Polish Geological Institute Special Papers, 20 (2005): 104–113
Proceedings of the Conference "Mass movement hazard in various environments"

RESEARCH AND MAPPING OF LANDSLIDES WITHIN THE BOUNDARIES OF THE MIDDLE DNIPRO INDUSTRIAL–URBAN AGGLOMERATIONS

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Abstract. Research on and mapping of landslides of Dnipropetrovs'k–Dniprodzerzhins'k industrial-city agglomeration were carried out during the period of 1978–2002, on the basis of geological material obtained with the help of funds, space pictures and own research. The results were as follows: rules of spatial landslides development and its dynamics for almost 30 years period have been recognised, the main natural and technical factors of landslides activation have been discovered; passports of the most dangerous moving sites have been created; sites of the high risk of landslides appearance and its possible negative consequences for nature and population as well as for technical constructions have been determined.

Key words: landslides relief, landslide activation, mapping of landslides, landslides.

Abstrakt. Osuwiska występujące na obszarze aglomeracji Dniepropietrowska i Dnieprodzierżyńska były badane i kartowane w latach 1978–2002, dzięki materiałom geologicznym uzyskanym przy pomocy grantów, wykorzystaniu zdjęć satelitarnych oraz badaniom własnym. W wyniku badań poznano prawa rządzące powstawaniem i rozwojem osuwisk przez prawie 30 lat, opisano główne przyrodnicze i techniczne przyczyny aktywacji osuwisk, opracowano opisy miejsc najbardziej zagrożonych ruchami osuwiskowymi, określono też miejsca dużego ryzyka powstawania osuwisk oraz potencjalnych zagrożeń dla środowiska naturalnego, mieszkańców i budowli technicznych.

Słowa kluczowe: rzeźba terenów osuwiskowych, aktywacja osuwiska, kartowanie osuwisk, osuwiska.

INTRODUCTION

Research on development rules of the last decades natural disasters has reached important results in the estimation of ecological safety. In particular, it concerned industrial-cities agglomerations where technical pressure essentially strengthened the natural development of dangerous processes, and made threats of their activation which could lead to catastrophes.

The Dnipropetrovs'k–Dniprodzerzhins'k industrial-city agglomeration is one of the greatest in Ukraine. It is located within the boundaries of the Middle Dnipro valley complexes and watershed plateau. On the territory of Dnipropetrovs'k and Dniprodzerzhins'k cities live over 1.3 million people. More than 400 industrial enterprises are located there, including powerful metallurgical, machine-building and chemical ones. Besides, the agglomeration is placed between two hydroelectric power stations built above (Dniprodzerzhins'k) and below (Zaporizhya) the current Dnipro course. Within the limits of the agglomeration functions also a thermal station Pridniprovska. All the above mentioned enterprises apply "wet" technologies that essentially influence process of raising the subsoil water level, which increases danger of the landslides activation.

Activation of landslides can have catastrophic character and threatens the environment by loss of natural stability of the geosystems. It belongs, therefore, to the most dangerous processes characteristic for the studied region. The appearance of these processes not only influences the natural rocks positions. It also destroys and changes morphology of ravines and gullies slopes, forms specific moving relief, and threatens the safety of the people residing there. That is why further development of theoretic-methodological research bases of the mass movement processes within the territory of industrial-city agglomerations is still actual, with a special emphasize on the complex optimization of the economic use of territorial resource.

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RESEARCH METHODS

Research on the landslides within the Dnipropetrovs'k–Dniprodzerzhins'k industrial-city agglomeration was carried out with the use of geological materials obtained thanks to funds allocated during the 1978–2002 period, with the use of satellite images, and the results of own studies. Funds from various sources (engineering-geological, municipal, architectural and land use planning) brought the information on the geological, geomorphologic, engineering-geological and hydrogeological parameters characterising the region, and also on specific situation of the population and technical objects (Sumatokhina, 2004; Sumatokhina, Diuk, 2004).

The previous studies and analysis of these data, and also the results of decoding the satellite images, have allowed to allocate a site of maximal landslides development within the agglomeration territory, and to define the basic natural and technical factors of their activation (Fig. 1).

Results of the previous estimation of landslides development were checked by visual inspection of dangerous moving sites, carried out during 2000–2005 years. Routine inspections have consisted of complex works directed to estimation of these sites condition, to the possibility of their economic use, and to the forecast of the development of displacement.

