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Sustainable Development of the Engineering Geological Environment of Urban Areas: Transition from Theory to Practical Solutions

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Abstract **-** Ensuring the safety of people's vital activities is one of the primary tasks of engineering environment research. The study and assessment of georisks is especially relevant for ur-ban areas, which are complex natural and technical systems with their own laws of existence and changes, which are caused by natural and man-made factors. The purpose of the article is to ana-lyse the modern theory and practice of making urban planning decisions, especially when placing responsible industrial, energy, and transport facilities; discussion of the need to consider the resource stability of natural systems, the peculiarities of the production of design and research works in conditions of increased georisks in connection with urbanisation and global climate changes. The main engineering and geological processes in urban areas, and their impact on the ecological situation under the conditions of global changes are considered. The main theoretical provisions for assessing the degree of impacts and associated georisks are outlined; a number of types of uncertainty in urban planning activity are characterised: natural, conceptual, strategic, methodical, temporal, and parametric. A critical analysis of the existing practice of making the most important decisions regarding the development of territories, placement, and construction of transport facilities was performed. Methods of developing a number of schemes of engineering-geological and ecological zoning of urbanised territories are proposed, in which categories are distinguished according to resistance to various types of impacts: floods, inundation, groundwater flooding, landslides, mudslides, snow avalanches, karst and suffocation processes, soil subsidence, etc., on the basis of which should be developed insurance risk assessment system. Examples of the assessment of the risk of engineering-geological conditions leaving the permissible regulatory state under some negative processes are given. Practical recommendations for solving the problem of sustainable development of urban areas are provided**.**

Keywords**:** Urbanised territories, georisk, landslide, sustainable development

1. Introduction

An analysis of the consequences of events such as earthquakes, tsunamis, mudflows, avalanches, landslides, and floods, which are often catastrophic, leads to the conclusion that it is necessary to revise the strategy and tactics, both in terms of human interaction with the environment, and design and construction in conditions of high level of uncertainty. This is especially true for urban areas, where, according to the United Nations, more than half of the world's population lives presently.

At present, there is a need to further focus the attention of specialists and society on the need to change traditional approaches to making urban planning decisions, the location of critical industrial and transport facilities, as well as changing the methodology and practice of design and survey work in front of increasing georisks associated with global climate change that is happening literally “before our eyes”.

In 2021, the Intergovernmental Panel on Climate Change (IPCC) released the report "Climate Change 2021: the Physical Science Basis", dedicated to a comprehensive assessment of the warming of the atmosphere, land and oceans [1]. Data for the report was provided by 234 leading climatologists from 66 countries. According to the conclusions of experts, in the coming decades, cli-mate change will intensify in all regions of the planet. With an increase in glob-al average temperature of 1.5℃, warm seasons will become longer and colder seasons will become shorter. Changes in the amount and nature of precipitation lead to more droughts and floods. Intensive melting of glaciers causes an increase in the level of the World Oceans, the occurrence of mudflows and landslides in mountains.

Diagrams of the increase in the number of natural disasters over the past decades are shown in fig. 1 below. Many disasters are directly related to human activity: the creation of large reservoirs in the mountains increases the seismicity of territories, deforestation leads to floods, excessive exploitation of aquifers and subsoil - to subsidence and surface failures.

