Using of GIS technology for avalanche hazard mapping, scale 1:10 000

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ABSTRACT. The sites with the size of $50 \cdot 50$ m^2 having a various probability of avalanche formation were revealed for a given territory covering an area of $3 \cdot 4$ km^2. Cross-classification of sites considering their slopes and snow cover thickness was applied. Absolute altitude of a site, it's orientation to a prevailing wind direction and measure of terrain curvature were taking into account in computation of snow thickness. The Windows applications GIS Idrisi and mapping system Surfer were jointly used for the analysis of maps.

INTRODUCTION

A custom of designing company has served as the motivation of a work: to reveal the places for installation of constructions for avalanche protection of a building site. The site is situated on a slope of Cumbel Mountain 80 km far from Tashkent City. A construction of hotel is planned here. Following data were available as an initial ones: 1:10000 map of a region with 10-m contours; the data of meteorological observations at the point on the top of Cumbel Mountain and the results of snow surveys carried out on 1985-86 winter season by glaciologists from Tashkent and Moscow and generalized by M.I.Getker and T.E.Ivanovskaya.

We decided to consider the task wider: to estimate how fortunate was a choice of the site. It should be correspond to the four demands:

- to have the size not less than 10 hectares;
- to consist from elementary sites having a slope less than 10°;
- to be situated within 1-km band around an automobile road;
- to have the minimum area, requiring an installation of anti-avalanche constructions.

RELIEF DIGITIZING

With the help of a scanner the image of a map in PCX format was obtained. Contours' digitizing was carried out by the utility «Digitize» of package Surfer [1]; coordinates of 5030 points were obtained. For elimination of distortions, causing by the scanning, a 500-m grid was previously drawn on a map. We'll not describe the order of corrective action and conversion from a system of coordinates of a PCX-file to the world one, however, we'll note, that such way of coordinates getting seams to be less labor consuming, than by digitizer. «Radial Basis Function» method of Surfer with default parameters was used for interpolation of altitudes of points to the nodes of a 50-m regular grid. By this way a rectangular matrix of altitudes of a territory, so-called digital terrain model (DTM), was constructed. The coordinates of the building site and automobile road were determined from the same map.

MAPPING OF SNOW THICKNESS

Repeated snowsurveys were carried out on the slope of a Cumbel Mountain on winter season of 1985-86. They have shown that the locations of lowered and increased accumulation of snow do not vary during the winter. There are some bases to believe that it is also true from year to year. Thus, having a map of a snow thickness on any moment within the winter, it would be possible to talk about the places with an increased accumulation of snow, which is of main interest for us. Unfortunately it turned to be not possible to link the points of measurements with the available map. It means, that we'll not be able to reveal some simple regression model and apply it for producing of the map of snow thickness. It was decided to use another way.

There are three well known phenomenon concerning spatial distribution of a snow in the winter at the mountains: a) snow thickness grows under increasing of terrain altitude; b) the snow is drifted out from upwind slopes and accumulates at downwind ones and c) especially intensively the snow accumulates within a negative forms of relief. As soon as DTM is available, it is possible to try to evaluate the last two factors by some numerical indexes (below we'll name them as indexes of an orientation and curvature of a surface, accordingly).

We'll assume that the points of mentioned snow surveys reasonably well reflect the distribution of snow thickness over a whole territory. Then by linking the snow thickness in the nodes of our grid with the three listed factors by some equation, we'll try to estimate the parameters of this equation so that to achieve the best coincidence of an empirical and designed curves of cumulative frequency of snow thickness. We'll use an obtained equation for a mapping of snow thickness.

An elementary site having the size of 50 on 50 m we'll call below as a point. Such simulation was used to calculate the snow thickness at a point (h_S):

$$h = \sigma_h(\alpha_Z \tilde{Z} + \alpha_W W + \alpha_C \tilde{C}) + \bar{h}$$

$$h_S = \begin{cases} h, \ for\ h > 0 \\ 0, \quad h \le 0 \end{cases} \qquad (1)$$

where: $\bar{h}$ and σ_h are an average and standard deviation of snow thickness on some date, accordingly; Z is an altitude; W and C are an indexes of orientation and curvature of a surface, accordingly; α_Z, a_W and a_C are parameters, which we are going to find. The symbol «~» over variable means it's standardization. The computations were done for snow survey on 28.02.1986, for which $\bar{h}$ was equal to 52, and σ_h to 31 centimeters.