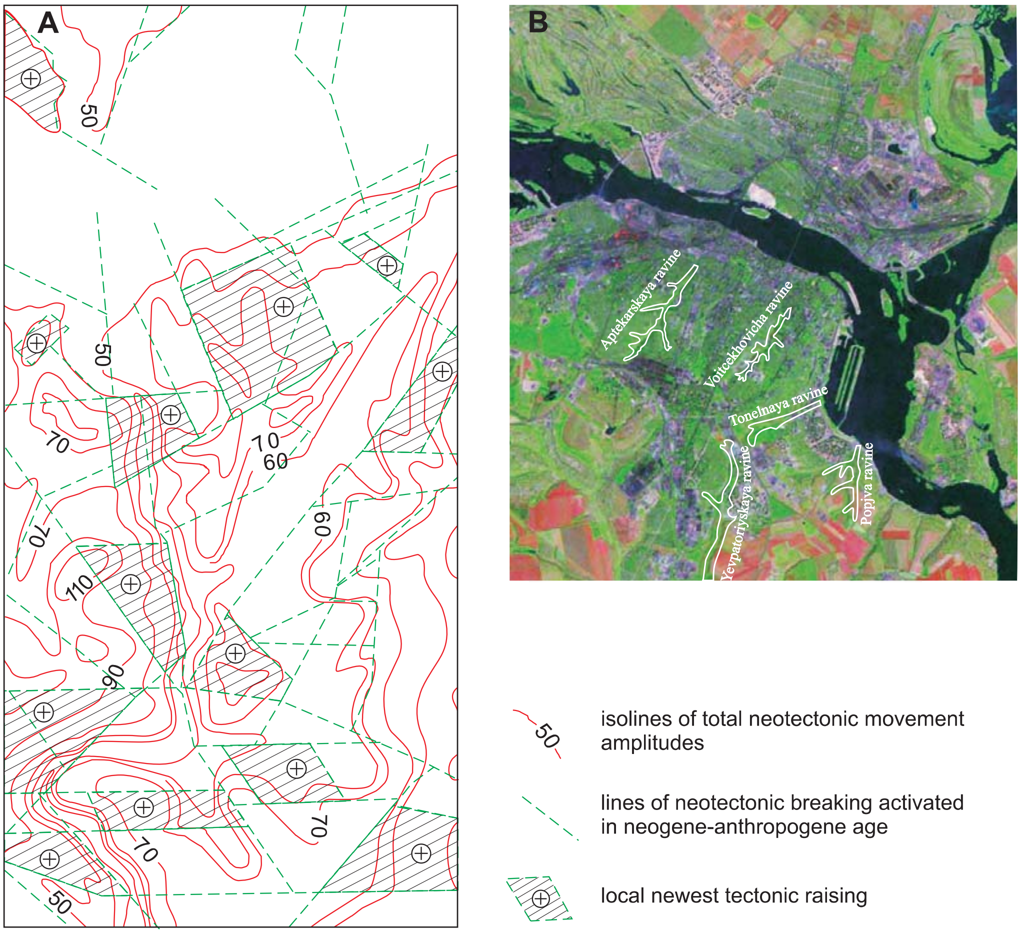

Fig. 1. Structural-geological factors of the exogenous processes development

A — neotectonic map; **B** — satellite image of Dnipropetrovs'k city

RESEARCH RESULTS

In effect, the following important scientific and practical results were received:

- principles of the spatial development of landslides and their dynamics during the almost 30 years period;
- list of the basic natural and technical factors of landslides activation;
- maps presenting natural and technical factors of landslide activation and their effects;
- the landslides cadastre including descriptions of the occurrences of extreme situations, having had negative consequences;
- passports of the most dangerous moving sites;

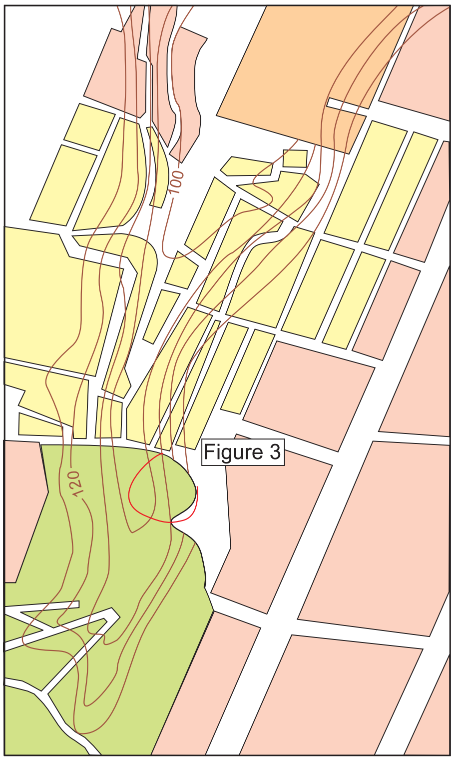

Fig. 2. Technical load on the Voycekhovich ravine slopes

Fig. 3. Abandon 14-storeyed dwelling house, deformed as result of landslide activation

