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# TO THE CONSIDERATION OF TERRITORY RELIEF FEATURES IN THE LAND CADASTRE

The aim of the research is to define the features of the relief of land plots of a territorial community (TC) in the mass valuation. The paper explains the use of a three-dimensional cadastral registration system on the example of one object, i. e., one TC. This results in the classification of TC land plots based on certain characteristics. *Methodology.* For the study, a digital terrain model was created for the object located in the Pokutska plain territory of southwestern Ukraine, on the territory of Uhrynivska TC in Ivano-Frankivsk district of Ivano-Frankivsk region, northwest of Ivano-Frankivsk. The characteristics of the land on the slopes were obtained by mathematical modelling using the SURFER software package. Two methods were used to calculate the amount of solar energy falling on a certain area of the Earth's surface: astronomical and technical. Each of the methods gives approximately the same result. *Results.* The digital model was used to create a 3D terrain model with the distribution of the study area by slope steepness. According to the model, slopes with slope angles of up to 3° prevail within the territorial community. Steeper slopes can be observed in the northwestern part of the Uhrynivska territorial community and on the southwestern slopes of Vovchynetskyi Hill (up to 17°). The paper shows the distribution of the solar energy coefficient received by a particular area of the Earth's surface, depending on its exposure and angle of inclination The solar energy coefficient distribution map allows visualizing the insolation of a particular agricultural land. It can be used to calculate the insolation, i.e., the amount of solar energy received per unit area, and subsequently used in the expert assessment of land plots. In this way, it is possible to determine the total amount of heat that falls on each land plot during the day or the entire growing season. Mathematical modelling methods were used to obtain the illumination characteristics of land on slopes. *Novelty and practical value.* The experimental studies of the three-dimensional cadastral registration system aimed at allocating surface areas with specific slope orientations have yielded valuable results. These findings can be applied to the study of the Earth's surface relief, which significantly influences the fertility of agricultural land., Additionally, this relief plays a critical role in environmentally hazardous phenomena, including the formation of ravines, floods, mudflows, landslides, and avalanches. Therefore, developing and improving a three-dimensional cadastral registration system for surface areas is an urgent task for the TC. Our research will contribute to the objectivity of mass assessment, allowing us to extend the methodology we have applied to other regions of Ukraine and abroad.

*Key words*: cadastre, registration, land plot, three-dimensional system, real estate object, relief.

## Introduction

In recent years, spatial planning of territories, including the land of territorial communities (TCs), has become widely used. Consequently, there is a need to identify ways to develop communities in the area of spatial planning, both for communities whose territory has been destroyed by war and for those that have received new challenges related to the accommodation of internally displaced persons and businesses. This is done to ensure that TCs have rational spatial planning, balance resettlement and job placement, ensure the sustainability of the urban mobility system, and are inclusive, energy efficient and environmentally friendly. It is necessary to amend a number of regulatory acts and test the effectiveness of the regulated mechanisms through the implementation of pilot projects and development planning regarding adjacent territories. In this regard, it is proposed to amend the Procedure for the Exercise of Powers by the State Treasury Service in a Special Regime under Martial Law, approved by the Resolution of the Cabinet of Ministers of Ukraine No. 590 of 9 June 2021, in terms of the use of local budget funds by communities for the construction, reconstruction, and overhaul of important social infrastructure facilities. Such changes, in particular, should provide for the distinction between land plots suitable for agricultural work and plots for the construction of solar energy installations.

Thus, land surveying and design rely on a variety of data sources, including environmental, socio-demographic, architectural, urban planning and historical-architectural surveys. Other important data sources involve transportation, economic, engineering-geological, hydrological, meteorological, geomorphological, engineering-geodetic surveys, soil surveys, agrochemical soil surveys, and geobotanical surveys. To ensure the accuracy and relevance of this data, its hould be obtained using modern methods. In addition, areas suitable for sustainable economic development should be identified, along with priority areas, their strengths, and potential opportunities.

## *Analysis of main publications related to the problem*

It is worth noting that there are few publications related to the three-dimensional cadastral registration system, especially domestic ones. The Law of Ukraine "On the State Land Cadastre" does not provide information on the specifics of using three-dimensional real estate objects, including land plots [Law of Ukraine "On Amendments to Certain Legislative Acts…].