The first derivative of terrain altitude alongside a direction of prevailing wind is accepted as an index of orientation (W). It reflects the inclination of a surface along a specified direction. In case of ascend - upwind slopes - this value is a positive one, in case of descent it is a negative value. The Surfer's utility «Grid - Calculus - Directional Derivative» with the options «First Derivative, Angle = 77^{O}» is applied for computations. The angle was set to 77^{O} because of following reason. Calculation of a resulting vector of wind velocity, based on the meteorological observations on the top of Cumbel Mountain for a winter period of 1986-1987, has shown that vector has an azimuth of 193^{O}. In the applied Surfer's utility an angle is measured counterclockwise from the positive direction of an axis of abscise, thus for the azimuth of 193 an angle should be set equal to 77 degrees.

By specifying our DTM as an input file for Surfer's module «Grid - Calculus - Terrain Modeling - Plan Curvature» we got a rate of change of an aspect in the plan for the grid nodes. In our case this value is the index that water flows to a given point - convergence, or water flows out - divergence. Positive meanings correspond to convergence, negative ones - to divergence. By such way an index of surface curvature was derived.

A relief of studied area and the other above listed variables are shown on Fig. 1 a, b and c. The values of various cumulative frequency for them are given in Table 1.

Table 1

The statistics of snow thickness and arguments of equation (1)

Element	Measured values				Standardized		
	5%	50%	95%	σ	5%	95%	Δ
h_S	115	40	0	31	2.03	-1.67	3.70
Z	2169	1693	1439	216	2.05	-1.33	3.38
W	0.32	-0.09	-0.49	0.25			0.81
C	0.022	0.000	-0.021	0.018	1.22	-1.67	2.89

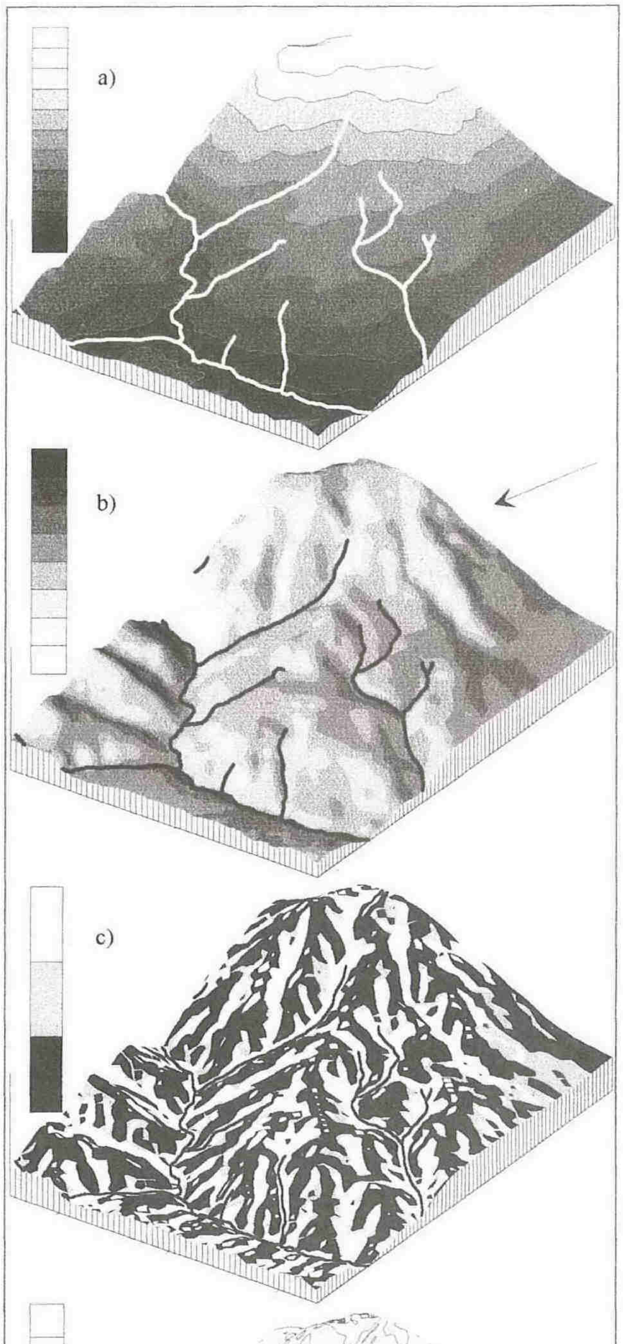

Fig. 1. A relief of a territory (a), distribution of an indexes of orientation to the wind (b) and curvature (c); computed distribution of snow thickness (d).
Arrow shows prevailing wind direction.