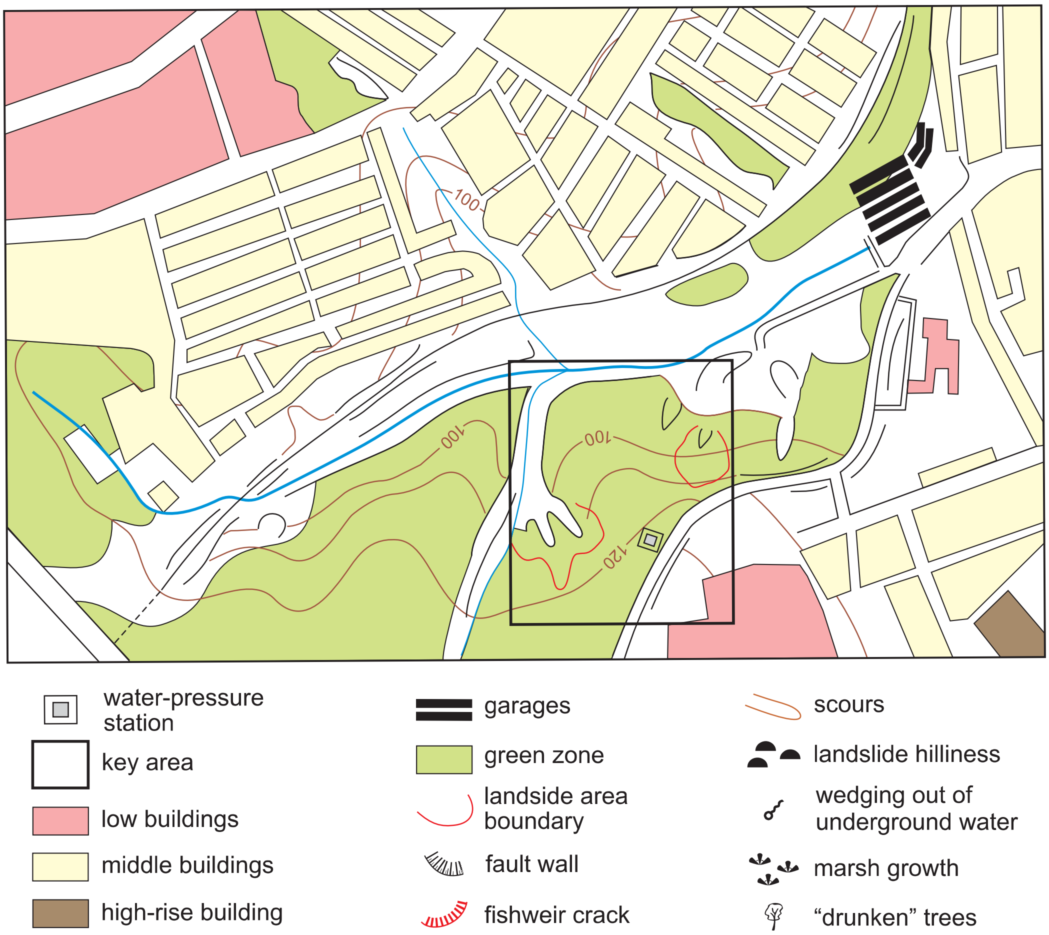

Fig. 4. Technical load on the Tonelnaya ravine slopes

— location of the sites with the increased risks of the landslides appearances and the connected possible negative consequences for the nature, population and technical objects.

The cadastre of disastrous landslides that have led to extreme situations consists of 22 active landslides. The landslides which have led to destruction of one-storied buildings and caused one person death, took place in 1978 on the territory of Dnipropetrovs'k. After that case, the state enterprise of city engineering protection had been created. Its basic function became the monitoring of moving sites, development of the protection actions against landslides, and prevention of the population and other state organisations of the landslides development risk. From that time on, the visual supervision and research on landslides were carried out within the territories of Dnipropetrovs'k and Dniprodzerzhins'k cities (Fig. 2, 3).

In 1983, slopes of Yevpatoriyska ravine have been covered with multi-storey buildings. It caused activation of landslide. As a result of the 0.5 m wide crack formation on the surface, destruction of two one-storey buildings and displacement of a road canvas has taken place.

During the 1991–1993 period became more active landslides located on ravines slopes of the right-bank parts of Dnipropetrovs'k and Dniprodzerzhins'k cities. They have caused a relief transformation of the inhabited areas, of the botanical garden, industrial enterprises (paint and varnish factory, metal bases, water supplying station, and others) and of the "Svitlofor" garages for 500 automobiles. A threat of the destruction of more than 1000 apartment houses, including 14 multi-storey (9–10 floors) houses, appeared on the general area of the 40,000 m^2 (Polischuk *et al*., 2003). The most dangerous situation was developed in riverhead of Tonelna ravine, where water supplying station functions for almost 30 years. As a result of its exploitation, according to inspections carried out during the 2000–2005 period, two moving bodies were formed there lowering the water tank of the 10,000 m^3 volume. This activity has already caused deformations of the construction, and provided a high degree of risk to safe functioning of the tank (Figs. 4, 5). Possible consequences of such voluminous water tank deformation for Dnipropetrovs'k are difficult to overestimate.

The landslide in 1997, which has led to very significant deformations and destruction of apartment houses in Dnipro-

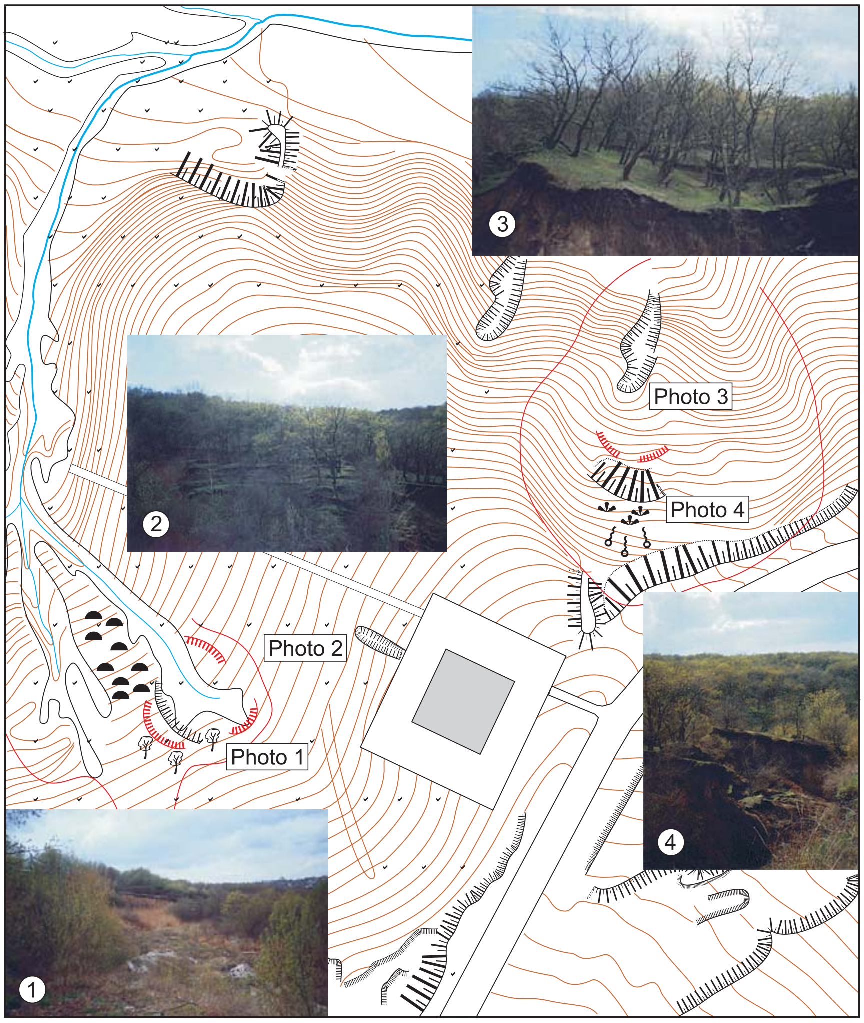

Fig. 5. Landslides relief of the Tonelnaya ravine slopes (key area)