As a result of reviewing the relevant elements of the legislative framework [Law of Ukraine "On Strategic..."; Law of Ukraine "On Topographic and Geodetic..."; Resolution of the Cabinet of Ministers of Ukraine of 9 June 2021 No. 590 "On the Procedure for the Use…"], studying and analyzing the manual [Manual for Authorized Officials...], it was found that spatial planning in Ukraine as a sector is in a transitional phase from centralized policies and approaches to planning to modern integrated and strategic approaches. Opportunities to update urban planning documentation and bring it closer to European requirements opened up with the entry into force of Law No. 711 "On Amendments to Certain Legislative Acts of Ukraine on Land Use Planning" on 24 July 2021. Still, new challenges related to the introduction of martial law in Ukraine and the large-scale destruction of community infrastructure caused by the actions of the aggressor country have hindered the gradual implementation of reforms.

An objective assessment of land that considers its properties and and reflects its actual value, is important for many purposes. These purposes include withdrawing land from agricultural circulation, selling land, determining the amount of compensation for any negative effects on agricultural land, etc. [Order of the Ministry of Ecology and Natural Resources of Ukraine…]. Modern technologies for growing major crops should take into account the natural processes of photosynthesis and thermal energy. These factors are crucial for the reproduction of soil organisms activating soil formation processes, facilitating moisture exchange, oxidation processes in the soil, and accelerating metabolic processes between soil and plants [Levchenko and Shynkarenko, 2003; Pistocchi, 2002].

The temperature distribution on slopes facilitates the flow of cold mountain air down the slopes and its retention in depressions. As for the gradient, it is usually higher at the foot of the slopes than at the mountain valleys on the southern slopes, which are exposed to the north wind [Rudyi, Kerker, Tkachuk, 2011; Horlachuk, Rudyi, Kravets, 2018].

The microclimate of agricultural areas is determined by the different amount of solar energy that falls on slopes of different steepness and exposure [Rudyi, Kerker, Tkachuk, 2011; Horlachuk, Rudyi, Kravets, 2018; Pistocchi, 2002]. The conditions in the upper and lower parts of the slopes are different due to different soil moisture conditions. The terrain affects the distribution of heat and moisture in the soil.

The microclimate of the fields is characterized by different amounts of solar energy that fall on slopes of different steepness and orientation. The characteristics of the upper and lower parts of the slopes differ significantly due to different soil moisture conditions, as the terrain affects the distribution of heat and moisture in the soil. It affects the productivity of fields and the value of land [GIS-based solar radiation mapping; Rudyi, Kerker, Tkachuk, 2011; Horlachuk, Rudyi, Kravets, 2018; Rudyi et al. 2021; Sánchez-Navarro et al. 2022]. It is pointed out that these factors should be considered when boning land plots.

The most thorough analysis of the conceptual capabilities of the 3D cadastre is provided in [Stupen, Melnyk, 2022]. The authors interpret this cadastre, analyze its capabilities, and propose a transition to a hybrid 3D cadastre with appropriate visualization of real estate objects.

The authors [Stupen, Melnyk, 2022; 2023] note that the study was carried out based on an analysis of available literature on the topic of "Conceptual models for 3D cadaster". Three conceptual models of 3D cadastre and their alternatives are identified and described. The article also considers Ukraine's legislative support in the three-dimensional display of real estate objects. 3D cadastral databases can be used by those involved in land development processes, including land registrars, surveyors, architects, developers, designers, real estate agents, local governments, and corporate owners.

The article [Kondratenko, 2015] analyses the legal problems of introducing a three-dimensional land registration system. The author provides basic definitions of a land plot and land cadastre, highlights the current state of development of the land cadastre system in Ukraine, provides the main prerequisites for the introduction of 3D cadastre in the domestic space, describes the problems associated with its introduction, and identifies the benefits of using a three-dimensional land cadastre.

The paper [Kereush, 2019], using the example of the then Zastavnivskyi district of Chernivtsi region, substantiates the methodology of efficient use of land resources to develop solar energy based on remote sensing and GIS technologies.