The values having cumulative frequency (exceedence) of 5, 10, 15 ... 90, 95% - total 19 values - were accepted as the points fitting probability curve of snow thickness. A criteria (φ) the minimum of which were searched during parameters calibration was calculated as follows:

$$\varphi = \sqrt{\frac{\sum_{i=1}^{19} (hm_i - hc_i)^2}{19}}$$

where: hm and hc are measured and computed snow thickness of various cumulative frequencies.

The initial and final values of parameters and criteria, as well as the restrictions to parameters are indicated in Table 2.

Table 2

Initial and final values of parameters of equation (1)

Parameter	Restriction	Initial	Final
α_Z	>0	1	0.851
α_W	<0	-1	-0.448
α_C	>0	1	0.481
φ, *cm*		26.5	4.7

For validation of parameters an algorithm of Nielder-Mild [2] was used. A great amount of calculations was done. The matrix of DTM has the size of 77 on 57 elements. It means, in particular, that one of the steps for each iteration was sorting of 4389 values of snow thickness. Comparison of cumulative frequency curves based on measured and computed values is given on Fig. 2.

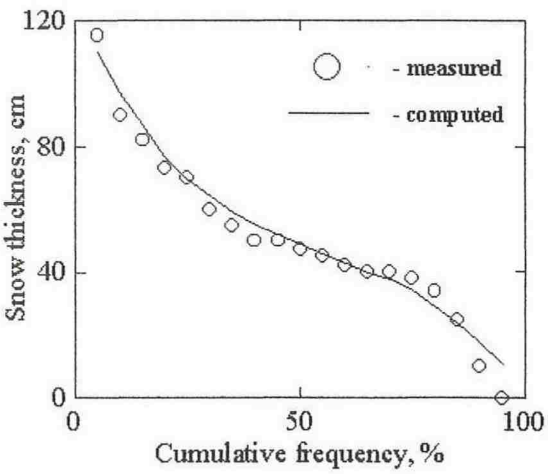

Fig. 2. The cumulative frequency (exceedence) curve of snow thickness.

So the circuit (1) got a shape:

$$h = 31(0.851\tilde{Z} - 0.448W + 0.481\tilde{C}) + 52$$

$$h_S = \begin{cases} h, for\, h > 0 \\ 0, for\, h \le 0 \end{cases}$$

Computed snow thickness is shown on Fig.1d.

In order of significance decreasing an arguments range so: altitude of terrain, index of surface curvature and index of orientation to the wind. For example, the difference of absolute altitudes having cumulative frequency of 5 and 95% results the change of snow thickness equals to 89 cm, for indexes of curvature and orientation the appropriate parameter is equal to 43 and 11 cm, accordingly.

MAP OF PROBABILITY OF AVALANCHE FORMATION

It was decided to consider slope as the second factor that determines a site as a dangerous one from the point of view of avalanche formation. The angles of inclination of a surface for grid nodes were derived by the utility «Grid - Calculus - Terrain Modeling - Terrain Slope». The DTM was specified as an input file; an output file was named as "Slope.Grd". The classification of sites was done with the help of GIS Idrisi [3] modules. The sequence of actions in terms of IDRISI macro commands (numbering of commands is given only for convenience of the comments) is as follows:

1. SrfIdris x 1 Snow Snow
2. SrfIdris x 1 Slope Slope
3. Reclass X "i" Snow SnowClas 2 1 0 21 2 21 83 3 83 295
4. -9999
5. Reclass X "i" Slope SlopClas 2 1 0 15 2 15 25 3 25 45 -9999
6. CrossTab x SnowClas SlopClas 1 Cross
7. Assign x Cross Danger Assign

The first two commands import matrixes of snow thickness and terrain slope from Surfer's Grid-files to the Image-files of Idrisi. The third command due to snow thickness clusters points to one of three classes. The borders of classes are 0 - 21 cm, 21 - 83 and 83 - 295 cm. For the second class the limits were defined as $\bar{h} \mp \sigma_h$. The fourth command clusters points against the slope to one of three classes with the borders 0 - 15°, 15 - 25 and 25 - 45° (the limits are proposed by experienced avalanche hunter G.N.Starygin). Command number 5 produces cross-classification by two considered attributes. As soon as each factor is divided into three classes, the resulting classification has 9 classes. And, at last, command number 6 assigns to each of 9 classes some rate, describing in our opinion a probability of avalanche formation at the site. An attribute value file named "Assign" serves for assignment of rates in respect to the following table:

Snow thickness, cm →		0-21	21-83	83-295
↓ Slope, °	Classes	1	2	3
0-15	1	1/0	2/0	3/0
15-25	2	4/0	5/0	6/1
25-45	3	7/0	8/1	9/2

A new value is shown as a denominator in the table. Qualitatively it is possible to characterize it like this: 0 - the avalanches don't form, 1 - formation of avalanches is possible, 2 - the probability of avalanche formation is high. The slopes and a map of degree of avalanche danger (in above described context) are shown on Fig. 3.