For explanations see Figure 4

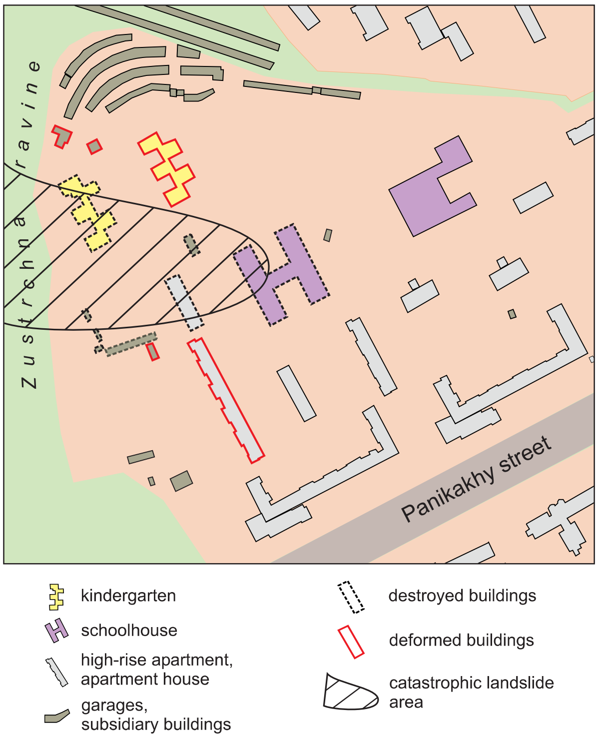

Fig. 6. Catastrophic area in 1997 in Dnipropetrovs'k

petrovs'k, had the most negative consequences known broadly in Ukraine and outside of the borders. It has forced removing of more than 500 inhabitants of these houses. Except for a school for 1000 pupils, two kindergartens for 250 children were completely destroyed then, and engineering communications damages have also taken place (Fig. 6). During 10 hours, a landslide body of over 1000 m^3 of water saturated loess has slipped down. Movement of the weighty rocks was a result of the combine action of natural and technical factors.

The natural factor was an influx of abnormal quantity of atmospheric precipitation to subsoil water: 801 mm/year instead of 483 mm/year — the many years average norm (Informational bulletin, 2003). The main technical factor of the landslides activities causing the down slope move of 0.5–1.0 m/year was, however, the raise of subsoil water level, which occurred in this territory during the last ten-years-period due to losses of the technical water from water supplying systems (near 800 mm/year), and to infringements of groundwater during reconstruction of a river valley slope. This process was strengthened by unloading of the diluvium subsoil water, and by influence of the vibrations of railway which passes Zustrichna ravine in the distance of 150–250 m from a landslide body. At present, the rocks displacements were somewhat stabilised.

In February 2005, within the agglomeration territory a series of new landslides displacements started, observed almost at the same time in different parts of the agglomeration. They have caused serious deformations of the inhabited and industrial buildings. Development of these processes, which occurred repeatedly within the agglomeration, was brought about by complex of factors of natural and technical origin.

Methodical aspects of the research on the landslides from the described region were based on the analysis of the quantitative and qualitative information received from engineering--geological and geomorphological (visual and/or instrumental) studies. Within the agglomeration boundaries, visual studies are carried out on a regular basis every 2–3 years for stable landslides sites, and on the active sites — usually twice a year, during the dangerous seasons (spring and autumn). Instrumental observations are carried out on two stationary sites located in Dnipropetrovs'k.

SUMMARY

Analysis of materials and results of own research allowed to define major factors and rules governing the landslides behaviour within the agglomeration boundaries.

NATURAL CONDITIONS AND FACTORS

Among all the natural factors, an exclusive role in activation of the landslides processes within the agglomeration territory play the following factors: structural-geological, geomorphological and hydrogeological conditions define rules and mechanisms of activation processes, and climatic (meteorological) factors influence the ways of the activation.

Structural-geological factors. The agglomeration is located at the border of complex tectonic part of the Ukraine platform, in the contact zone of the Ukrainian shield and Dnipro–Donets troughs, and is characterised by the presence of crossed regional faults zones and complex of broken blocks structures (Fig. 1).

The main roles in landslides activation play features of the geological structure. The area is build up by Precambrian crystalline basement covered with sedimentary Palaeogene and Neogene deposits, mainly in the crystalline basement depressions, but also with anthropogenic deposits. Tectonic mobility of crystalline basement also causes activation of landslides. General direction of big gully-ravine systems (e.g. Yevpatorijska, Krasnopovstanska, Pharmaceutical and Dry ravines) is consistent with the directions of tectonic faults. Activation of the landslides advanced on slopes of mentioned ravines, and can occur with influence of tectonic movements of fault zones.

Anthropogenic accumulations are present everywhere and are appearing in loess and soils horizons, the general thickness of which is between 5–7 m (left-bank terraces) and 40–57 m (a site of watershed plateau on the right bank).

Geomorphological factors. The relief of the studied region is characterised by polygenetic origin and contrasts. Polygenesis is seen in the agglomeration area of the raised, denudated, eroded and accumulative, lowly laying plains. The relief contrast is seen due to the presence of sites with different degree of relief diversification. The result of morfometric analysis is subdividing agglomeration territories into zones on the base of relief diversity and probability of the development of sliding processes. On the base of a complex morfometric and hydrogeological parameters there were the following areas determined: poorly breaking, characterised by absence of sliding processes; fairly breaking with possible development of small landslides; strongly breaking with the appearance of deep landslides.

The mechanism and dynamics of sliding processes are substantially defined by the structure, condition and properties of relief making accumulation. In the studied area, the basic material influencing relief, in which the most intensive deformations take place as a result of landslides occurrence, is loess accumulation (loess loams, sandy loam). They sodden very easily and fast that characterises water-instability of their structures. Loess has a middle damp capacity and weak or very poor water permeability. Its filtration factor (K_f) changes from 0.15 to 1 m per 24 hours. It is necessary to note that in the vertical direction its water penetration is higher than in horizontal one, and consequently it is anisotropic as far as the filtration is concerned.