The paper [Liulchyk, Kyiko, Rusina, 2020] points out that the conventional land management system based on a 2D cadastre does not allow for a vertical division of the object's space, forcing the investor to purchase the entire object or obtain other rights that allow for the use of a certain space of someone else's property, such as an easement of right.

Implementing such investments in urban areas, which involve the acquisition of entire facilities, creates additional costs; making investments only under municipal or state-owned land without purchasing the property of other parties may lead to suboptimal location of facilities.

Thus, the demand for three-dimensional (3D) cadastre has grown significantly over the past decade. At present, a multi-purpose 3D cadastral graphic image with spatial extension of land plots is not enough. Creating a multi-purpose 3D real estate cadastre in Ukraine is relevant and important.

Doner [2021] analyses the literature on three-dimensional (3D) cadastre from the perspective of legal, institutional and technical aspects. To this end, the author studied 441 publications published from 2001 to 2019. The research is mostly focused on technical issues in the literature, which includes publications from 59 different countries. It is pointed out that it is difficult to reach an international consensus on the legal, institutional, and technical aspects of a 3D cadastral solution. Since the rights, restrictions, and obligations with a 3D component are somehow registered administratively, legal stakeholders are reluctant to accept a 3D cadastre. From a technical point of view, the technology required to use three-dimensional digital data for registration has developed sufficiently over the past twenty years. The author states that further research into a true 3D cadastral solution is needed, creating a workflow that considers both the current legal and technical framework.

Tekavec, Ferlan, and Lisec [2018] indicate that the three-dimensional real estate cadastre is an important interdisciplinary research topic at both European and international levels. The initial theoretical scientific discussions on 3D cadastre began in the 1990s and gained momentum at the turn of the millennium. The article provides a chronological overview of research activities, highlighting publications that have significantly impacted 3D cadastre research. Over the past two decades, significant progress has been made. However, many new and challenging issues have arisen, including implementing 3D concepts in cadastral systems in different countries, the idea of a multi-purpose 3D cadastre, and the integration of different spatial datasets into a 3D cadastre.

The manual [Li et al. 2021] on spatial planning for authorized urban planning and architecture authorities of amalgamated communities, written by a group of advisers on the implementation of the state regional policy in Ukraine of the U-LEAD with Europe Programme: Tetiana Kryshtop (Ukraine), Raimund Ryś (Poland), and Ljubica Kosheljuk (Croatia), provides the main recommendations for the implementation of 3D cadastre in Ukraine.

No other property of the earth's surface has such a substantial impact on its suitability for agricultural use or other needs as relief, which contributes significantly to improving soil quality. In particular, the need to take into account the peculiarities of the earth's surface relief is indicated in the section of the manual [Manual for authorized persons...]. A feature of the microclimate of fields determined by the relief is the different amount of solar energy that falls on slopes of different steepness and orientation. The characteristics of the upper and lower parts of the slopes differ significantly due to different soil moisture conditions, as the terrain affects the distribution of heat and moisture in the soil. It affects both the productivity of fields and the value of land. These factors need to be considered in the process of land bonneting. Thus, developing and improving objective methods for classifying surface areas is a pressing task for scientists.

That is why the study aims to define certain characteristics of individual land plots of TC that affect the use of land resources to ensure their optimal use.

## Objective

The purpose of the research is to define the features of the relief of TC land plots in mass valuation (obtaining spatial characteristics of TC land plots for mass valuation). This study uses the example of a single object (TC), to demonstrate the possibilities of a three-dimensional cadastral registration system. This system enables the classification of TC land plots based on the specified characteristics. Additionally, we will compare various methods of territory assessment for the placement of solar power plants.

## Statement of the task

The regulation of the land turnover of a particular TC in accordance with the principles of spatial planning necessitates the selection of standards based on digital elevation model (DEM) data and the improvement of their objective assessment. This is essential to differentiate land plots according to the selected benchmarks for comparison when performing monetary valuations. Since slope exposure significantly influencesthe qualitative characteristics of land plots, it should be taken into account This consideration will facilitatemore accurate differentiation and expand the range of coefficients used in the regulatory and expert monetary valuation of land. Additionally, it is important for the installation of solar energy systems, particularlyfor industrial purposes.

