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GIS analysis of the hydrogeological conditions as the factor of the development and activation of landslide processes (by the example of Ivano-Frankivsk region)

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SUMMARY

The research is devoted to the influence of hydrogeological conditions on the formation of landslides for the territory of Ukraine. Special attention is paid to Ivano-Frankivsk region, where landslides have a significant spread. GIS analysis of the localization of landslides in relation to the structural units of hydrogeological zoning allowed to establish certain patterns of the territorial intensity of landslide processes coordinated with the mountain and plain landscape-hydrogeological complexes.

Introduction

Determining triggers, natural and man-made factors, which influence on the exogenous geodynamical activity are playing the dominant role in the theory and practice of the study of exogenous geological processes (EGP). Factors of EGP activation are considered both in the classical (Emelianova, 1978; Lomtadze, 1978; Sheko et al., 1999) and in special (Rudko and Osiiuk, 2012; Kuzmenko and Chepurna, 2014, Kuzmenko et al., 2016) literature on engineering geology, devoted to questions of forecasting exogenous geodynamical conditions. In the referenced works it is proved that the most objective is a comprehensive approach to the analysis and forecasting of EGP, which takes into account the quantitative measure of factors (numerical characteristics of exogenous dynamic), because in the general case none of the factors is dominant and it is necessary to take into account each of them. However, it should be noted that certain factors, firstly, are necessary to take into account in studies of any type of EGP, and secondly, they are so effective that deserve special attention.

This paper deals with natural hydrogeological factors, which can be divided into two groups: static and dynamic (Fediv and Davybida, 2015). Static factors include constant (or slowly changing) hydrogeological conditions (area of distribution and water enrichment of aquifers, composition and capacity of the aeration zone, aquifer and confining formation, filtration coefficients, chemical and physical properties of groundwater, etc.), which are factors of zoning of territories for studying of spatial distributions of EGP. Dynamic factors include the variability of the hydrogeological regime elements, first of all, the level and flow of groundwater, which should be considered as triggers of EGP activation in the temporal prediction.

Landslides are one of the most dangerous and active exogenous geological processes, widespread in Ukraine. It should be noted that the influence of hydrogeological conditions and fluctuations in groundwater levels on the occurrence and activation of landslides has not been studied enough. However, previously the role of groundwater in the formation of landslides has been considered by researchers both at local (Purgina et al., 2016; Heruk et al., 2017; Koshliakov et al., 2018) and regional (Bileush, 2009; Shatalin, 2013; Kuzmenko et al., 2016; Ivanik et al., 2019) levels.

In this paper the study of the relations between the hydrogeological factors action and the landslides is conducted for purposes of the importance of their impact on the possibility of landslides occurrence. The main task is to identify and substantiate the spatial patterns of influence of hydrogeological conditions for the landslide-affected area on a regional level using GIS technologies.

General characteristics of the landslide occurrence within the main hydrogeological structures of Ukraine

Regional studies and forecasting of landslide hazards are based on the analysis of factors that influencing the development and intensification of landslides. The impact of groundwater on the activation of landslides is the most significant if the zone of landslide deformation is confined to groundwater aquifers. A simple comparison of two cartographic layers modelling the spatial distribution of landslides and hydrogeological regions (aquifer systems) of the first order, selected by the structural-hydrogeological principle, does not allow us to trace the natural connection between the occurrence of landslides and regional conditions of groundwater formation. (Fig. 1).

To compare the intensity of landslides for individual hydrogeological regions, territorial normalization of the landslides distribution is required using a quantitative characteristic of the contrast coefficient (Ri), which reflects the impact of the area by landslides (Kuzmenko et al., 2016). It is assumed that the results indicate the highest impact of landslides in the Crimean, Transcarpathian, Precarpathian hydrogeological regions, as well as the Carpathian folded region, which is characterized by significant dissection of the terrain, as well as the variability of the depth of the groundwater level. For these regions, taking into account the numerical characteristics of the position of the groundwater

level in the study, modelling and forecasting of EGP is complicated by the lack of the precision regional cartographic models of the aquifers' level surfaces.

Obviously, a more detailed zoning of territories should be taken into account for the spatial analysis of the relations between the development of landslides and hydrogeological conditions.