For the right understanding of the landslides mechanism, the solidity and deformation properties of the main deformed horizon, which develops the loess thickness within the agglomeration boundaries, have to be studied. General deformation module of the loess soil changes in natural conditions from 5.5 up to 15.0 MPa. In natural humidity, loess accumulation is characterised by insignificant deforming ability, despite its high porosity (40–48%). Nevertheless, with the increase of humidity, resulting from the technical influences (higher then W), loess deformability considerably increases. Durability as well as deforming properties depend on the generalised parameters which characterise resistance of landslides: humidity and density. The internal friction angle of the loess material changes from 10° up to 26°, and its specific coupling 0.015–0.03 MPa.

In the bottom part of the loess series, a layer of hard brown and red-brown loams of zavadivsky age appear which, except for basic parameters of properties, come nearer to their host: red-brown clay of martonosky age. Hard loams and clay have lower porosity (25–40%) and filtration factor (K_f= 0.001 m/day), higher numbers of plasticity (0.20–0.26) and higher module of general deformation (E = 0.13–0.38 MPa). Therefore, taking into the consideration filtration, solidity and deformation properties, layers of zavadovsky age loams and martonostsky age clay can play an important role for landslides as a waterproof horizons and a sliding surfaces.

Climatic factors. The mode of activation of the relief making processes is considerably influenced by climatic factors, namely, by the long-term average quantity of precipitation, a mode and intensity of their drop-out, and freezing and melting of soil. Climatic and meteorological conditions were observed within the agglomeration for 170 years, however, the reliable instrumental research started in 1893. A meteorological station functioned in Dnipropetrovs'k from 1833 untill 1955, and then supervision of the meteorological conditions was taken over by the hydrometeorological centre of the Dnipropetrovs'k city airport.

The long-term average quantity of precipitation for territory of agglomeration amounts to 470–480 mm, middle term average monthly norms — 70–80 mm, and the maximum quantity of their drop-out is marked during the spring-elderly period, and amounts to 280 mm (or 60% of its average annual quantity). Activation of landslides is also connected with abnormal precipitation during April–July. The greatest quantity of the precipitation during one downpour was noted on July 28, 1977, when 120 mm of rain water has fallen in 2 hours. The soils freezing depth in the studied region reaches usually 0.11–0.50 m. Soils thawing is observed frequently enough, fast snow melting assists also the landslides developments. For example, a series of landslides developed in the malicious 2005 year in the agglomeration territory, and one of the reasons was quick snow thawing (Fig.7).

Hydrogeological factors. This is a very important factor, characteristic for the first water horizon formed within the early Pleistocene and Neogene soils loams. Its water table appears at the depth of up to 2 m on landslides and low terraces, and at 5–20 m on the watershed plateau.

The agglomeration is located at the borders of the two hydrogeological areas: Dniprovsk–Donets artesian pool and the Ukrainian shield, different as far as hydrogeological characteristics are concerned. The location of the main water horizons and complexes within the agglomeration boundaries is influenced by engineering-geomorphological conditions: (1) lower or higher position of anthropogenic and recent alluvia; (2) modern alluvial-diluvial adjournment; (3) lower, middle or higher posi-

Fig. 7. Catastrophic activation of landslides as the result of the climatic and technical factors actions

tion of the anthropogenic aeolian-diluvial sediments; (4) uniform deposits of the Poltava series (berekska–novopetrivska svit); (5) higher position of the crystalline basement fissure zones and aeration zone of Archaic–Proterozoic age.

It is necessary to emphasize, that the behaviour of the first water horizon can be one of the main conditions of the landslides activation within the boundaries of the whole investigated territory. This horizon is formed in the loess loams and developed on the red-brown clays which lie in the bottom part of the anthropogenic deposits. At the beginning of XX century, the water horizon had no universal distribution, its capacity did not exceed 8–10 m, and its depth reached 40–50 m on watersheds. In 1930., a period came when the technical change of subsoil water mode has begun because of the hydroelectric power station construction in Zaporozhye city, located approximately 80 km from Dnipropetrovs’k. As a result, the Dnipro River level had risen by 4.4 m that also had caused rising of subsoil water level (Fig. 8). Within the agglomeration boundaries, level of groundwater had risen during the last 100 years by 20–47 m.

