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# RISK OF DANGEROUS EXOGEODYNAMICAL PROCESSES DEVELOPMENT ON THE TERRITORY OF LARGE CITIES

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**Abstract**. The risk of development of dangerous exodynamical processes was investigated at the national and regional levels. Basic natural and technological factors of risk were determined on the basis of geological, geomorphologic, and geological-engineering methods and cartographical modelling. Classification of 45 large Ukrainian cities was implemented as a result of study of variety and estimations of intensity of man-caused influences on the cities territory.
Scientific-methodical approach is suggested for estimation of the total risk of dangerous exogeodynamical processes on the large cities territories. It is based on the complex analyses of natural and technological risk factors. An approach is presented on the example of Dnipropetrovsk —one of the largest industrial cities in Ukraine.
The risk estimation was developed within the limits of engineering and geomorphologic zones, which were chosen on the base of morphogenetical, morpholithological, morphometrical, morphological, and engineering-geological characteristics. Developed estimation is executed using both the probability of the negative processes and possible expenses caused by them for forecasting of man-caused geosystems position and working-out of control systems and defence arrangement of the high-risk zones. Its result is a series of cartographic models, including map of a ratio of total risk degrees and intensity of man-caused loading on a city relief.

**Key words**: risk, dangerous exogenical processes, engineering and geomorhological analyses, industrial cities.

**Abstrakt**. Ryzyko rozwoju niebezpiecznych procesów egzogeodynamicznych zostało zbadane na poziomach krajowym i regionalnym. Na podstawie badań geologicznych, geomorfologicznych, inżynieryjno-geologicznych oraz modelowania kartograficznego ustalono podstawowe czynniki przyrodnicze i technogeniczne warunkujące rozwój procesów egzogeodynamicznych. Na podstawie wyników badań różnorodności i oceny intensywności wpływu technogenicznego na terytoria miast została urzeczywistniona klasyfikacja 45 dużych miast Ukrainy.
Zaproponowano metodologiczne podejście do oceny ryzyka rozwoju procesów egzogeodynamicznych na obszarze miast, oparte na kompleksowej analizie przyrodniczych i technogenicznych czynników ryzyka. Za przykład posłużył Dniepropietrowsk — jedno z największych miast przemysłowych Ukrainy.
Ocena ryzyka została przeprowadzona w granicach jednostek taksonomicznych rejonizacji inżynieryjno-geomorfologicznej, które wyodrębniono z uwzględnieniem charakterystyki morfogenetycznej, morfologicznej, morfometrycznej, inżynieryjno-geologicznej i innych. Przy ocenie uwzględniono zarówno prawdopodobieństwo przejawu procesów negatywnych, jak i powiązanych z nimi ewentualnych nakładów dla prognozowania stanu systemów technogenicznych i opracowania systemów kontroli i przedsięwzięć z ochrony stref zwiększonego ryzyka. Rezultatem jest seria modeli kartograficznych, w tym również mapy podsumowującej współzależności stopnia ryzyka sumarycznego oraz intensywności wpływu technogenicznego na ukształtowania terenu miasta.

**Słowa kluczowe**: zagrożenie, zagrożenia procesami egzogenicznymi, analizy geomorfologiczne i badania geologiczno-inżynierskie, aglomeracje przemysłowe.

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Because of the combined activities of natural and man-caused conditions, there are activation and disastrous manifestations of dangerous exogeodynamical processes within the limits of large industrial cities. That is why timely ascertainment, forecasting and evaluation of risk potentially caused by these processes, from the prevention point of view, are topical and promising approaches of scientific investigations (Palienko, 1999; Goshovskiy *et al*., 2002).

The risk of development of dangerous exodynamical processes is investigated at the national and regional levels. The objects of our research are man-made morpholithosystems, relief, relief-forming deposits and exogenetic processes in the big cities of Ukraine.

Taking into account classifications accepted in geography of cities and town-planning, as category of "big" we consider cities which have reached a population of 100 thousand and more men living on the territory of 30 $km^2$ up to 800 $km^2$ and more, where one can observe man-caused impacts on geological environment variable as their depth and type are concerned. According to data from the 2001 census, 45 Ukrainian cities belong to that group.