## Methods

The research was carried out on an area of the Earth's surface with a weakly pronounced relief. Mathematical modelling methods using the SURFER software package were applied to obtain the illumination characteristics of the land on slopes. The study performs a comparative analysis of the solar energy production calculation at a certain site using the above-mentioned software package alongside traditional methods for calculating solar panels. The methodology for calculating the distribution of solar energy in a certain area is described in more detail in our publication [Rudyi et al., 2021].

## Presentation of the main material

The boundaries of the TC on a topographic map with a relief image are shown in Fig. 1.

For the study, a digital terrain model was created for the object located in the Pokutska plain in South-Western Ukraine. This site is part of the Uhrynivska territorial community within the Ivano-Frankivsk district of the Ivano-Frankivsk region, which lies northwest of Ivano-Frankivsk. The A7TC was formed by the amalgamation of Uhryniv and Kluziv village councils in Tysmenytsia district. It comprises the villages of Horishniy Uhryniv, Dolishniy Uhryniv and Kluziv. The community covers an area of 17.9 km² and has a population of 3,366 residents. The administrative centre is the village of Uhryniv. The village of Kluziv is located at the foot of Vovchynets Hill, to the west of the Bystrytsia Solotvynska River.

There are 196.85 hectares of arable land within the TC, of which 85.52 hectares belong to Uhryniv village, and 21.33 hectares belong to Kluziv village. In addition, about 30 % of the arable land is located in household plots.

Fig. 2 shows a 3D image of the TC territory relief. As can be seen from the figure, the area is dominated by flat and undulating terrain with heights of 240-360 m.

Fig. 3 shows a 3D relief model with the distribution of the study area by slope steepness. According to the model obtained during the research, slopes with slope angles of up to 3° prevail within the territorial community. Steeper slopes can be observed in the northwestern part of the Uhrynivska territorial community and on the southwestern slopes of Vovchynetskyi Hill (up to 17°).

The illumination map shown in Fig. 4 allows visualizing the insolation of the relevant agricultural or other land. It can be used to calculate the insolation, i. e., the amount of solar energy received per unit area, and subsequently, this data can be used for expert evaluation of land plots.

In fact, Fig. 4 shows the distribution of the solar energy coefficient K in the study area at noon on 22 June, when the Sun's height is maximum. The scale on the right side of Fig. 4 characterizes *K* as a fraction of the maximum value, which is 1. On the Figs. 2–4 *X, Y, Z* are axes of a geodetic system of coordinates.

The amount of solar energy $E_C$, which falls on a particular area, is determined by the formula:

$$E_C = E_O \cdot K\,, \qquad (1)$$

where $E_O$ is the solar constant. It characterizes the intensity of solar radiation and depends on the location, weather conditions, and time. The solar constant is measured in W-h/m$^2$ for a certain period, i. e. an hour, a day, a year; *K* is the coefficient of solar energy received by a certain area of the earth's surface depending on its exposure *A* and the angle of inclination *i*.