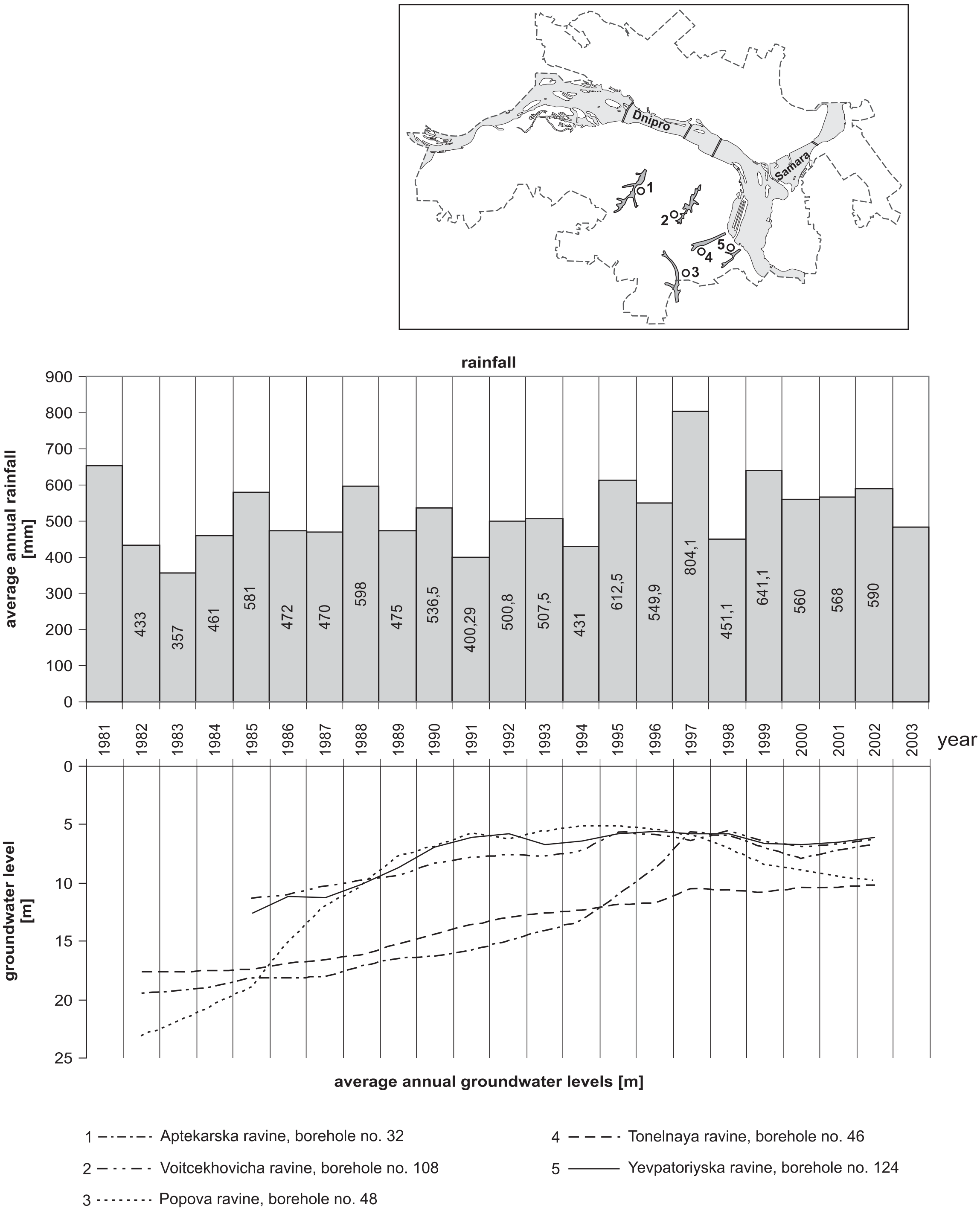

Fig. 8. Comparison of the dynamics of average groundwater levels and average annual rainfall (1982–2002)

Presently, capacity of this water horizon is not sustained and closely connected with the depth of water appearance: in areas where the red-brown waterproof basement is elevated, the capacity of the horizon is minimal, being 0.5–1.0 m thick, and in the basement depressions is maximal, with the horizon thickness of 6–9 m. The average depth of the subsoil water level varies from 0.5 up to 10.0 m, but within the boundaries of the high right-bank terraces it increases to 14–25 m. On flood--lands and low terraces, the subsoil water appears on surface in places, forming boggy sites. Water in the water horizon is replenished by the infiltration of atmospheric precipitation, by water inflowing from the lower water horizons, and also by water seeping from water pipelines. Behaviour of the anthropogenic water horizon is changeable, closely connected with quantity of water which it carries.

The great importance for the development of relief and sliding processes has also Neogene water horizon contained in the sediments of the Poltava series, lying at the depth of 4–6 m in ravines, and at the depth of 26–55 m on the watershed plateau and the left-bank of accumulative plain (absolute marks 65–75). The Neogene sand is a host for this water horizon. The water replenishment of the horizon in watershed is supplied by vertical infiltration from the anthropogenic water horizon, in places where waterproof bed is lacking, and in the ravines — by infiltration of the atmospheric precipitation and flowing surface water. The Neogene water horizon is unloading into the Dnipro River.

The main types of technical operations which change the hydrogeological conditions of the city territory are: formations of depressive cones in water complexes, use of "wet" technologies by enterprises, faulty operations of water pipelines, water drainage from underground tunnels, etc.

Technical factors. The main technical causes of landslides activation within the agglomeration boundaries are as follows:

— regulation of the Dnipro River and rise of its level by 4.4 m in average as a result of the construction of a water basin in 1932 as well as of the destruction of many natural drains by infilling;
— significant age of water carrying networks (30–60 years) and the resulted considerable water loss (15–35%);
— presence of the "wet" technologies enterprises (metallurgical, electropower, chemical and others);
— increased loading of the slopes by the too dense construction of multi-storey houses;
— undercutting slopes during roads and/or pipelines construction;
— influence of vehicles vibrations.

The potentially movable areas are recently actively utilised for recreational purposes. For instance, constructions of a sports complex, such as skating rink and artificial ski line (Fig. 2, 3) are carried out on moving terrace in a Tunnel ravine. Construction of this complex negatively influences stability of the potentially sliding site because of large scale works and the increase of static load.

REGIONAL CONDITIONS FOR THE APPEARANCE OF SLIDING PROCESS

Within Dnipropetrovs'k–Dniprodzerzhins'k agglomeration boundaries, there are 202 landslide sites, including 23 active sites (Fig. 9). The total area covers 2,663 km^2. Almost 50% of it is located within the inhabited and industrial areas (Fig. 10).

Landslides developed on the gullies-ravines slopes on the right-banks of both bridges are made mainly of loess identical to loams of late anthropogenic age, and are characterised by high sensitivity to various technical influences. Having a weak hardness and significant susceptibility to deformations, the loams under certain conditions (high humidity, increase of upload) undergo plastic deformations which can lead to catastrophic infringement of stability and the landslide deformation of slopes. The majority of landslides activate on the over wetted slopes.

The greatest deformations caused by landslides are observed on territories with high changeability of surface relief, characterised by quick level changes, from 8–12 m up to 25–35 m, and steepness of more than 5–10°. Every landslide makes a moving site which sizes define scale of the phenomenon. They can be different. Areas of some landslide sites change from 90 square m up to 5,000–6,000 m^2, and even up to 45,000 m^2. Landslides in the city territory are also very variable in morphological features. The most widely spread are circus type and face-to-face landslides. Sliding occurs on red-brown clays or kaolins.