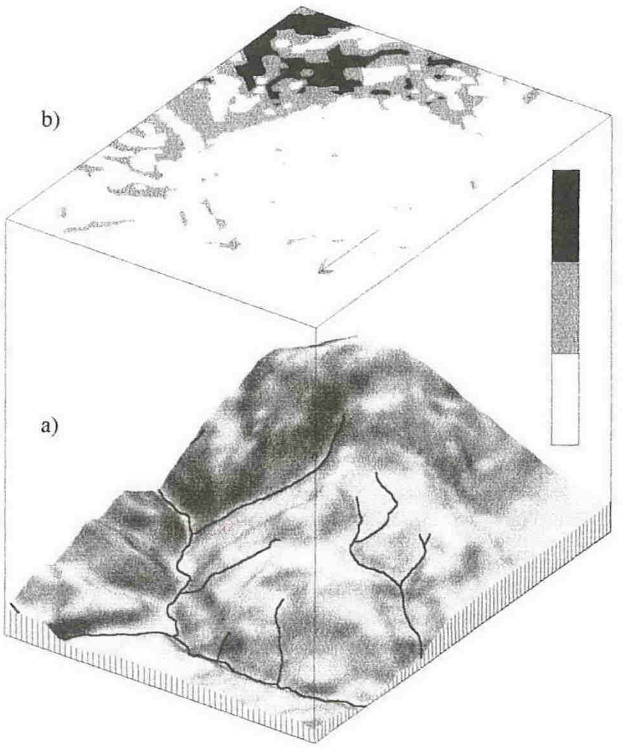

Fig. 3. The slopes (a) and a map of avalanche hazard (b)

Let's note that in case of availability of data on distribution of roughness of a surface, there is a possibility to assign classes of snow thickness more reasonably.

ESTIMATION OF A LUCK OF BUILDING SITE CHOICE

Following group of Idrisi macroinstructions shows how this problem was solved:

1. Reclass X "i" Slope Sites 2 1 0 10 0 10 45 -9999
2. Initial X Empty 1 1 0 1 Slope
3. XYZIdris X HighWay.Dat HighWay plane m 1.0
4. Convert X HighWay HighWay v 1 2 1
5. PointRas X HighWay Empty 1
6. Distance X Empty Distance
7. Reclass X "i" Distance DistSuit 2 1 0 1000 0 1000 35000 -9999
8. Overlay x 3 Sites DistSuit SlopSuit
9. Group X SlopSuit Y SlopGrup
10. Area x SlopGrup 1 2 SlopArea
11. Reclass x i SlopArea SlopSuit 2 0 0 10 1 10 100 0 100 1000 -9999

The first command masks all elementary sites with an angle of inclination more than 10^{O}. Commands from 2^{nd} to 7^{th} choose points, situated within the 1-km band far from car road. For that objective a matrix consisting from zero members and having the same size, as a matrix of slopes, is created. The module «XYZIdris» imports coordinates of a road into a vector file, and then the former is transformed to a proper format. The command «PointRas» changes values of a zero matrix' components corresponding to road location into nonzero ones. The sixth command computes the distance between each point and the road, and, at last the module «Reclass» masks all points outside the 1000-m strip. Elementary flat sites, located in the given band, are revealed with the help of logic operation «AND» by 8^{th} command. The compact groups of sites are defined, their areas are calculated and those of sites that have the area less than 10 hectares are masked.

Three areas appeared to be the suitable ones for construction are shown on Fig. 4 by gray filled squares.

