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Analyzing Slope Steepness for Sustainable Agricultural Land Management in the Vinnytsia Urban Territorial Community Using GIS

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SUMMARY

This research focuses on the crucial role of slope steepness in agricultural land management within the Vinnytsia urban territorial community, recognizing its impact on land productivity, erosion, and crop suitability. Employing GIS technologies and digital elevation models (DEMs), the study analyzed terrain characteristics to develop slope steepness maps. The methodology involved using QGIS software with the GRASS plugin to generate DEMs from contour lines, derive slope aspect, and calculate slope steepness.

The findings highlight that a significant portion of arable land (96.6%) in the Vinnytsia community is on slopes up to 3°, belonging to the first ecological and technological group (ETG I). However, 3.0% falls within ETG II (3°–5° steepness) and 0.4% within ETG III (steeper than 5°), necessitating differentiated land use approaches due to elevated erosion risks. The study proposes specific erosion control measures and restrictions for steeper lands, including conservation agriculture principles, exclusion from intensive use, and transformation into pastures or forest plantations for ETG III lands. This GIS-based analysis provides accurate data for effective spatial planning and sustainable agricultural practices in areas with complex terrain.

Introduction

Slope steepness has a significant impact on land productivity and its suitability for cultivating various agricultural crops, as it determines the intensity of erosion processes, accessibility for agricultural machinery, and the overall potential for land use. This factor must be taken into account in areas with complex terrain, where improperly organized land use can lead to soil degradation and loss of fertility. The use of GIS technologies enables effective terrain analysis and the creation of slope steepness maps based on digital elevation models (DEMs) (Kumar et al., 2017).

Method and/or Theory

The research employed a comprehensive set of methods, including statistical analysis, which was used to examine the structure of the land fund in Vinnytsia Oblast and the land category distribution within the Vinnytsia urban territorial community. The cartographic method enabled the visualization of the spatial characteristics of the territory and facilitated the analysis of the location and morphometric features of slopes. The monographic method involved the study of literature sources, bibliographic information, and scientific publications related to terrain analysis, morphometric characteristics, and the specific features of land use on slopes. The analytical method was applied to construct digital elevation models (DEMs), which serve as a key tool in modern spatial analysis.

In addition, Geographic Information Systems (GIS) were extensively used in this research. Core spatial analyses, terrain modeling, and slope steepness determination based on DEMs were conducted using QGIS software (with the GRASS plugin) (Chaskovskyi et al., 2021).

In the research, slope steepness is an indicator that describes the inclination of the Earth's surface and is measured in degrees or percent (Do et al., 2024). The steeper the slope, the more intense the soil erosion processes – particularly in mountainous and hilly areas – leading to land degradation and a decline in soil fertility. Moreover, steep slopes hinder the mechanization of agricultural activities and limit the choice of crops that can be cultivated. Each slope is characterized by its steepness, cross-sectional height, contour configuration, and slope length.

Results

The experimental and practical implementation of slope steepness analysis approaches was carried out using the case study of the Vinnytsia urban territorial community. The total area of Vinnytsia Oblast is 2,649.2 thousand hectares (4.4% of Ukraine’s territory). The majority of this area (76.03% of the total) is occupied by agricultural lands. Approximately 25% (672.8 thousand hectares) of all agricultural land is affected by water erosion, 7% (179.7 thousand hectares) suffers from wind erosion, and 57% (1,511.0 thousand hectares) consists of acidic soils.

Among the primary causes of erosion processes are irrational land use practices. These include the intensive plowing of slopes with inclinations greater than 3° for row crop cultivation, especially sugar beet, the lack of an integrated approach to implementing anti-erosion measures, and the overrepresentation of row crops in the structure of arable land.

The area of the Vinnytsia urban territorial community is approximately 256,344.4 hectares, with over 50% of the territory classified as agricultural land. The level of arable land use within the community is 93.01%, and the ratio of arable land to ecologically sustainable agricultural lands is 13.32, indicating an extremely high level of anthropogenic pressure on the soil cover of the community's agro-landscapes.

Overall, land use in the Vinnytsia region is characterized by a high degree of plowing on sloping lands, expansion of row crop cultivation areas, inadequately justified large-scale reclamation of waterlogged and swampy lands, neglect of scientifically grounded soil-protective crop rotations, and the widespread application of industrial agricultural technologies. These practices have led to a significant reduction in the areas covered by natural vegetation communities (meadows, forests, wetlands), accompanied by an increase in the proportion of developed agricultural lands, primarily arable land (Boiko and Maksymova, 2021).