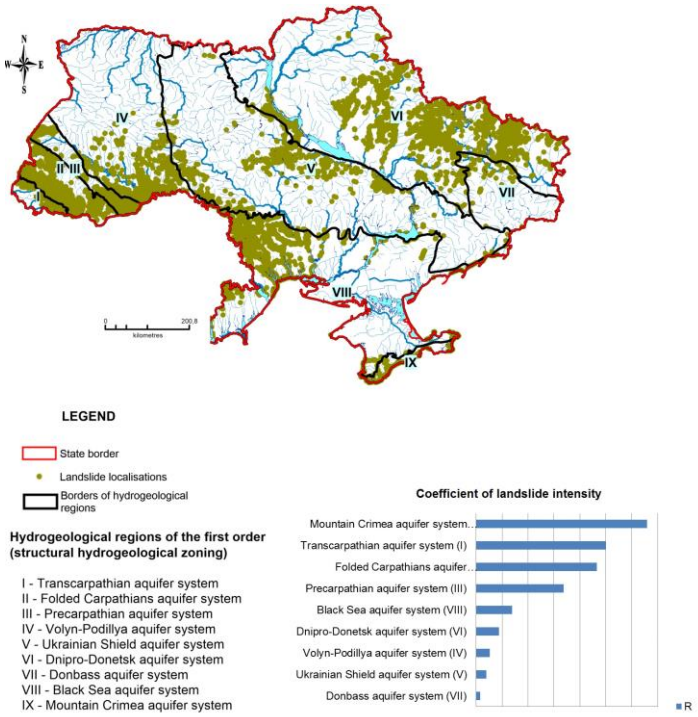

Figure 1. *Scheme of hydrogeological zoning and landslides for the territory of Ukraine*

In our opinion, such spatial patterns are landscape hydrogeological complexes (LHGC), which are azonal hydrogeological units and are characterized by general features for most hydrogeological regions (Ruban and Nikolishina, 2005). The allocation of LHGC takes into account the structural peculiarities of the aeration zone, the aquifer and the aquiclude, as well as the collecting properties of the aeration zone rocks, from which the groundwater recharge (the infiltration of atmospheric precipitates) depends and, consequently, a groundwater level regime, that affects the activation of landslides, is formed. Further, increasing groundwater levels in sloping areas, which are affected by landslides, leads to an increase in the weight of the landslide body due to water saturation, wetting the surface of the landslide slip horizon and reducing the adhesion of landslides and underlying rocks, the involvement of additional soil in the landslide process, change the slope of the groundwater table, reduction of compression and other physical and mechanical properties of rocks.

Geoinformation analysis of landscape-hydrogeological conditions of Ivano-Frankivsk region as a possible factor influencing landslides

The study area is located in the region with a difference of absolute relief from 230 to 2061 m above sea level within such hydrogeological regions as Volyn-Podolian, Precarpathian artesian basins and Carpathian hydrogeological folded region. Due to the complex hydrogeological structure and significant diferentiation of the relief, the depths of the groundwater aquifer vary in a very wide range (from 0 to more than 30 m). In particular, 10 varieties (7 plains and 3 mountains) of the landscape hydrogeological complexes are allocated within the region (Davybida et al., 2018; Davybida and Karpinskyi, 2019). Groundwater is confined mostly to Quaternary alluvial deposits and is almost universally used for domestic water supply. This administrative region is also characterized by the significant occurrence of dangerous exogenous geological processes, primarily landslides.

Overlay analysis of the layers of areas with certain intervals of groundwater table (0-3 m, 3-5 m, 5-10 m, 10-20 m, 20 m and 3-20 m), LHGC of different types, localization of landslides within the studied area was carried out in GIS environment, as well as the calculation of contrast factors (Ri), which characterized spatial intensity of landslides occurrence.

The results indicate the highest damage by landslide processes of territories with ranges of variability of groundwater levels between 3 and 20 m (Ri = 1,56). For the territories where the groundwater level is situated at 0-3 m and 5-10 m from the surface, the lower vulnerability is characteristic (Ri = 0.74 and Ri = 0.91 respectively), whereas areas with levels of 3-5 m, 10-20 m and> 20 m have the similar value of the contrast coefficients (Ri≈0,45). What about the damage of various types of LHGC by the landslides, the highest values of the contrast coefficients are obtained for the areas of such mountain LHGC as M (3) (Ri = 3.34), M (1) (Ri = 1.41), and such plain LHGK as 5a (9) (Ri = 1.38) and 4 (a) 7 (Ri = 0.99). The landslides damage for another type of mountain LHGC, M (2), within the region is not significant (Ri = 0.49). Within the region, landslides are not observed (Ri = 0) in the plain LHGK 9a (17), 7a (13) and 7b (14). Analysis of stratigraphic sections and groundwater properties allows noting significant heterogeneity of rocks of aeration zone and water-bearing stratum (in particular, the presence of sandstones, argillites, marls, sand and clay deposits), the variability of filtration coefficients of aeration zone is in the range of 0,5-15 m per day for the LHGC with a high level of landslides. At the same time, the structure of LGGK, for which the development of landslides is not observed, is usually more homogeneous, the filtration coefficients of there aeration zone vary from 0,01 to 8,2 m per day.

Conclusions

Therefore, the significant occurrence of landslides within Ukraine indicates the need of their study. Existing methodologies for their forecasting have to be improved, first of all by considering a wider range of triggering factors of landslides intensification. Primarily, natural hydrogeological factors have to be involved. For the territory of Ivano-Frankivsk region considered in this work, the spatial distribution of landslides is consistent with the taxons of hydrogeological zoning (LHGC), which should be used as spatial patterns in creating regional forecasting models of landslides. Further perspectives of the research are to increase the probability of the digital models of groundwater levels, in particular, by using fuzzy logic methods, determining the spatial correlation between hydrogeological conditions and localization of landslides and other exogenous geological processes, taking into account the temporal patterns of the hydrogeological regime to further improve the methodology for predicting exogenetic geodynamical activity.

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