All big Ukrainian cities are characterised by certain historical and geographical features, for instance their location and development, which have affected their functions, structure of industrial complexes and appearance of the development of exodynamical processes risk to the considerable degree. One of the most important methods of the complex objects studies is the method of their arrangement in scientific order. It enables to define their similarities and/or differences. Taking into consideration the subjects of research, it is proposed to apply a complex of attributes for the typology of cities, which take into account both natural and man-caused conditions of risks, namely: features of a geodynamical situation in a specific zone of the city, size of territory, duration of man-caused impact, reasons for location of cities and their functions at the present stage of development.

The natural factors (especially structural—geological, geomorphologic) predetermine appearance and development of exogenetic processes of different genetic types on the cities territory. Based on the features of natural conditions and on spectrum of exogenetic processes, the following groups of cities were distinguished:

— cities with a very high level of ecological-neogeodynamic intensity (Informational…, 2000), connected with an arrangement in the limits of a mobile folded zone and with a wide appearance of subsidence of rock, plane- and ravine-erosion, and deep shifts;

— cities with an average level of ecological-neogeodynamic intensity, caused by location of cities in the tectonically complex zones of contrast tectonic structures junction of an ancient platform (for example board and hollow) and in morphostructural units, which represent zones of crossing of regional fractures and tectonic weak zones, and which are characterised by development of flood, subsidence of rocks, shifts, karst, plane- and ravine-erosion, and abrasion;

— cities with a faint level of ecological-neogeodynamic intensity, caused by homogeneous structural-geological conditions, and development of swamp processes, flood, subsidence of rocks, superficial shifts, plane- and ravine-erosion.

On the base of territory size, the following groups of cities are distinguished: with the area of 30–100 $km^2$ — 60% (among them Uzhgorod, Simferopol, Poltava, etc.); with the area of 100–200 $km^2$ — 20% (including Odessa, Lviv, Sevastopol etc.); with the area of 200–300 $km^2$ — 6.5% (Lugansk, Makivka, Gorlivka); with the area of 300–400 $km^2$ — 9% (Dnipropetrovsk, Donetsk, Zaporizhzhya, Kharkiv); and with the area of more than 400 $km^2$ — 4.5% (Kyiv, Kryvyi Rig).

Exclusive role in the activation of dangerous exogenetic processes on the territory of big cities play man-caused factors, which can be characterised with the help of quantitative and qualitative attributes, particularly, with duration of action, intensity and character of impacts.

The duration of the man-caused impact on geomorphologic sphere is hard to define exactly, but it is an important feature of a city. As it is known, the cities pass certain stages of their development: origin, formation (or development), and aging. Some cities have gone through decline, destructions, and later — revival, for example, Kyiv and Sevastopol. Therefore, lasting of the man-caused impact was determined by the length of the historical nucleus of city period of presence during the important historical events and stages of development. In accordance with duration of man-caused impacts, the following groups of cities were distinguished:

1. Very long term of man-caused impact (with some periods of discontinuation):

a) over 1500 years — Kyiv, Sevastopol (Khersones), Kerch and Evpatoria;

b) 1500–1000 years — Chernigiv.

2. Long term, 1000–500 years, of man-caused impact — Poltava.

3. Long term, 1000–500 years, of man-caused impact (with some periods of discontinuation) — Uzhgorod, Chernivtsi, Zhytomyr, Vinnytsya, Lutsk, Bila Tserkva, Lviv, Rivno and Simferopol.

4. Average duration, 500–250 years of man-caused impact (with some discontinuations) — Khmelnytsky, Cherkasy, Niokpol, Ivano-Frankivsk, Kremenchuk, Sum,y Ternopil, Kharkiv and Slovyansk.

5. Short term, less than 250 years, of man-caused impact — Mariupol, Dniprodzerzhynsk, Dnipropetrovsk, Kryvyi Rig, Pavlovgrad, Gorlivka, Donetsk, Yenakiyeve, Kramatorsk, Makivka, Berdyansk, Zaporizhzhya, Melitopol, Kirovograd, Alchevsk, Lysychansk, Syrvyerodonetsk, Odessa, Kherson and Mykolaiv.