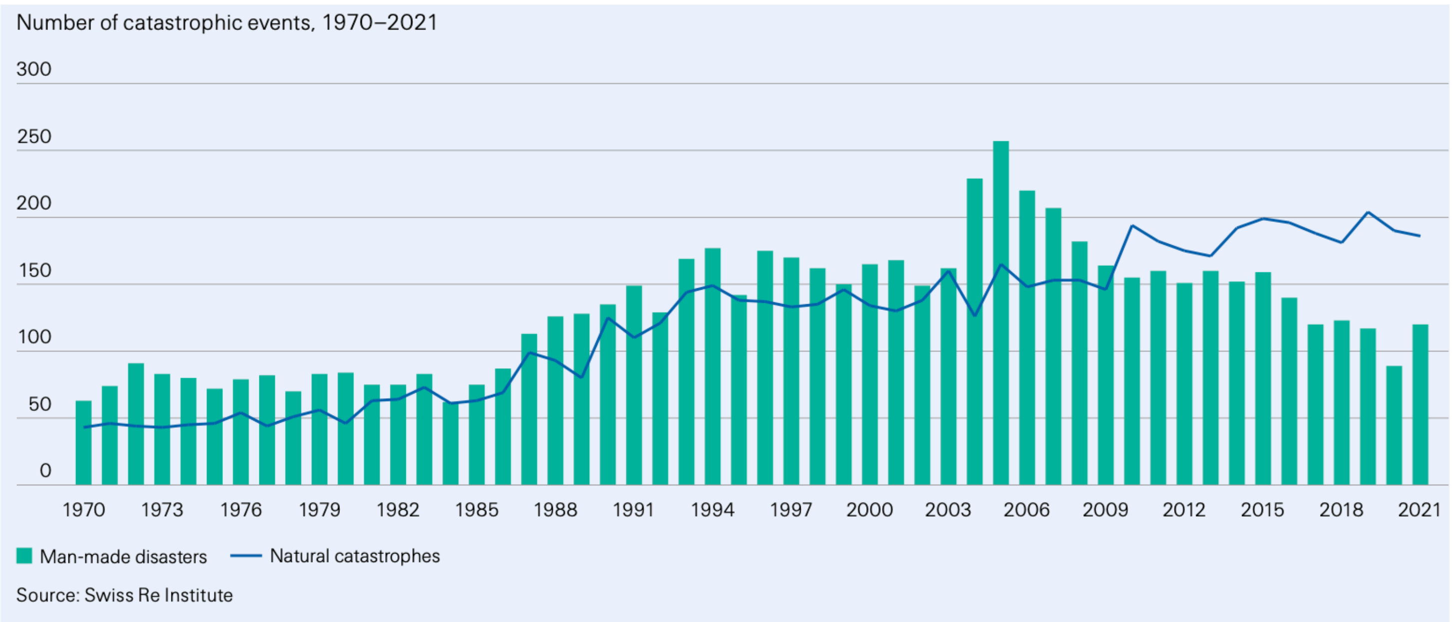

Fig. 1. The number of natural disasters in the world for 1970-2021 [2]

Problem statement. To solve the problems of reducing the consequences of catastrophic events, the world community has now adopted the concept of "multi-risks", which consists in studying a group of several events that threat-en a certain common region with an assessment of their interactions. This concept was considered at the UN Conference on Sustainable Development in Rio de Janeiro in 1992 [3], and then included in the Johannesburg Plan, 2002 [4]. According to this concept, “multi-risk assessment should be understood as the process of determining the probability of occurrence of various hazardous phenomena: occurring at the same time or soon after each other, since they are interconnected; or because they are caused by the same initiating cause; or they threaten the same objects without chronological reference.

It should be emphasised that in addition to the risks due to global climate change, in modern conditions there are such problems at construction sites which did not even arise some ten years ago. These problems are associated with global urbanisation, the progress of building technologies, with the massive development of territories that were previously considered unsuitable for construction at all (wetlands, floodplains, steep and landslide-prone slopes, coastal abrasion areas, etc.). In this regard, the responsibility for making urban planning decisions and the requirements for their justification are significantly important.

Analysis of recent research and publications. The main tasks facing engineers-geologists and ecologists in the study of urban areas and possible ways to solve forecasting problems have been identified in this paper [5]. Based on the published results of our previous works [6-8], the greatest attention in this article is paid to the issues of sustainable development of urban areas in general and harmonisation with the natural geological environment, as well as georisks in the development of natural areas.

Among the most recent publications on the issues of engineering-geological processes in urbanised areas are: studies of the activation of landslides in comparison with non-built-up lands in various natural zones [9-11]; assessment of risks associated with an increase in the intensity of precipitation due to global climate change, dangerous floods and flooding [6-8, 12-14].

In general, the research topic can be assessed as follows:

– theoretical and practical studies on the interaction of urban agglomerations with the natural geological environment are widely represented;

– cases of consequences of technogenic impact on soils are investigated;

- numerous examples of activation of hazardous engineering-geological processes as a result of man-caused impact are given;

– issues of methodology of engineering and geological surveys, the possibility of obtaining complete and reliable information for making urban planning decisions have not been studied enough.

The aim of this research is to focus on the attention of specialists and society on the need to increase responsibility in making urban planning decisions, especially when placing critical industrial, energy and transport facilities with the mandatory consideration of the sustainability resource of natural systems in the context of increasing georisks associated with urbanisation and global climatic changes.

2. Presenting Main Material

Elements of the theory in assessing georisks and analysis of existing decision-making practice. In the process of making urban planning decisions, locating critical industrial and transport facilities, one often has to act in conditions of uncertainty. The following types of uncertainty can be distinguished [5]: natural, conceptual, strategic, methodical, temporal and parametric.

