

Figure 3. Comparison of characteristics of the test contour lines in relation to the recovery contour lines built on DEM with sampling intervals: a) 1 cm; b) 3mm