It is necessary to notice, that the activation time of man-caused impacts is one of the major factors of dangerous processes. However, short-term intensive man-caused impacts play greater role in activation of dangerous processes, than long-term moderate ones. For example, centres of cities which exist less than 250 years, are characterised by a high and very high degree of risk of various techno-natural processes development, and other cities, which exist 1000–1500 and more years (for example, Chernigiv, Vinnytsya, Lutsk and other) — are characterised by moderate degree of risk. Therefore, studies of recent man-caused impacts are very important.

As a result of studies on variety of man-caused impacts on the territory of cities, and the estimations of their intensity,

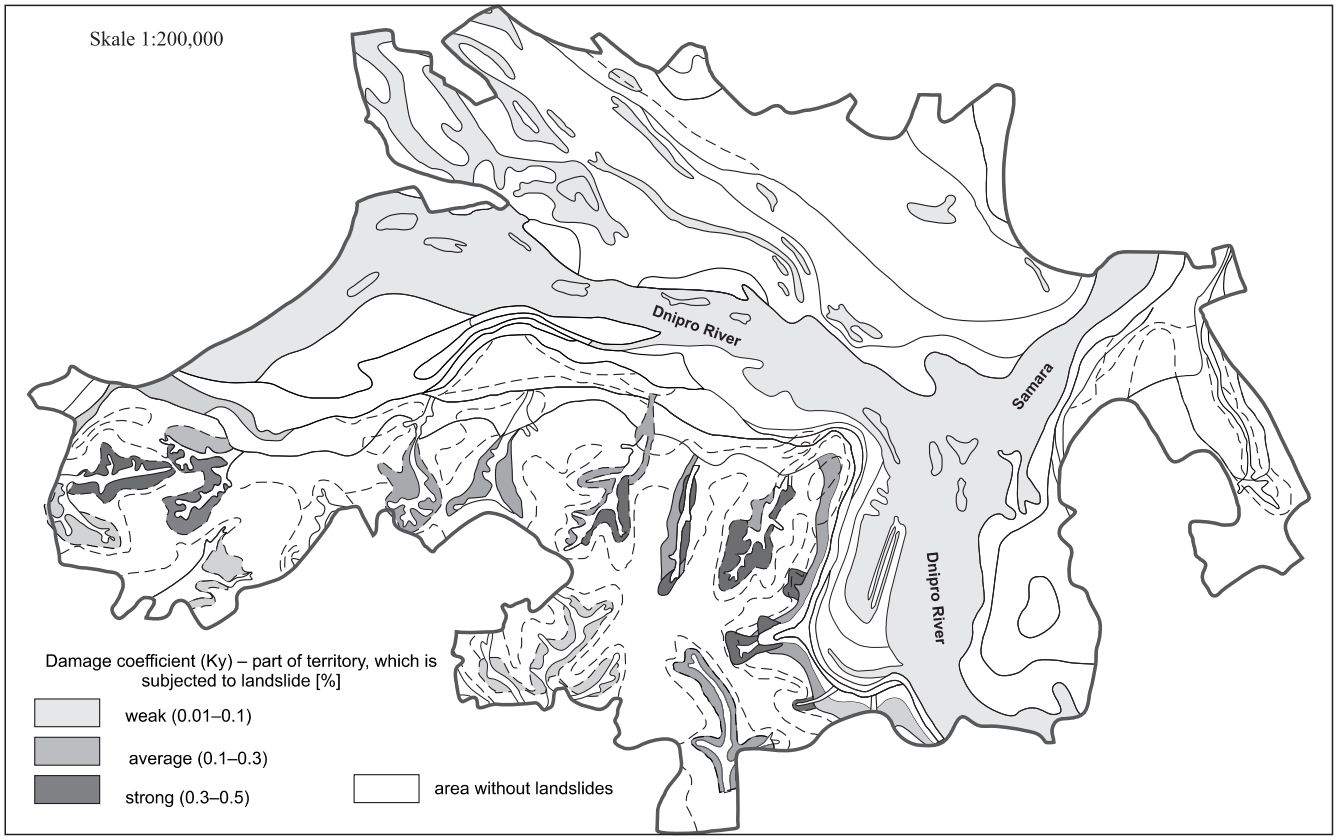


**Fig. 1. Development of landslide processes in Dnipropetrovsk**

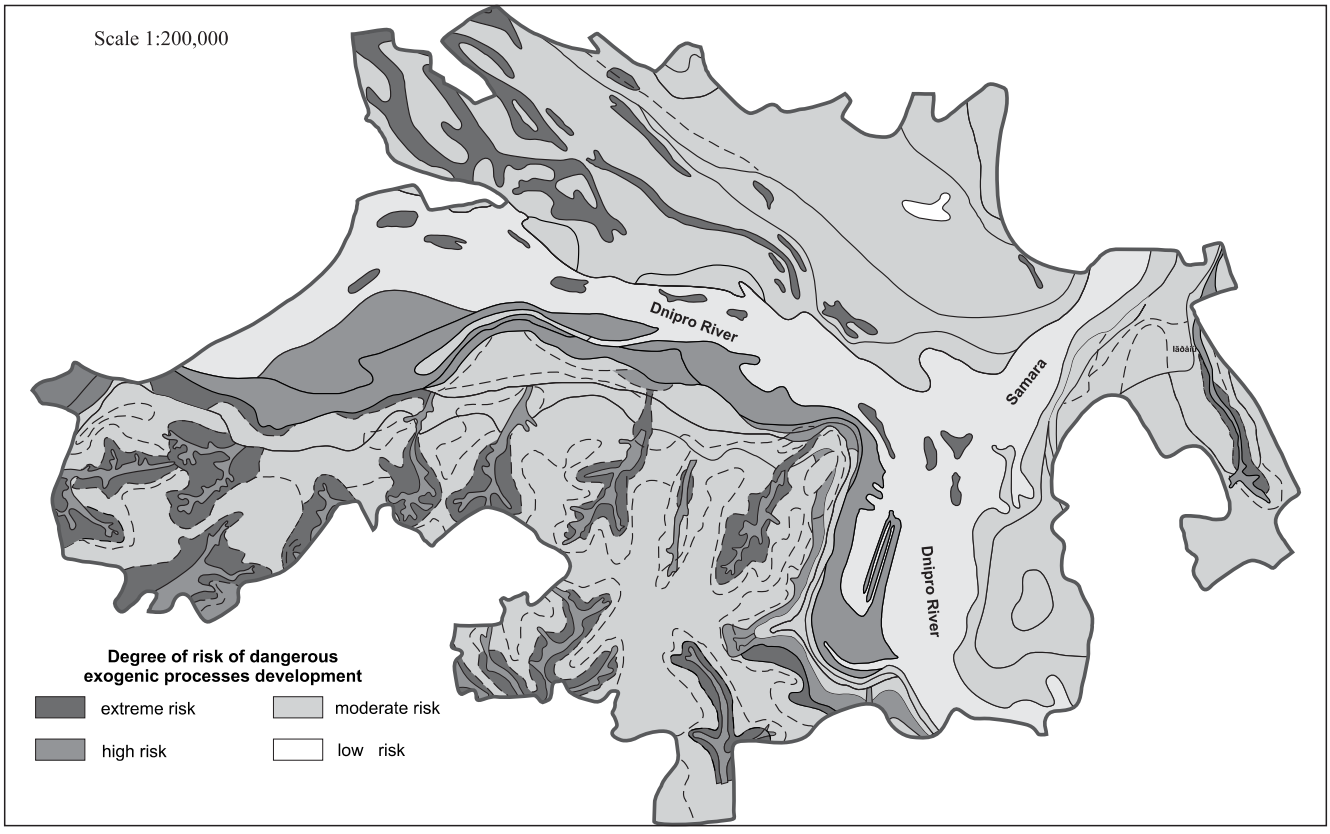


**Fig. 2. Degree of total risk of dangerous exogenical processes development in Dnipropetrovsk**

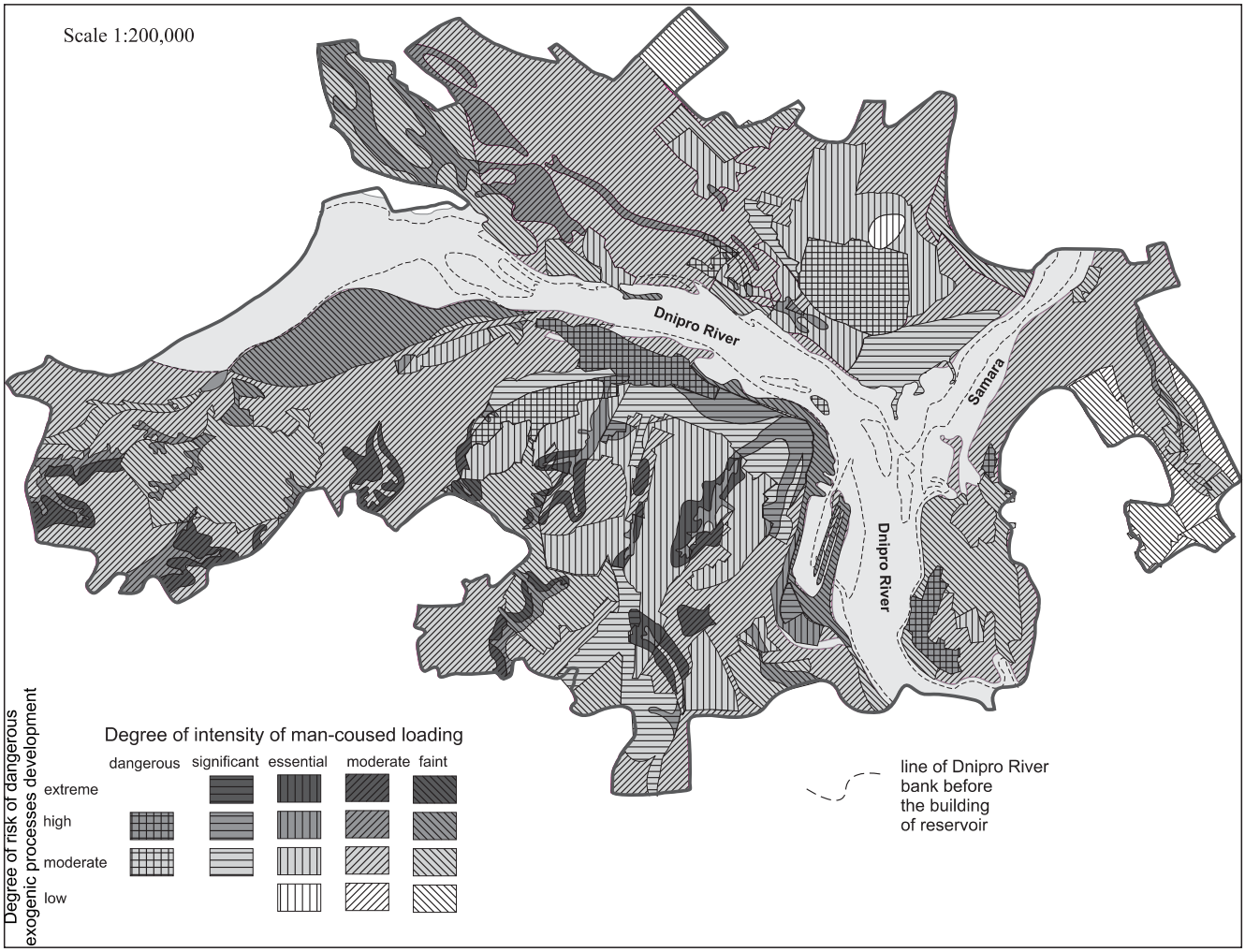


**Fig. 3. Ratio of risk degree of dangerous exogenetical processes development and intensity of man-coused loading**

three groups of cities have been distinguished (Soumatokhina, Duk, 2004; Atlas..., 2001):

1. Cities with a weak degree of intensity of man-caused impact, which created moderate and weak risks of geodynamic processes development. These are cities, in which a rather small quantity of enterprises function, mainly of mechanical engineering and light industry.