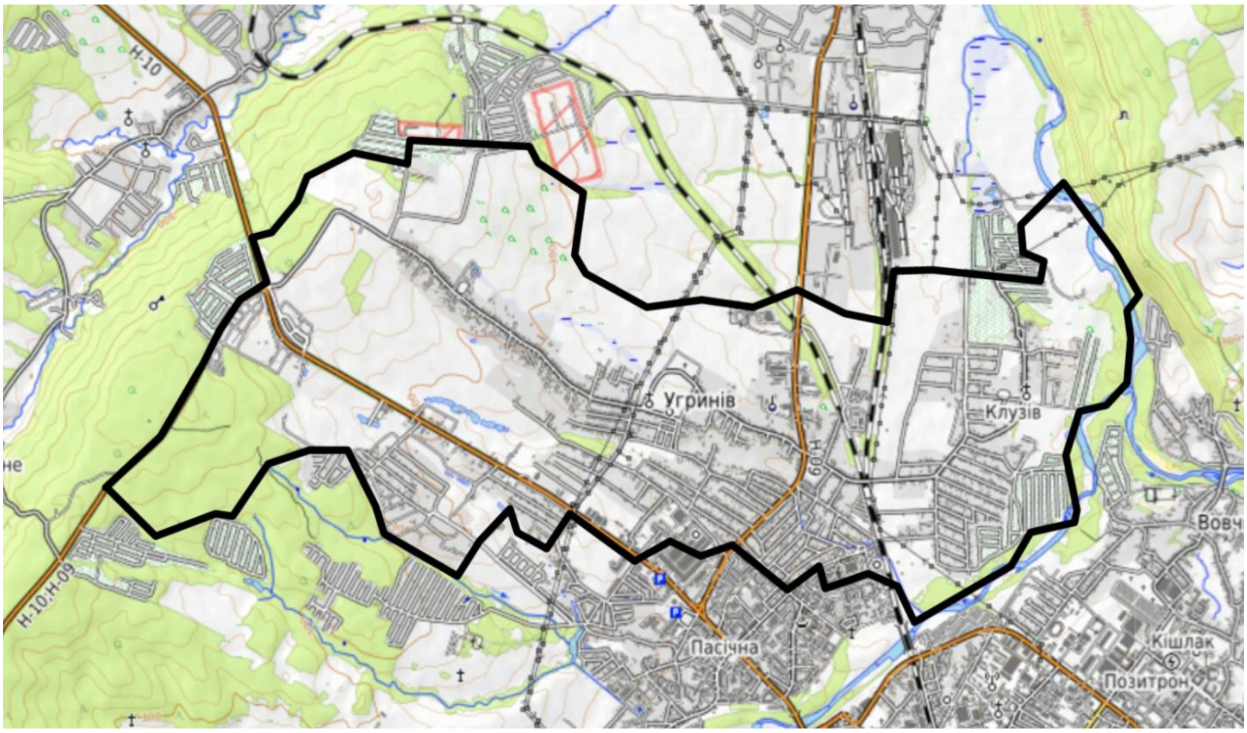


*Fig. 1. Location of the Uhryniv territorial community on the topographical map (black line shows the border)*