Within the agglomeration territory, there are two types of the most widespread landslides as far as the depth of their basement deformations is concerned: deep and superficial. Deep landslides develop on slopes with steepness higher then 15°. They have complex structure and mainly circusidentical and face-to-face forms. They are widely spread in homogeneous and isotropic loess, identical with loams. They activate under influence of natural and technical factors. These landslides are responsible for greater erosive systems of the right-bank part of the city. They slowly move down the slope on a distance of 120 to 520 m. The maximal depth of their deformations reaches 20–30 m.

Superficial landslides within the cities territory have small sizes (up to 100 m^2), and developed in aeolian-diluvial loams of the late anthropogenic age. They are characterised by incorporating a part of slope into the deformed basic horizon, not reaching the slope's bottom part, though. The landslides develop on slopes with steepness of 5–15°. The depth of slopes deformation does not exceed 1–3 m. As far as their form is concerned, the superficial landslides have circus, angular outlines, similar to typical glaciers. There are also old, already stabilised, landslides within the cities territory. These landslides reveal traces of two-three former displacements complicated by small landslides and ravines which still continue to grow.

The studies on the rules governing the activation of the sliding processes and on their factors within the industrial agglomeration boundaries allowed to develop the following main models of the preventive (precautionary) protective actions:

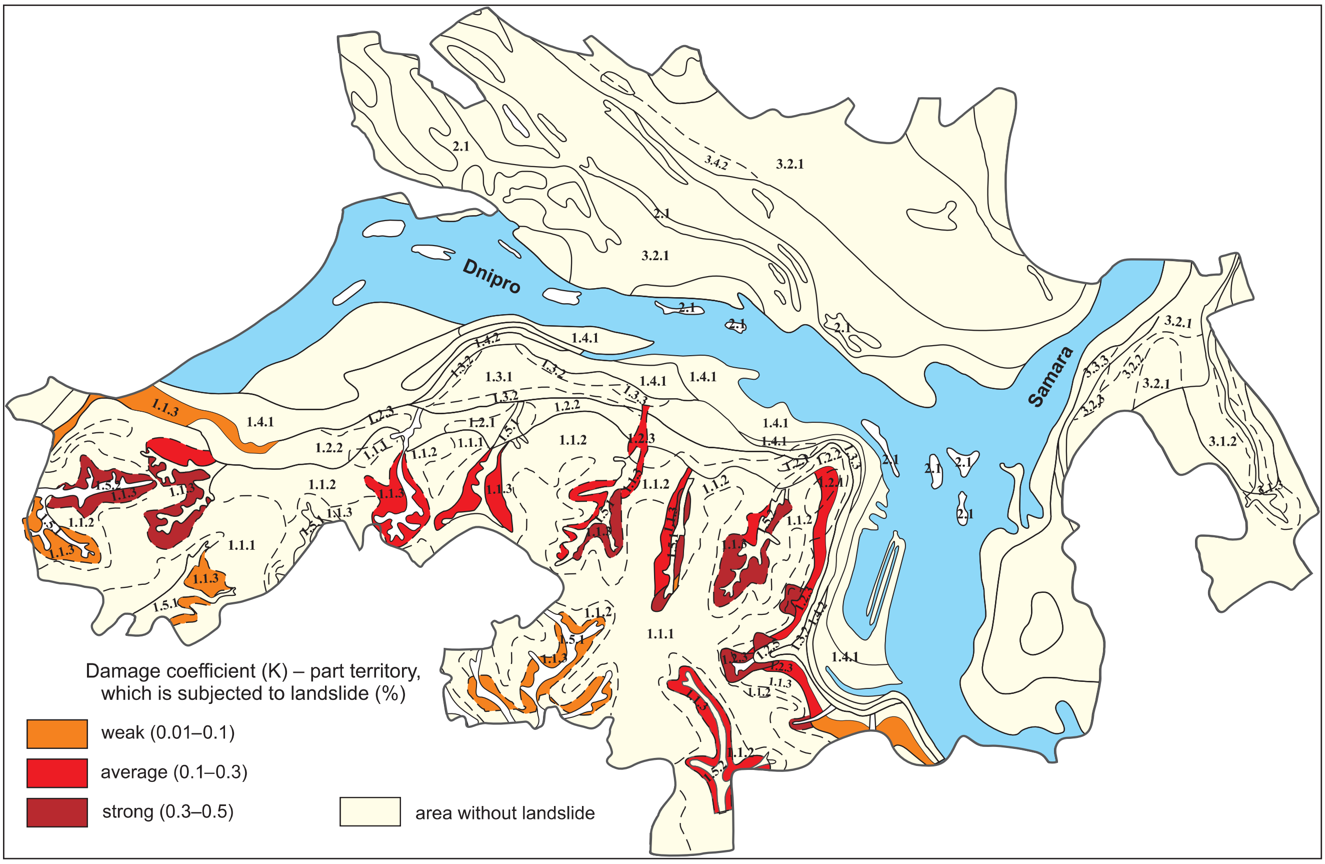

Fig. 9. Development of landslide processes in Dnipropetrovs'k

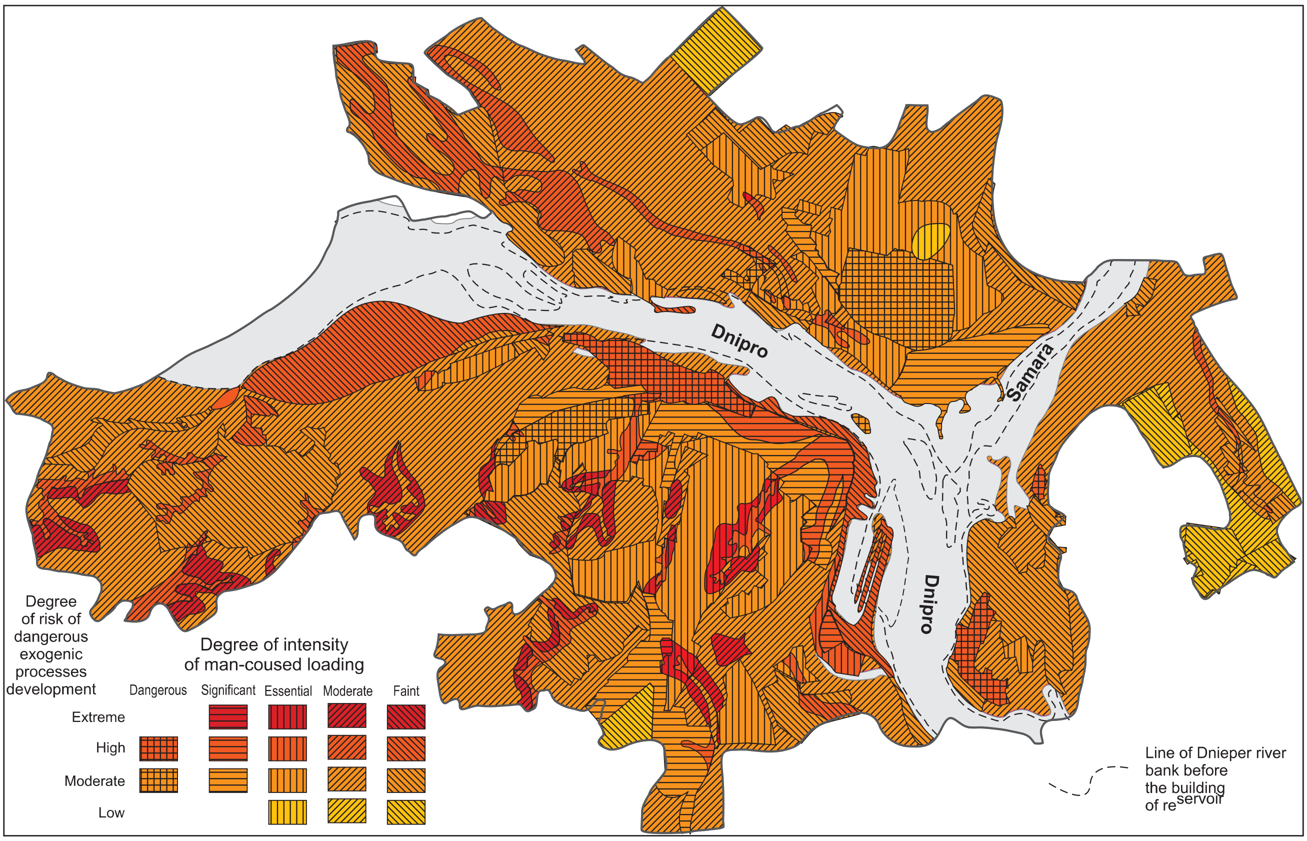

Fig. 10. Ratio of risk degree of dangerous exogenetic processes development and intensity of man-caused uploading

1. As the soils slopes stability depends on the balance conditions between a landslide and stabilising forces, the designing of a slope uploading should take into consideration the preservation of an appropriate amount of stabilisation forces which will prevent displacement of the ground. Landslide activation forces have mainly gravitational character and depend on the combined weight of ground and water. There could be the following ways of the reduction of landslide activation forces and the increase of stabilising forces: changing the landslide direction and structure, strengthening slopes by buttresses, keeping prisms, retaining walls etc., and forming constructions for tapping superficial and groundwater.