For the geoinformation-based analysis of slope steepness in agricultural land parcels within part of the Vinnytsia urban territorial community, contour (elevation) isolines provided by the State Scientific and Production Enterprise "Cartography" were used. The initial step involved importing a .shp file containing elevation contours of the study area into QGIS software. Next, a point layer was generated from the contour lines, and new fields for coordinates (X, Y) and elevation values (Z) were added to the attribute table of the point layer.

To convert the vector isolines into raster format, the GRASS tool *v.to.rast* was applied. Then, to generate a Digital Elevation Model (DEM) from the rasterized contours, the *r.surf.contour* tool was used, which interpolates elevation values between isolines to create a continuous surface model (GRASS, 2025). After clipping the raster using the “Extract raster by mask” function, slope aspect was derived – this parameter indicates the direction of surface inclination and is important for analyzing the amount of solar radiation received by the terrain. The aspect analysis was performed using the *r.slope.aspect* tool.

Subsequently, slope steepness was calculated – an essential parameter that characterizes the inclination of the surface and directly influences land suitability for different types of agricultural use. To digitize the agricultural land parcels, their coordinates were converted into the Ukrainian Spatial Coordinate System 2000 (USK 2000). Using the “SAGA Convert Lines to Polygons” tool, contour lines were converted into polygons, ensuring the proper geometric representation. The “Check Validity” and “Fix Geometries” tools were then applied to detect and correct geometry errors in the polygon layer (SAGA-GIS, 2025).

After clipping the slope raster to the boundaries of the agricultural land parcels, raster reclassification was carried out using the GRASS tool *r.reclass*, based on a predefined classification scheme that corresponds to slope steepness categories.

The final stage of the geospatial analysis involved generating a slope steepness report. This was done using the GRASS tool *r.report*, which produces a table summarizing the area of each slope category.

Based on the comparison of the slope steepness map with the identified arable land parcels, the slope steepness of agricultural landscapes was determined (Jarasiunas, 2016). These data were then used to classify the land into ecological and technological groups. As a result, areas of arable land located on slopes with steepness levels unsuitable for intensive agricultural use were identified (Fig. 1).

The analysis of slope steepness on which arable lands are located revealed that 96.6% of arable land lies on slopes with an inclination of up to 3° and belongs to the first ecological and technological group (ETG I). Arable land situated on slopes with a steepness of 3°–5° accounts for 3.0% and belongs to ETG II, while only 0.4% of arable land is located on slopes steeper than 5° and is classified as ETG III.

These lands are predominantly located along gullies in the eastern part of the study area, near the village of Velyki Krushlyntsi.

Within subgroup I-a of ETG I – which includes arable lands on slopes with an inclination of up to 1° – no ecological or technological restrictions are applied due to the minimal risk of soil erosion. This subgroup requires only shelterbelt-based reclamation measures and protection against deflation. The total area of arable land in subgroup I-a amounts to 2,444.71 hectares.

Subgroup I-b of ETG I includes arable land on slopes with a steepness of 1°–3°. Due to the higher erosion risk compared to subgroup I-a, certain restrictions are imposed on tillage direction and crop sowing. In this subgroup, both tillage and sowing must be carried out strictly across the slope. Overall, intensive crop production technologies are applied within ETG I to achieve maximum yields with minimal environmental impact. Preference is given to a differentiated soil cultivation system and maximum fertilization to enhance economic efficiency.

The second ecological and technological group (ETG II) includes arable lands located on slopes with a steepness of 3°–5°, where the soil cover is predominantly composed of slightly and moderately eroded soils. Due to the elevated erosion risk, ecological and technological restrictions are applied regarding the placement of bare fallow and row crops. According to the recommendations of research institutions, the cultivation of bare fallow, row crops (including technical, vegetable, melon, potato, and root fodder crops), and other erosion-sensitive crops is not permitted on lands classified as ETG II.

On these lands, soil-conservation crop rotations are to be introduced, incorporating crops with high erosion-preventive capacity. Principles of conservation agriculture are implemented here, with an emphasis on natural soil restoration methods. Preference is given to gentle soil management technologies, complemented by subsoiling and mulching with plant residues.
The third ecological and technological group (ETG III) includes arable lands located on slopes steeper than 5°, where moderately eroded soils dominate the soil cover. Due to the high erosion risk, strict ecological and technological restrictions are imposed on their use in intensive farming.
The economic use of ETG III lands is considered environmentally hazardous and economically inefficient. Therefore, these lands are excluded from intensive agricultural use, subjected to land conservation measures, and subsequently transformed into natural pasturelands or forest plantations.