Natural uncertainty is associated with incomplete knowledge of the properties and characteristics of the natural environment from the micro-structural level to the level of the required generalisation. Attempts to make up for this short-coming by applying the methods of probability theory have not yet been successful, since they require long periods of observation and a deep understanding of the laws that determine the periodicity of catastrophic events.

The source of conceptual uncertainty is the lack of long-term plans related to environmental impact. Reducing this type of uncertainty can bring success with a higher level of organisation of the world community, which is not yet realistic. This can be seen from the not-so-successful attempts to regulate car-bon dioxide emissions into the atmosphere.

Strategic uncertainty, consisting in the need to choose one of two strategies: "prevent" or "take into account and protect yourself".

Methodological uncertainty is associated with a large number of insufficiently substantiated, and often simply erroneous approaches to predicting possible events in the presence of a large number of variables and, accordingly, under conditions of high uncertainty in all components.

Temporal uncertainty is characteristic of both natural and natural technogenic events. It determines the timing and frequency (or lack thereof) of the occurrence of events in the absence of the possibility of their precise determination.

For methodological purposes, it is necessary to divide the impacts into two levels - "weak" and "strong". With weak impacts, the object or system functions within acceptable or specified parameters up to certain levels, with "strong impacts" - after a certain threshold value of the degree of impact, the system goes into a new state and ceases to function in a normal, specified or acceptable mode. Catastrophic impacts include strong impacts in which objects and the environment acquire new unacceptable properties. Naturally, interactions in natural technogenic systems should occur within the framework of weak impacts or, in special cases, in the regime of controlled strong impacts that do not have global consequences, that is, local ones.

The basis for assessing impacts at the initial stage is the identification of types of geological, climatic, man-made hazards, their spatial distribution and intensity. Then, an analysis of the stability of the territories should be carried out, in terms of geological structure, geomorphology, geotechnical and hydrogeological conditions. Particular attention is required to areas with residential development, as the most vulnerable to negative geological processes, as well as large industrial and transport facilities, both existing and planned.

Sustainable development of the geological environment of cities. The problem of sustainable development of a complex open dynamic city system should be considered on the basis of the idea that the system is stable if, under differ-ent influences, it retains its appearance and functional properties. In other words, the phase coordinates of the system do not exceed the allowable maxi-mum and do not fall below the allowable minimum. That is, the system changes (develops) within the limits acceptable from the user's point of view.

Naturally, one can use these concepts having an idea and having information about the state of the geological environment and the permissible impacts on the main components from the standpoint of both geotechnical and environ-mental sustainability.

It is important to consider that in many cases we can correct the ability of the system (environment) to perceive the impact due to special measures to in-crease the initial natural resource of sustainability. For the geological environment of the urban area, these activities may consist in increasing the stability of the base soils by compaction, silicification, cementation and other methods. In other cases, it becomes necessary to arrange drainage (reservoir, ring, horizontal, etc.). At the same time, it is necessary to take into account not only the new properties of development sites, but also the impact on other objects of the urban environment. Water intake devices within the boundaries of the city can lead to dehydration-gravitational subsidence of the surface or the development of suffusion processes with dips. Leaks from water communications can cause subsidence of loess soils at the base of buildings and structures. Backfilling of beams and ravines leads to flooding of bulk soils, the formation of groundwater spreading domes and a decrease in the strength properties of soils. Vibro-dynamic effects can lead to thixotropic liquefaction of soils and filling of underground structures with a liquefied mass of silty and fine sands, for example, when drilling underground tunnels. Laying roads on steep (over 150) slopes can reduce their stability and cause landslides during construction and soaking.

Examples of assessing the risk of engineering-geological conditions from an acceptable normative state as a result of some negative impacts are given in Table 1.

Table 1. Assessing the risk of exit of engineering-geological conditions from an acceptable (normative) state

Processes	Parameters			Risk assessment	Recommendations for risk elimination
	established	forecast	permissible (normative)		
Landslides	$K > 1.25$ (stability factor)	$K > 1.25$ (stability factor)	$K \geq 1.25$ (stability factor)	Low risk	Activities are not required
	$K \leq 1,25$	$K < 1,00$	$K \geq 1.25$	Significant risk	Organization of surface runoff, restriction of construction in the near-edge zone, construction of drainage and retaining structures, other anti-landslide measures (terracing of a slope, planting trees and shrubs, arrangement of a drainage network). Establishment of a network of observations and organization of monitoring of the dynamics of landslide processes
	$K < 1,00$	$K < 1,00$	$K \geq 1.25$	Extreme situation	Measures for the evacuation of the population and the restoration of the normative stability of the slope
Collapses	≥ 60 degrees, there are signs of collapses	≥ 60 degrees	< 60 degrees	Significant risk	Terracing, limited using