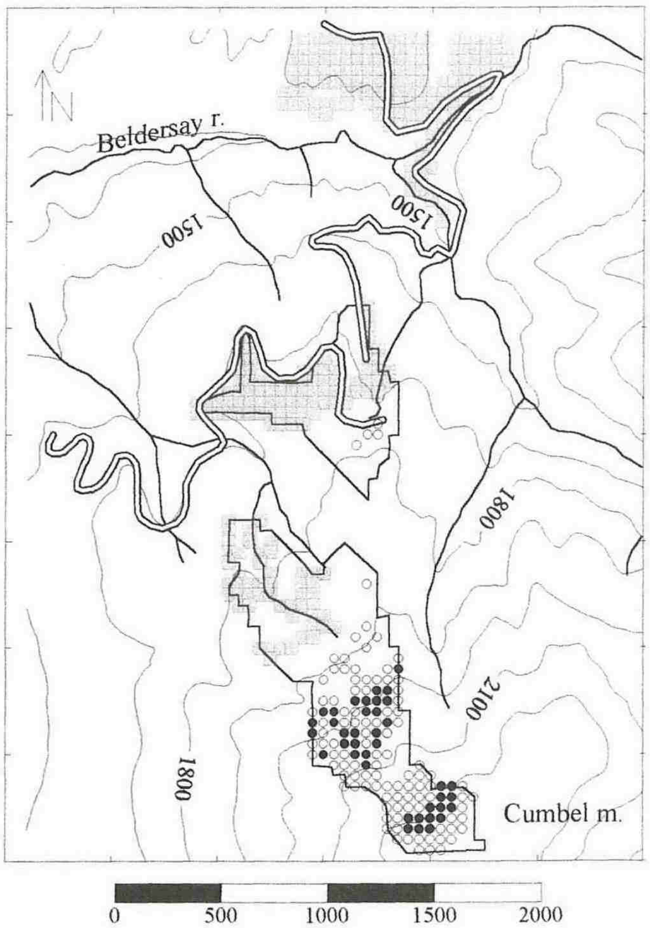

Fig. 4. Comparison of avalanche danger for the sites

As soon as the northern one of areas is engaged recently by other buildings, we have excluded it from the further analysis. So it is necessary to find out to which of former two an avalanches threaten in a greater degree. This problem was also solved with the help of GIS Idrisi:

1. SrfIdris x 1 Aspect Aspect
2. WatrShed x Aspect SlopSuit 90 Ovens
3. Overlay x 3 Danger Ovens DangOven

The module «SrfIdris» imports an aspects of sites, computed by Surfer, and the module «WatrShed» defines the sizes of watersheds (here - an avalanche ovens) acting onto the each of the suitable area. Then with the help of logic «AND» the dangerous sites belonging to the ovens are revealed. The circles indicate them on Fig. 4; filled circle marks an elementary site with the high probability of avalanche formation.

As one can see, there are 138 dangerous sites in a watershed of southern area, and for 39 of them the probability of avalanche formation is high. The central area is safer, - within the limits of its valley there are only 4 potentially dangerous sites. Just for it we were asked to reveal the locations for installation of anti-avalanche constructions. As current work shows the area was rather successfully chosen.

RELIABILITY OF RESULTS

An author understands that the most risky assumptions were done during mapping of snow thickness. It concerns to a shape of relation (1) and, especially to the using of adjustment of frequency curve for the calibration of parameters of equation. It is also possible to discuss about assigning of borders for classes of snow thickness and slope. Therefore an author proposes to consider current work as the possible approach for estimation of avalanche danger at the briefly studied territory. It must be confirmed by the field investigation.

At the same time the obtained distribution of the snow looks to be the most interesting result. The following testifies to its advantage. As it is evident from equation (1), the change of snow thickness caused by 100 m of difference in absolute altitudes can be calculated from the follows:

$$\gamma_h = 100\frac{\sigma_h \alpha_Z}{\sigma_Z}$$

Replacement by numerical values results 12 cm that well corresponds to the gradient measured in the region one equals to 10 cm per 100 m (oral message of A.A.Isaev). Let's return to Fig. 4. On place checking on February 1997 has confirmed presence of avalanche danger at two sites located just above the road. The traces of small-sized avalanches were discovered. Two other sites have appeared too densely covered by the forest; the formation of avalanches at them seems to be improbable.

CONCLUSIONS

- application of GIS-technology permits newly suit to the avalanche danger zoning;
- the information on roughness of a surface and density of the forest is extremely required ones for mapping of avalanche danger. Let's mark an opportunity to associate these parameters. For example the site covered by a dense forest, could be considered as a place with a very high roughness;
- the studies linking the statistics of snow thickness with some numerical characteristics of relief, for example, measure of its irregularity, could be of great interest in the avalanche hazard zoning.

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