2. Cities with intensive man-caused influence, of certain specifications and presence of extreme risk zones of dangerous processes development. They are cities of mining areas with active metallurgical enterprises and production of coal, iron, manganese ore, etc. (Kryvyi Rig, Donetsk, Makivka and others). Thus, the exploitation of ore minerals in the territory of Kriviy Rig by an open pit technique, with rocks landslides, results in creation of terraces, cracks and shifts of rocks. And it results in change of structure and properties of rocks, exposing the existing and forming new man-caused cracks, strengthening connections of groundwater horizons with surface water, as well as with infiltration of atmospheric precipitation (Bagriy, Blinov, 2002) The man-caused water infiltration actively develops floods. It also changes hydrochemical characteristics of groundwater. As a result of mining, and also because of floods or the increase of humidity, the loess strata made active shifts. Closure of coal mines in Donetsk, Makivka, Gorlivka and Yenakievo (up to 40% of them) developed zones of the increased risk for the following processes (Trofimchuk, 2003): flood and swamping; decrease of the durability of the rocks top zone, including rocks beneath the buildings and structures foundations; additional subsidence and weakening of rocks beds with risk of engineering structures deformation; increase of chemical aggression of soil, and accumulation of solid and liquid waste products in surface and groundwater; increase of chemical aggression of soil and soil-waters on ferro-concrete and metals; formation of new migration routes of explosive gases because of an increase of hydrostatic pressure in flooded mines; shifting the tectonic zones; decreasing the engineering seismic stability of rocks beds due to concentration of flooded mines, of significant quantity of potential energy and hydro-geodynamic pressure.

3. Cities with intensive various duration of man-caused impact and presence of extreme and high-risk zones on their territory. Among them: diversified industrial centres, which are characterised by presence of numerous enterprises of heavy industry, including “wet” technologies (metallurgy), multi-storey build-

ings and large reservoirs (Kyiv, Dnipropetrovsk, Kharkiv, Zaporizhzhya, Mikolaiv, Odessa, Kherson, Mariupol and other).

The city of Dnipropetrovsk, on the example of which a methodical approach towards risk evaluation was carried out, is a tectonically complex zone — a combination of the Ukrainian shield and Dniprovsko-Donetska trough, is one of the largest multi-domain industrial city in Ukraine (above 1 million of people). According to the above-mentioned classification, Dnipropetrovsk belongs to cities with intensive and various man-caused influences, which have resulted in the development of extremely dangerous and of high risk, processes. Activation of dangerous exogeodynamic processes in the city is technically conditioned. There are the following main man-caused impacts on the geological environment: raise of the Dnipro River of 4.2 m on average as a result of the reservoir construction in 1932; liquidation of many natural absorbing wells; a significant duration (30–50 years) of the water carrying nets exploitation and connected loss of 15–35% of water; presence of enterprises with wet technologies (metallurgical, electro energy, chemical etc.); large-scale multi-storeyed building on plateau slopes and gullies; construction of waterproof covering.

Taking into account the man-caused conditions for activation of the dangerous exogenetic processes on the territory of big cities, a research was carried out on man-caused risk factors and probability of their display (Soumatokhina, Duk, 2004).

As a result of the estimation of intensity of man-caused impacts on the city's territory, several degrees of their intensity have been distinguished: faint (21.1%), moderate (46.8%), essential (16.3%), significant (5.65%) and dangerous (6.45%). As the final result of the research on the man-caused factors, a map of the integrated estimation of the intensity of man-caused influences on a relief and relief-forming processes was constructed.

The risk estimation was carried out within the limits of engineering-geomorphologic zoning taxons, which were chosen on the base of morphogenetical, morpholithological, morphometrical, morphological and engineering-geological characteristics. The main criterion during the risk degree determination was a possible economical loss and probable people losses as a result of the development of dangerous processes within the limits of engineering-geomorphologic districts.

A probability of simultaneous occurrence of unwanted exogeodynamical processes i.e. floods; subsidence of rocks and erosion during the engineering-geomorphologic estimation of risk was calculated (Fig. 1). At first, damage coefficient (Ky) was estimated for every process on the territory of engineering-geomorphologic districts as a ratio of an area damaged by some process to the general area of a district. On this basis, a degree of damage by specific processes was estimated, and classified as very weak (Ky <0.01), weak (Ky = 0.01–0.1), average (Ky = 0.1–0.3), strong (Ky = 0.3–0.5) and very strong (Ky >0.5).

