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Determination of karst collapse intensity indicator in area of nuclear power plant construction using incomplete data

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Abstract. The paper deals with the definition of karst collapse intensity. The technique for determining the intensity of karst formation and collapse on the basis of calculation and probabilistic method is given. Karst collapse formation is affected by a great variety of natural and anthropogenic factors. Each factor can vary quite widely. The paper describes a technique for determining karst collapse intensity from incomplete data. It uses karst processes monitoring data in the area and monitoring data of areas with similar values of the most significant factors leading to the karst collapses. The method used for determination of karst collapse intensity indicator in area of Nizhny Novgorod nuclear power plant construction.

1. Introduction

Karst-suffusion processes are treated to a number of dangerous geological processes of natural or technogenic origin. They occupy large territories. Exclude such territories from the development and use is not possible. Therefore actual problems are karst processes observing and the assessment of karst hazard of territory and reducing to a minimum the risk of accidents on the newly constructed buildings and structures, caused by the development of karst processes [1, 2].

In observing the karst processes actively used various indicators studied manifestations of exogenous processes. One is karst collapse intensity indicator. It belongs to a group of quantitative indicators of karst processes [3].

Karst collapse intensity indicator describes the average annual number of karst forms on the 1 km^2. It is measured in units/m^2·year [1]:

$$\lambda = \frac{n}{S \cdot t},$$

where n – number of karst forms, S – space of area (m^2), t – the number of observation years (year).

Karst collapse intensity indicator can be easily determined for the areas which are carried out systematic observations of karst processes. Unfortunately, in actual practice often we have to deal with incomplete data obtained during periodic observations of small areas of the territories. Sufficiently accurate information on karst collapses there are for well-established areas. For underdeveloped areas such information may be missing. Thus, there are some difficulties with the definition of karst collapse intensity indicator to territories with slightly studied areas.

Purpose of paper is determinate of karst collapse intensity indicator using incomplete data.

2. Method for determination of karst collapse intensity indicator using incomplete data

The formation of karst collapses affects a large variety of natural and anthropogenic factors. Despite the fact that each area is exposed to a set of factors, it is possible to find small areas, characterized by the same values of the major influencing factors. This can be used to assess the karst hazard of area. In [4] proposed a method for determination of karst collapse intensity indicator, depending on the combination of the values of natural factors. It is shown that the distribution of mutually independent karst collapses in a territory for a certain period of time subject to the Poisson distribution. Karst collapse intensity indicator corresponds to the expected value of karst collapses number in the study area for some time.

Suppose that the flow of karst processes affect n factors weakly dependent on each other. Then:

$$\lambda = \sigma^2 = \sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2 + \sigma_{rem}^2, \tag{1}$$

where σ^2 – the variance of karst collapse intensity indicator, σ_1^2, σ_2^2, …, σ_n^2 – variances, caused by the n factors, σ_{rem}^2 – the remain variance.

In the case study areas of the territory with the same sign of some factor we can form the expressions:

$$\begin{aligned} \lambda_{11} &= \sigma_{11}^2 = \sigma_{2-11}^2 + \sigma_{3-11}^2 + \ldots + \sigma_{n-11}^2 + \sigma_{rem-11}^2 \\ \lambda_{12} &= \sigma_{12}^2 = \sigma_{2-12}^2 + \sigma_{3-12}^2 + \ldots + \sigma_{n-12}^2 + \sigma_{rem-12}^2 \\ &\cdots \\ \lambda_{ij} &= \sigma_{ij}^2 = \sigma_{1-ij}^2 + \sigma_{2-ij}^2 + \ldots + \sigma_{n-ij}^2 + \sigma_{rem-ij}^2 \\ \lambda_{nk} &= \sigma_{nk}^2 = \sigma_{1-nk}^2 + \sigma_{2-nk}^2 + \ldots + \sigma_{n-1-nk}^2 + \sigma_{rem-nk}^2 \end{aligned} \tag{2}$$

where λ_{11} – expected value of karst collapse intensity indicator on the territory with sign 1 of the factor 1, σ_{11}^2 – variance of karst collapse intensity indicator on the territory with sign 1 of the factor 1, λ_{ij} – expected value of karst collapse intensity indicator on the territory with sign j of the factor *i*, σ_{ij}^2 – variance of karst collapse intensity indicator on the territory with sign *j* of the factor *i*, σ_{1-ij}^2 – variance caused by the variability signs of factor 1 in the area with sign *j* of the factor *i*, σ_{rem-ij}^2 – remain variance in the area with sign *j* of the factor *i*.