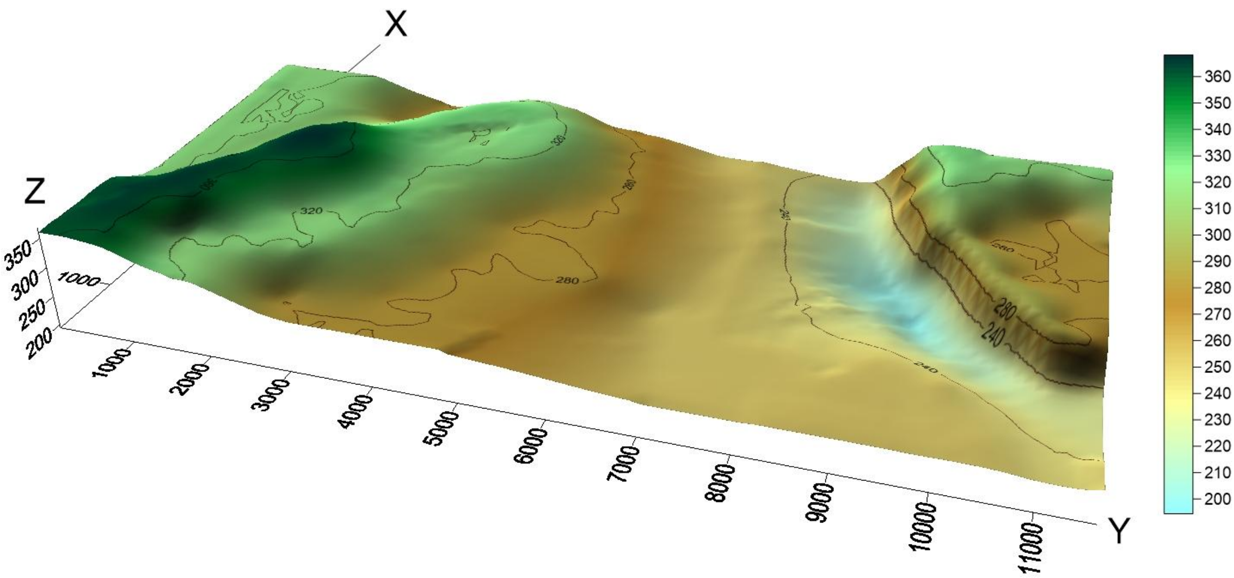


*Fig. 2. Digital model of the TC territory relief*

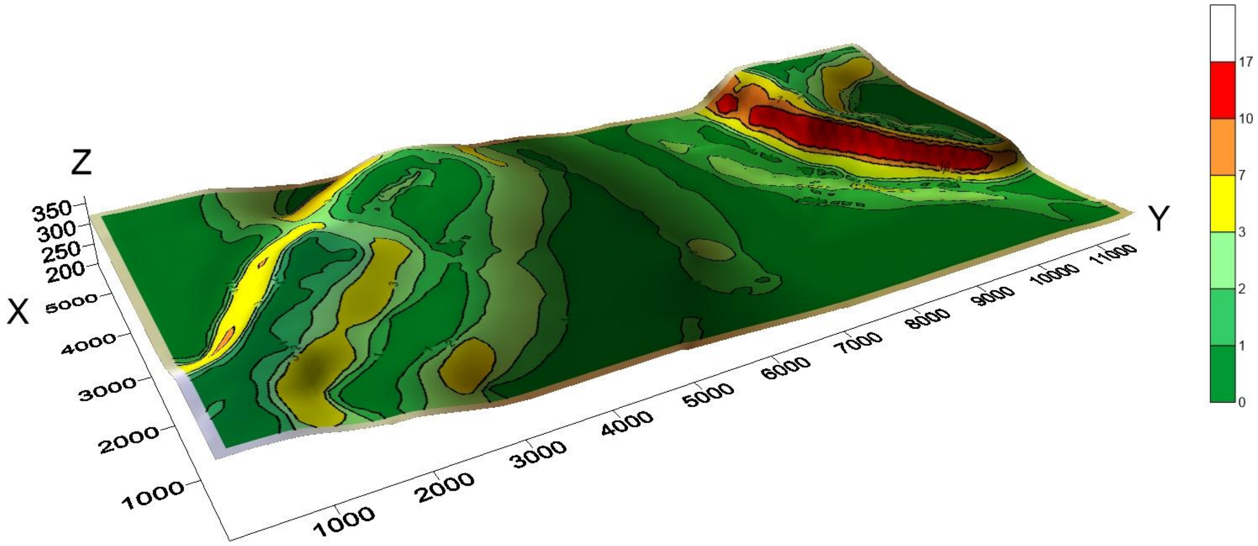


*Fig. 3. Map of the distribution of slope steepness on the territory of the TC*

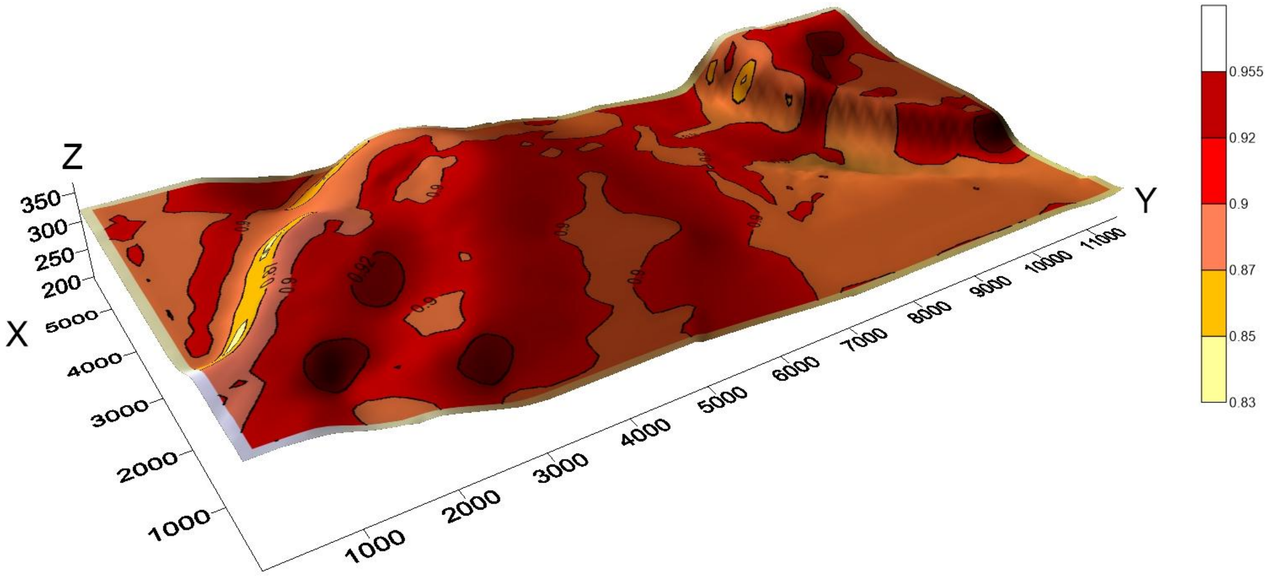


*Fig. 4. Map of the distribution of the solar energy coefficient K on the territory of the TC*

**Changes in the amount of solar energy depending on the height of the Sun**

| $H$ | 10° | 20° | 30° | 40° | 50° | 64° |
|---|---|---|---|---|---|---|
| $K$ | 0.17349 | 0.34626 | 0.50422 | 0.64664 | 0.76916 | 0.89981 |
| $E_C$, kWt h/m$^2$ | 0.23595 | 0.47092 | 0.68574 | 0.87943 | 1.04606 | 1.22373 |

The coefficient $K$ is the cosine of the angle between the normal to the earth's surface and the direction to the Sun and is determined by the formula [Kravets, 2006]:

$$K = \cos H \cdot \sin i \cdot \cos\left(180 - A \pm \cos^{-1} \frac{\sin\varphi \cdot \sin H \cdot \sin\delta}{\cos\varphi \cdot \cos H}\right) + \sin H \cdot \cos i, \quad (2)$$

where $H$ is the height of the Sun; $i$ – is the slope angle; $A$ – is the exposure of the slope; $\varphi$ – is the geographical latitude of the observation site; $\delta$ – is the declination of the Sun.

Table shows the results of calculations regarding changes in the average $K$ value for the Uhryniv TC territory based on the height of the Sun from sunrise to noon on 22 June. It also includes the corresponding amount of solar energy per 1 $m^2$ per 1 s. The significances of the *K* coefficient and $E_c$ will be similar from the midday to the sunset analogical. By summing the solar energy values for the altitude of the Sun from 10° at sunrise to 10° at sunset, we determined the total solar energy received throughout the day, which amounts to 7.86 $kWt{\cdot}h/m^2$. Considering that during the transition through the atmosphere under the influence of different factors, almost 30 % of the solar energy is loosed, its quantity on the Earth's surface will be approximately 5.27 $kWt{\cdot}h/m^2$.

The above calculations allow us to assess and profitably use land, in particular for the location of solar power plants. It is also worth noting that the efficiency of solar power plants does not exceed 15–20 %, although modern advertising declares a higher figure.

