Considering emergency hazards in construction and operation of infrastructures

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Abstract. The paper presents a forecast on how hazardous exogenous geological processes caused by whether natural or man-caused flooding may affect the condition of infrastructures. The authors propose using an integrated R-score, which is a linear combination of partial criteria R1, R2, R3, R4 of the weighting factor (the weight) k; these criteria are determined by experts as a function of partial indicators or on the basis of foundation cracks and settlement observation data. Reducing the integrated R-score to nearly zero is what indicates a reduction in the emergency hazards by preventive and protective actions. To address this problem is imperative for cities, where the developed areas are non-homogeneous and vary in time and space. Such areas must be run in accordance with the fundamental principle of geological safety and reliability in the context of actual and potential flooding.

1. Introduction

Any existing or under-construction building or structure does interact with the natural environment. This interaction alters the stress state of soils and massifs, disrupts the thermal and hydrological parameters of soils, and affects the hydrogeology. Thus, the problem of forecasting the exogenous geological processes and designing effective measures to combat those is closely connected to the necessity of researching natural and man-caused risks [1].

The Republic of Tatarstan has four types of objects that comprise groups of manifestations of such processes and are adjacent to infrastructures [2,3]:

1. Subsoil areas exposed to hazardous exogenous geological processes within waterbody areas.
2. Subsoil areas exposed to hazardous exogenous geological processes within human settlements.
3. Subsoil areas exposed to hazardous exogenous geological processes due to agriculture.
4. Subsoil areas exposed to hazardous exogenous geological processes due to the development of hydrocarbon deposits [4].

To reduce the likelihood of emergency caused by exogenous geological processes, the Republic of Tatarstan had to:

- examine and assess the impact that exogenous geological processes had had on the developed areas in settlements at risk of being exposed to hazardous exogenous processes, as well as in the city of Kazan;
- inspect the structures of residential buildings registered in the Register of Houses in Potential Landslide Areas;
- use field survey data on the settlements as well as geological archives to assess the activity of the identified exogenous geological process, find the causes behind their progression, produce a short-term expert forecast of hazards, and identify housings to be the first to move from dangerous landslide areas [5].

2. Methods

The developed areas of Kazan are non-homogenous and vary in both space and time; however, the unfavourable geotechnical and hydrological processes in the city have not yet been studied thoroughly [6], meaning that these areas must be run in accordance with the fundamental principle of geological safety and reliability in the context of actual and potential flooding [7]. This principle is based on creating an emergency prevention system for flooding-initiated emergencies. The system must comprise three subsystems for comprehensive monitoring and forecast of hazards; managerial decision-making; engineering activities to control the soil parameters and arrange protective measures[8].

For the city’s developed areas, the most common type of flooding is man-caused / mixed flooding, which may trigger landslides as well as karst processes. This necessitates forecasting the emergency factors and finding ways to predict flooding[9,10].

The condition of an infrastructure in case of flooding can be determined by the integrated R-score, see Figure 1.

![Integrated R-score for an infrastructure](image)

**Figure 1.** R-score of an infrastructure in case of flooding.

The R-score, is a linear combination of four partial criteria (R₁, R₂, R₃, R₄) which have the weights \( k_i \); these criteria are determined by experts as a function of partial indicators or on the basis of foundation cracks and settlement observation data. Figure 2 shows the interface of the special software for computing the R-score of a structure [11].
3. Results

The integrated R-score is computed by the authors-proposed algorithms and software [12,13]. Partial scores $R_i$ must be measured before and after taking preventive and protective action.