The estimation of risk of dangerous processes development was carried out on the basis of a geomorphologic model, which consisted of a series of maps: basic (geomorphologic, spatial and presenting a century structure of techno-morphosystems) and estimated (estimation of risk of processes development on morphological parameters, engineering-geomorphologic zoning, intensity of man-caused impact on relief, zoning of damage by exogenetic processes, degree of total engineering-geomorphologic risk, risk factors, etc.).

The result of risk estimation was a constructed map of the degree of total risk of the combination of the most dangerous exogenetic processes (flood, subsidence, landslides, landslips), and confirmation of correct use of the relief. The summary map was made on the basis of the maps of damages caused by certain types of processes on the city's territory.

The risk degree of the dangerous processes development was established with the help of empirical coefficient (W), the amount of which depends upon degree of dangerous development (dynamics, recurrence, possible activation or disastrous manifestations) and critical layers of all exogeodynamic process. The highest values of W were established for districts, which were badly damaged by the most dangerous processes of shifts. That gave a possibility to take into account shifts manifestations on the base of engineering-geomorphologic taxons, also in areas where shifted objects are insignificant. The districts with manifestations of rock subsidence and floods have significantly lower coefficient.

Integral index of total risk, calculated as a sum of W of all processes, enabled to distinguish zones of different degree of dangerous processes, developed on the territory of Dnipropetrovsk (Fig. 2). The zone of an extreme risk (3.7% territory) comprises steep districts (slope steepness more than 5 degrees) of a divide plateau and the highest terraces with a very strong damage caused by rock subsidence and erosive processes, Those processes were also a threat of destruction and considerable deformations of buildings for the neighbouring districts, and of potentially very high material losses. In order to carry out monitoring of dynamic processes, an efficient estimation of man-caused loads, able to challenge the activation of the mentioned processes, is recommended. The use of necessary defence actions (erosion prevention, forest amelioration, drains construction, electric-and-chemical soil treatment) is necessary.

High-risk zone (12.6%) includes districts of steep slopes of high, average and low terraces of the Dnipro River, damaged by rock subsidence and erosive processes, and districts of high flood-lands of the Dnipro River with very strong damage caused by floods. These processes constitute a threat of considerable damage of buildings, communications etc., and of huge material expenditures. Monitoring of the processes and carrying out prevention measures as well as lowering water losses by underground communications as well as fortifying slopes, is recommended.

The zone of a moderate total risk (80%) corresponds with flat districts (slope steepness 2–5 degrees) of low and average terraces of the Dnipro River, where a low degree of damage by all the mentioned processes is occurring. These processes can cause partial deformations of buildings and roads, and pipes breaking. Material losses are non-significant. Anti-erosive measures, e.g. planting of trees and gardens, and drainage of surface waters, are recommended.

The zones of a low risk degree (3.7%) comprise districts of the divide-water plateau (slope steepness 0–2 degrees) where a weak manifestation of erosion and non-significant slumps are occurring, but they also urge for anti-erosive measures. In this zone, an increase of man-caused loading on a relief is possible.

Final investigation phase is the prediction-constructive stage connected with acceptation of the final administrative decisions as far as warning, reduction and prevention of catastrophic consequences of dangerous processes are concerned. It is based on establishment of dependence of a degree of risk from man-caused factors from application of methods of mathematical-cartographical modelling. As the result, a new cartographic model of a ratio of total risk degrees and intensity of man-caused loading on the city relief, received as a result of imposing the appropriate layers of the information, has been obtained (Fig. 3). The analysis of the model testifies that the greatest city areas contain sites of moderate risk and moderate man-caused loading on a relief (42%), moderate risk and faint man-caused loading (15%), and moderate risk and essential man-caused loading (14.5%). The zones of higher risk correspond to sites with an essential, significant and dangerous degree of intensity of man-caused influence. The analyses of entropy (E) parameters for different parts of the city, based on the map, allow to assert that the greatest heterogeneity and complexity of engineering-geomorphologic characteristics is inherent to sites of a relief of the city right-bank, where man-caused loading and its variety differ to the greatest degree. Result of the risk estimation is an appraisal of dangerous processes, possible consequences and compensatory expenses for their liquidation, expenses for prevention measures of risk, and recommendation for use of relief as the territorial resource. That technique can be applied in other cities, with insignificant variations, for risk estimation of appearance of geodynamical processes.

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