The results of the research can be used in agriculture for the rational placement of fruit and berry plantations, in gardening, as well as in renewable energy to select locations for solar power plants. Thus, it is possible to determine the amount of solar energy for each point of the digital model and the site as a whole on a certain date and per unit area. Summing up these data, the daily or monthly radiation is determined for the entire growing season from March to September, depending on the steepness and exposure of the slopes.

There is also a simplified approach to determining the amount of heat reaching the earth's surface. In particular, [Assessment of solar energy…], states that to simplify $E_o$ calculations, the maximum intensity values are chosen, i. e., when the sun's rays are perpendicular to the respective surface of the land plot or solar panel. In mountainous areas and foothills, solar irradiance is mainly dependent on the terrain. On average, in Northern European countries, it is 1,000 $kWh/m^2$ per year, and in deserts up to 2,000–2,500 $kWh/m^2$ per year.

For our territory, the solar constant can be approximated as 1 $kWh/m^2$ per hour. To simplify calculations, it is recommended to take five such values per day, i. e. 5 $kWh/m^2$ per hour. This value is approximately equal to 5.27 $kWt{\cdot}h/m^2$, as obtained earlier using the formula (1) and the data presented in Table.

## Scientific novelty and practical value

The experimental studies of the three-dimensional cadastral registration system for *t* allocating land with with slopes of a certain orientation provide valuable insights into the earth's surface relief. This relief significantly influences fertility of agricultural land and contributes to environmentally hazardous phenomena, namely, the formation of ravines, floods, mudflows, landslides, and avalanches. Therefore, developing and improving a three-dimensional cadastral registration system for TC plots is an urgent task and contributes to its effective use for the appropriate purpose.