Reducing the integrated R-score to nearly zero is what indicates a reduction in the emergency hazards by preventive and protective actions (reinforcing the foundation, reducing the water level, etc.):

- $R_1$ can be reduced by lowering the water level by pumping, drainage, use of water curtains, etc. Near-zero $R_1$ indicates a non-flooded structure (the flooding indicator is found by the authors-developed PUGV software using a special situational model [14]);
- $R_2$ can be reduced by reinforcing the soils and eliminating the foundation settlement; near-zero $R_2$ means there settlement is even, the foundation is not deformed, and the building is not tilted;
- $R_3$ can be reduced by joint actions to reinforce the foundation, renovate the building, and lower the water level; near-zero $R_3$ means there is no visual cracking in the building walls and joints;
• \( R_{4} \) reflects the wear of an infrastructure, reducing which is associated with substantial costs and capital investment; near-zero \( R_{4} \) indicates a good condition of the building, resultant from an overhaul and replacing the worn elements.

Exceeding a certain R-score threshold necessitates protective, water-level lowering, and sundry emergency prevention activities.

\[
R = \sum_{i=1}^{4} k_{i} R_{i} \rightarrow \min
\]

where \( k_{i} \) are the weights; \( R_{i} \) is a structure-specific parameter determined by observations or simulation forecasts based on a situational model: low-hazard \( (0 \leq R_{i} \leq 0.3) \), median-hazard \( (0.3 < R_{i} \leq 0.7) \), high-hazard \( (0.7 < R_{i} \leq 1.0) \).

The weights in the formula (1) are determined by experts in significance for each object of a particular factor. For ease of calculation and visibility of the results, the values of the particular indicators \( R_{i} \) are normalized from zero to one. If the definition of the R-indicator uses data for all \( R_{i} \)-indicators, the weight coefficients in the general case can take the same value equal to 0.25. If there is information on objects only on flooding and on building deterioration, and there are no data on other private indicators, then the corresponding weighting factors are equated to zero, i.e. \( k_{2} = k_{3} = 0 \), then respectively, for example, \( k_{1} = k_{4} = 0.5 \).

The numerical value of the object state indicator \( R = 0.25 \) can be considered as the lower limit for the R-indicator, the excess of which should already be alarming (danger warning). The justification of the numerical value of \( R = 0.25 \) as a critical value of the state indicator is explained by the fact that with equal weight coefficients (normalized in the range [0.1]) and the numerical value of one of the particular indicators equal to 1 (threatening degree), and at the same time, the remaining particular indicators may have, for example, zero values, then the value of the cumulative R-indicator will be equal to \( R = 0.25 \).

4. Conclusions

Analysis of works carried out in Kazan shows that most of the city has geotechnical conditions of average and high complexity. The near-surface deposition of groundwaters causes flooding and waterlogging within the low terraces [15,16]. Ravine plantations are emerging throughout the high terraces and the left bedrock slopes of the Volga River. The dilution or continued condensing of subsoils was precured by the presence of sandy loams and clay loams as well as by various filled soils in combination with the rapid general flooding caused by public utilities; this has resulted in an uneven settlement of buildings and structures. Given the old age of the surveyed houses, the deterioration of the water pipes and sewers, these processes will continue indefinitely in the old town [17].

Therefore, when forecasting the condition of Kazan’s infrastructures, it is necessary to determine which of the R components must be reduced first from the standpoint of economic optimization and historical significance of buildings. This is enabled by creating a situational model that uses the R-score to compute the flooding-triggered emergency hazards in the construction and operation of infrastructures, making a standardized and affordable prevention and monitoring tool [18].

In addition, it should be noted that today even a small number of conducted instrumental observations carry valuable information not only for the ministries and departments responsible for public safety, but also for the local municipal authorities where the observations are being conducted. It is obvious that the number of instrumentally observed areas should be increased [19]. However, municipalities who are most interested in carrying out monitoring work are not able to allocate funds from their observation budget, and republican executive authorities do not include monitoring of exogenous geological processes in the zone of influence of reservoirs into the republican budget. Theory refers to the objects of federal regulation. In order to increase the efficiency of the data
obtained and to more accurately predict the development of exogenous geological processes of various types, it is necessary to increase the number of observation sites in the Republic of Tatarstan [20].