The values of the residual variance can be represented by expressions:

$$\begin{aligned} \sigma_{rem-11}^2 &= \sum_{h=1}^{n} \overline{\sigma}_{h-11}^2 + \sigma_{oth.11}^2, \\ \sigma_{rem-12}^2 &= \sum_{h=1}^{n} \overline{\sigma}_{h-12}^2 + \sigma_{oth.12}^2, \\ &\cdots \\ \sigma_{rem-ij}^2 &= \sum_{h=1}^{n} \overline{\sigma}_{h-ij}^2 + \sigma_{oth.ij}^2, \end{aligned} \tag{3}$$

where $\overline{\sigma}_{h-ij}^2$ – the average variance value that occurs due to variability signs values of factor *h* inside these sign *j* of the factor *i*, $\sigma_{oth.ij}^2$ – variance caused by other unaccounted factors.

Various factors have different effects on the formation of karst collapses. Therefore, we can choose *n* most significant factors. Effect of other factors can be shared equally among the first terms of (3). Then the expression takes the form:

$$\sigma^2_{oth-ij} = \sum_{h=1}^{n} \overline{\sigma^*}^2_{h-ij} \quad (4)$$

Suppose that A_{ij} – the area of distribution of sign *j* of the factor *i*, A_{hg-ij} – area of the sharing distribution of sign *g* of factor *h* and the sign *j* of factor *i*. Then

$$\sum_{g=1}^{k_h} A_{hg-ij} = A_{ij} ,$$

where k_h – signs count of factor *h*.

The average variance has the form:

$$\overline{\sigma}^2_{hg-ij} = \frac{1}{A^2_{ij}} \sum_{j=1}^{k_i} \sigma^2_{ij} A^2_{hg-ij} \quad (5)$$

Suppose that $A_{hg-ij} / A_{ij} = \alpha_{hg-ij}$, then equation (5) has the form:

$$\overline{\sigma}^2_{hg-ij} = \sum_{j=1}^{k_i} \sigma^2_{ij} \alpha^2_{hg-ij} \quad (6)$$

Then equation (3) can be represented as:

$$\begin{aligned} \sigma^2_{rem-11} &= \sigma^2_{11} + 0 \cdot \sigma^2_{12} + \ldots + \alpha^2_{11-nk} \cdot \sigma^2_{1h} \\ \sigma^2_{rem-12} &= 0 \cdot \sigma^2_{11} + \sigma^2_{12} + \ldots + \alpha^2_{12-nk} \cdot \sigma^2_{1h} \\ &\ldots \\ \sigma^2_{rem-nk} &= \alpha^2_{nk-11} \cdot \sigma^2_{11} + \alpha^2_{nk-12} \cdot \sigma^2_{12} + \ldots + \sigma^2_{1k} \end{aligned} \quad (7)$$

The number of equations is equal to the sum of factors signs count: $k = \sum_{i=1}^{n} k_i$, where k_i – signs count of factor *i*.

The result is a system of k linear equations with k unknowns. Values σ^2_{h-ij} are means of variance analysis [5]. σ^2_{rem-11}, σ^2_{rem-12}, …, σ^2_{rem-nk} calculated from the expression (2):

$$\sigma^2_{rem-ij} = \lambda_{ij} - \sum_{x=1}^{n} \sigma^2_{x-ij} \quad (8)$$

Solving the system of equations (7), we can find expected value of karst collapse intensity indicator λ with a combination of various factors using the property of variance (1)

$$\lambda = \sum_{i,j}^{n} \sigma^2_{ij} . \quad (9)$$

3. Determination of karst collapse intensity indicator in area of nuclear power plant construction

Construction project of Nizhny Novgorod nuclear power plant (NPP) is being developed in area, called "Monakovo". Area is located in the basin of the lower reaches of the Oka River. Right tributary of the Oka River is Bolshaya Kutra. River drains the water alluvial, urzhum, lowerkazan and faithfulcoal deposits. Lowland karst formation is due to the large amount of carbonate and sulfate rocks, which lie near the surface and the presence of low-mineralized water in the alluvial layer. Technogenic increase in groundwater level may lead to a more active karst formation and increase the risk of catastrophic situations at NPP.

Assessment of karst hazard of area NPP construction is difficult. Earlier in the territory not carried out comprehensive monitoring of karst processes. Detailed monitoring carried out in the villages Monakovo and Chud. Some data on karst processes are available in the area of agricultural fields and roads. Information about the karst processes in forest and non-agricultural areas almost missing.

Comprehensive observation of the karst processes development in NPP construction has made only a few years ago. This is not sufficient for accurate determination of karst collapse intensity indicator. Thus, we used method for determination of karst collapse intensity indicator using incomplete data.

Research results showed that in the Nizhny Novgorod NPP construction area there is karst hazard. Part of the territory of construct NPP has manifestation of karst activity. During the construction and exploitation nuclear power plants may be a risk of new karst collapses formation. Therefore it is needed make an additional comprehensive study of the territory Nizhny Novgorod NPP construction area.

4. Summary

Described method can be used to determine the intensity of karst collapse indicator using incomplete data. Using the method on the example Nizhny Novgorod NPP construction area allowed evaluating karst hazard.

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