	> 60 degrees, collapses are frequent	> 60 dgrees, colapses are frquent	< 60 degrees	Extreme situation	Not suitable for building, need to relocate people
Flooding by groundwater	GWL deeper than 5.0 m	GWL deeper than 5.0 m	GWL deeper than 2.0 m	Low risk	Activities are not required
	GWL deeper than 5.0 m	GWL ≤ 1,5 м	GWL ≥ 2,0 м	Significant risk	Decreased supply of groundwater. Improving the conditions of runoff (discharge) of groundwater. Arrangement of drains. Waterproofing of underground parts of houses and structures
	GWL ≤ 1,0 м	GWL = 0,0 м	GWL ≥ 2,0 м	Extreme situation	It is necessary to protect the territory from flooding or resettlement of people

It must be admitted that increasing reliability and safety requires additional costs and, in connection with this, special control levers which can be a system of "insurance against geo-environmental risks". The main principles are outlined below.

3. Practical Recommendations

To make more meaningful urban planning decisions, an insurance system can be used, when insurance payments, in the case of an insured event, are made according to an expert assessment of geo-risks and reliability coefficients of implemented technical solutions.

In this regard, authors propose the development of a number of schemes for engineering-geological and ecological zoning of urbanised territories, in which categories of territories are distinguished according to their resistance to various types of impacts: earthquakes, floods, water-logging, landslides, mud-flows, avalanches, karst and suffusion processes, soil subsidence. On the basis of such schemes, a system for assessing insurance risks, relevant insurance premiums and compensations can be developed.

This approach will help to improve the reliability of objects and life safety in various natural conditions, and, ultimately, will stimulate the process of harmonising the relationship between man and the environment. The introduction of the proposed methodology should begin with the addition of regulatory requirements for engineering surveys, by introducing special assessments that make it possible to reasonably select sites for development, as well as methods of protection against hazardous natural processes.

It is also being emphasised that the insurance procedure should also include expert assessments of the study of the territory, the validity and reliability of the initial data for design, and compliance with the requirements of regulatory documents. Currently, there are significant shortcomings in these issues. The operation, purchase or sale of real estate objects will not be possible if they are not provided with appropriate protective structures or are themselves sources of danger.

In a state of uncertainty, high-quality monitoring and more stringent regulation of technogenic impacts is required, as is customary, for example, in relation to monitoring the quality of atmospheric air or surface water, as examples of taking into account the resource of the natural environment's resistance to various types of pollution and regulating impacts at global level. It is necessary to regulate the volumes of surface runoff of rivers, groundwater pumping, movement of large volumes of soil, additional loads from buildings and reservoirs.

An example of assessing the stability of the territory of a large city to the most significant external influences is the scheme which authors developed for the city of Kharkiv [7]. Compiled on the basis of geomorphological, hydrogeological, taking into account many years of experience in engineering surveys for construction, this scheme reflects the georisks associated with excessive water infiltration: flooding, activation of dangerous slope processes (landslides, erosion of soils and underlying strata).

Given the real military experience of the city of Kharkiv, the following urban planning solutions can be recommended:

- buildings in the city centre must be restored using modern building technologies, but taking into account their architectural features;

- residential buildings in residential areas should be built with parking lots, which, if necessary, can be used as shelters; hospitals, kindergartens and schools should be provided with shelters;

- the heat supply system should be divided into zones so that the entire system is not switched off in case of an accident; the water supply system should be changed, with the priority of using groundwater instead of surface (river) water.

4. Conclusion

The study of natural and technogenic georisks, together with the analysis of resources for the sustainability of the human environment, is necessary for the revision of building codes, as well as the implementation of preventive measures in order to ensure the safety of people, buildings and structures in cases of natural disasters caused by climate change, technogenic accidents and catastrophes.

Having considered the main problems related with the safe life of the population, the followings are being recommended:

to revise and supplement normative documents on engineering surveys for construction which will include questions of responsibility of stakeholders for the quality of initial data for design and construction, as well as for compliance with the requirements of regulatory documents;

- develop and implement a system of "insurance against geo-environmental risks", taking into account both risk assessment and the degree of information support for reliable construction and safe life;

- to introduce special disciplines into the system of professional training of surveyors, designers and builders, which will further bring the construction industry to the modern level of synergistic relations with the environment.

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