2. As an alternative, a decision could be made on changing the site of housing and linear engineering constructions.
3. In cases, when transferring of the objects planned or constructed within the dangerous landslide site limits is impossible, a variant of unstable ground removal should be considered. This can be economically advantageous only then, when the small volumes removal of weak soils, lying at insignificant depth, would be at stake.

Unfortunately, very little is applied from the above suggested actions in the most dangerous sites of Dnipropetrovs'k–Dniprodzerzhins'k agglomeration (Fig. 5).

CONCLUSIONS

Within the studied region boundaries, activation of landslides caused by technical reasons became a very serious problem, especially in the situation of a very intensive industrial and housing engagement of that territory.

The geological environment of the agglomeration is suppressed by various influences, especially connected with industrial infrastructure, especially with enterprises functioning on "wet" technologies, with water pipelines losing significant amounts of water, and because of the insufficient development of the drainage constructions.

The non-uniformity of the geological environment increases the danger of the cumulative actions of all kinds of technical causes impact, raising the degree of landslides development risk. Thorough investigations of the landslides activation behaviours will greatly assist in making the right decisions on different types of constructions location as well as on the recommendations for stabilisation of the endangered landslides sites.

REFERENCES

GOSHOVSKY S.V., RUDKO G.I., BLINOV P.V., 2004 — Engineer-geological analysis, monitoring and defence of the landslides territory. ZUKC, Lviv.

GOSHOVSKY S.V., RUDKO G.I., PRESNER B.M., 2002 — Ecological safety of the techno-natural geosystems in connections with catastrophic development of geological processes. Nechlava, Kiev.

INFORMATIONAL BULLETIN on the state of the geological environment of Ukraine in 1997. 2000. Issue 16.

POLISHUK S.Z., KUSHINOV N.V., SERDYUK Y.Y. *et al*., 2003 — Forecasting of dangerous geological processes (on example of Dnipropetrovs'k region). *In*: Countries and regions on the way of balanced development: 111–114. Academperiodika. Kiev.

SUMATOKHINA I.M., 2004 — Estimation of damaging of the large city territory by exogenic processes. *In*: Ukraine: geographical problems of constant developing. Collection of scientific articles. In four volumes. VGO Obrii, **3**: 173–174.

SUMATOKHINA I., DUK N., 2004 — Risk of dangerous exogeodynamical processes development on the territory of large cities. *Polish Geol. Inst. Sp. Papers*, **15**: 85–90.