A comprehensive assessment of the territory will facilitate the implementation of future use and obtain information on the engineering protection of the territory, design features, and planning goals of a particular structure.

Thus, the presented and analyzed terrain characteristics can be used in a massive assessment. Alternative land use options may also be indicated.

## Conclusions

Experimental studies based on terrain modelling using the SURFER package, as well as traditional methods of calculating the efficiency of solar panels have shown approximately the same accuracy of the results obtained by both methods. In addition, the use of the SURFER package makes it possible to improve processes related to the spatial planning of the territory of the TC, in particular

– selection of methods of using certain land plots for their capitalization;

– clustering of TC land to improve or facilitate the assessment of their value;

– planning crop rotations in rural areas.

The proposed methodology for spatial planning in territorial communities (TC) enhances the objective identification of priority land areas. This approach contributes to the objectivity of mass assessments, enabling us to apply the methodology used for studying relief features for land cadastral purposes in other regions of Ukraine and internationally.

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## ДО ВРАХУВАННЯ ОСОБЛИВОСТЕЙ РЕЛЬЄФУ ТЕРИТОРІЇ В ЗЕМЕЛЬНОМУ КАДАСТРІ

Мета досліджень – аналіз особливостей рельєфу земельних ділянок територіальної громади (ТГ) під час масової оцінки. На прикладі одного об’єкта, тобто однієї ТГ, продемонстровано використання тривимірної системи кадастрового обліку, в результаті чого здійснюється класифікація земельних ділянок ТГ за певними характеристиками. *Методика.* Для дослідження створено цифрову модель рельєфу об’єкта, що розташований на Покутській рівнинній території південного заходу України, на території Угринівської ТГ, розміщеної в Івано-Франківському районі Івано-Франківської області на північний захід від м. Івано-Франківськ. Методами математичного моделювання з використанням програмного пакета SURFER визначено характеристики земельних угідь, що розташовані на схилах. Використано два методи розрахунку кількості сонячної енергії, яка потрапляє на певну ділянку земної поверхні, – астрономічний та технічний. Застосування кожного з методів дає приблизно однаковий результат. *Результати.* За цифровою моделлю створено 3D-модель рельєфу з розподілом досліджуваної території за крутизною схилів. Відповідно до одержаної в ході досліджень моделі, в межах територіальної громади переважають схили з кутами нахилу до 3°. Крутіші схили можна спостерігати в північно-західній частині Угринівської територіальної громади та на південно-західних схилах Вовчинецького пагорба (до 17°). Наведено розподіл коефіцієнта сонячної енергії, яку одержує та чи інша ділянка земної поверхні залежно від своєї експозиції та кута нахилу. Карта розподілу коефіцієнта сонячної енергії дає змогу візуалізувати інсоляцію відповідного сільськогосподарського угіддя. За її допомогою можна розрахувати інсоляцію, тобто кількість сонячної енергії, що потрапляє на одиницю площі, і надалі використати в експертній оцінці земельних ділянок. Так можна визначити сумарну кількість тепла, яке потрапляє на кожну земельну ділянку протягом дня чи всього періоду вегетації. Методами математичного моделювання отримано характеристики освітленості земельних угідь, розташованих на схилах. *Новизна та практична цінність.* Експериментальні дослідження тривимірної системи кадастрового обліку із виділенням ділянок поверхні зі схилами певної орієнтації та аналіз результатів дають змогу використовувати їх під час дослідження рельєфу земної поверхні, який великою мірою визначає родючість сільськогосподарських угідь, впливає на екологічно небезпечні явища, а саме утворення ярів, повені, селі, зсуви та снігові лавини. Отже, розроблення та вдосконалення тривимірної системи кадастрового обліку ділянок поверхні є актуальним завданням ТГ. Виконані дослідження сприятимуть об’єктивності масової оцінки, що дасть змогу поширити застосовану методику на інші регіони України та зарубіжжя.

*Ключові слова*: кадастр, облік, земельна ділянка, тривимірна система, об’єкт нерухомості, рельєф.

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