References
[1] Arefyeva E V 2007 Regulation of ground water conditions in case of project and built-up area inundation *Industrial and Civil Engineering* **11** 47–48

[2] Aref’eva E V 2016 Information Support of Modeling and Forecasting of the Hazards Associated with Underground Hydrosphere Built-up Area *Civil Security Technology* **1** 28–34

[3] Arefeva E, Rybakov A, Ziganshin A 2012 Situational and Optimisation Model for Determination the Danger of the Built Up Areas *Scientific & Educational Problems of the Civil Defence, scientific journal* **1** 31–37

[4] Arefeva Ye V 2004 *System for Prevention and Handling of Flooding-Related Emergencies* (Moscow: Academy of Civil Defense, EMERCOM of Russia) p 143

[5] Arefieva E V, Bolgov M V 2018 Specifics of Natural Flood Forecast for Disaster Risk Reduction. Case Study of Krasnodar Krai *Civil Security Technology* **4(58)** 40–48

[6] Zagrebina Ye I 2014 State-of-the-Art Technology to Alert People of Emergencies *Search for Effective Solutions in the Russian Aerospace and Rocket Science Research and Development International Research and Practice Conference* pp 261–264

[7] Kuzmin A V 2014 The Use of Innovative Methods of Risk Analysis to Reduce Emergencies on the Roads of the Republic of Tatarstan *Vestnik NisBZhD* **3(21)**

[8] Guidelines on the Risk Analysis and Assessment of Damage from Natural and Man-Caused Emergencies 2008 (Moscow) vol. 1

[9] Muravieva E V, Romanovsky VL, Kuzmin A V 2016 Applied technosphere riskology - management of technosphere complexes *Quality and Life* (Moscow) **2(10)**

[10] Muravyeva E V, Romanovsky V L 2014 Urban Risks: Ability to Analyze and Forecast *Izvestia of Samara Scientific Center of the Russian Academy of Sciences* **1(7)**

[11] Muraveva Ye V, Romanovsky V L, Davingtayaeva L D 2016 Tree Structures as a Risk Analysis Method to Identify the Systematic Connections of Hazards *Proceedings of the 24th International Conference Prevention. Rescue. Aid.* March 17 (Khimki: FSBHEI HE ACD, EMERCOM of Russia)

[12] Reutmann A G 1987 *Building Deformation and Damage* (Moscow: Stroiizdat) p 159

[13] Romanovsky V L, Semenov V Yu 2014 Principles and Approaches to the Concept of Urban Risks *Vestnik NtsBZhD* **2**

[14] Romanovsky V L 2007 Graph-Based Risk Analysis by Means of Tree Structures *Izvestia of Samara Scientific Center of the Russian Academy of Sciences. Special issue: ELPIT-2007. Series Mechanical Engineering and Ecology* **2**

[15] Romanovsky V L, Muraveva Ye V 2007 *Applied Technosphere Riskology: a monograph* (Kazan: RIC School)

[16] Romanovsky V L 2012 Use Graphic Analytical Methods of Risk Analysis "Tree Structure" to Find the Most Probable Cause Failure of Technical System *Vector of sciences. Togliatti State University* **1(19)**

[17] Lyapin M N *Scientific Foundation and Improvement of the Standards and Guidelines*

[18] Gumerov T Yu, Faizulla G G, Dobrynina A F, Yusupov R A Features of complexing in the Al(III) - H2 O - OH- - Cl-(SO4 2-) - Flocculant system in the presence of the fat-containing disperse phase *Journal of Water Chemistry and Technology* **28(2)** 19–24

[19] Shakurov R F, Sitnikov O R, Galimova A I, Sabitova A F 2018 Investigation of the influence of acoustic oscillation parameters on the mechanism of waste rubber products combustion *IOP Conference Series: Materials Science and Engineering* **317** 012061

[20] Information Bulletin on the Subsoil Conditions in the Republic of Tatarstan for 2016