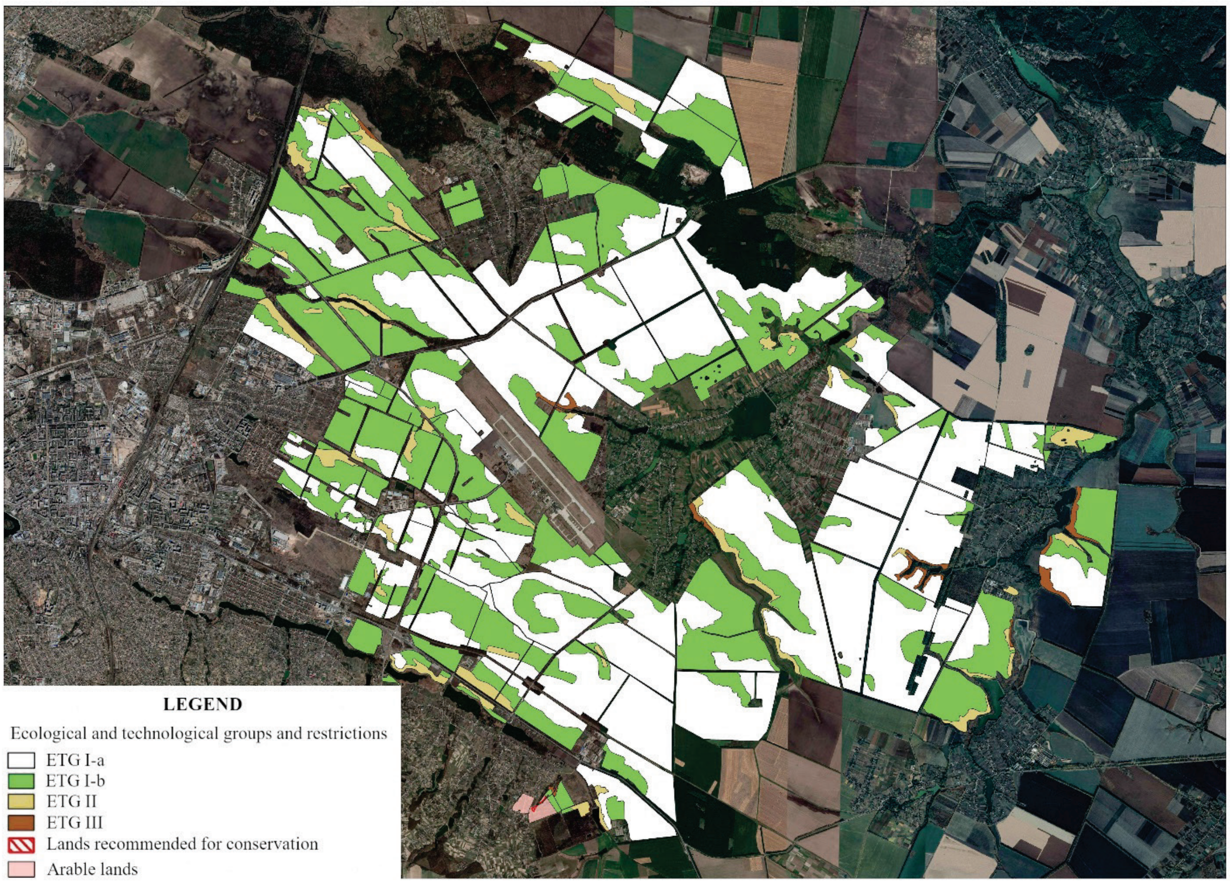

Figure 1 *General Scheme of Recommendations for the Formation of Ecological and Technological Restrictions within the Territory of the Vinnytsia Urban Territorial Community*

Conclusions

Slope steepness is one of the key factors influencing the quality of agricultural lands, the intensity of erosion processes, and the selection of optimal agrotechnical measures. GIS technologies serve as highly effective tools for slope steepness analysis, providing high accuracy of results, prompt data acquisition, and the capability for comprehensive spatial data analysis in combination with other territorial characteristics. The effectiveness of slope steepness analysis on agricultural lands largely depends on the accuracy and resolution of the initial geospatial data, as well as the correctness and proper configuration of digital

elevation model processing parameters. This is confirmed by the experimental and practical implementation of slope steepness determination in part of the Vinnytsia urban united territorial community.
The obtained results demonstrated that a significant portion of the study area exhibits varying slope steepness, necessitating a differentiated approach to land use, including specific erosion control measures and restrictions on intensive agricultural activities on notably steep slopes. For such lands, a set of anti-erosion measures can be proposed, including contour-reclamation land organization, the application of no-till soil cultivation, implementation of soil-protective crop rotations, and the establishment of buffer zones.

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