GIS-BASED OPTIMIZATION OF SUITABLE LOCATIONS FOR GSM STATION DEPLOYMENT AT MAXIMUM ALTITUDES

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Abstract: *The optimal placement of GSM communication stations in mountainous areas is a key step in ensuring network coverage and operational efficiency. This paper proposes a complete and automated GIS-based methodology for identifying locations situated at altitudes above the 1000 m threshold, using TIN terrain models, raster conversion, spatial selection, and 2D/3D validation of the results. The method eliminates the subjectivity of manual selection and provides a rigorous technical basis for telecommunications design in rugged terrain.*

Keywords: *GIS; TIN; raster; altitude; telecommunications; spatial analysis; GSM stations*

1. Introduction

Mobile communications networks in mountainous areas directly depend on the optimal positioning of transmission equipment. In particular, the choice of locations at the highest possible altitudes determined or efficient signal propagation, reducing the number of required stations and uniform coverage of the territory. For this reason, establishes some important points in this context must be based on GIS quantifiable criteria, not just on visual inspection or intuitive expertise. In the specialized literature, optimizing the location of communications infrastructure in areas with rugged terrain is placed at the intersection of analytical geomorphology, geoinformatics and territorial planning. In this paradigm, the relief is no longer perceived only as a static representation of altitudes, but as a complex, continuous surface, bearing functional significance: obstacle, infrastructural support and, at the same time, mediator of electromagnetic wave propagation.

2. Necessity and justification

The need for conducting a rigorous optimization process in the selection of locations situated at maximum altitudes is justified by the direct relationship between landform morphology and the degree of functional accessibility of the territory. The analytical image of the studied area reveals a fragmented mountainous relief, with abrupt alternations of ridges, slopes, and deep valleys, which leads to an uneven distribution of territorial coverage. In particular, the thematic map of communication coverage (2G, 3G, 4G) highlights the presence of extensive areas characterized by a low probability of signal reception, clearly correlated with topographic depressions and orographic barriers.
This spatial reality demonstrates that relief does not act solely as the physical support of infrastructure, but also as a limiting factor of territorial functionality. Low-altitude areas

enclosed by high slopes are subject to a pronounced shielding effect, which leads to the weakening of connectivity and to the emergence of spatial discontinuities in access to communication networks. In this context, precise identification of points located in altimetrically dominant positions becomes necessary, as these are capable of overcoming such natural barriers.

At the same time, the cartographic analysis of the altitudinal maxima represented in the image (high hypsometric patches, point values exceeding 1200 m) highlights the existence of morphologically dominant cores that are not systematically utilized. The absence of an objective selection methodology leads to empirical decisions, dependent on accessibility, apparent visibility, or logistical constraints, without truly integrating the three-dimensional potential of the relief.

In this regard, the necessity of the research is twofold: on the one hand, it is imposed by the need to transform relief from a simple cartographic representation into an analytical decision-making tool, capable of supporting optimal spatial positioning; on the other hand, it is determined by the need for a quantitative, reproducible approach that allows the limitations of intuitive analysis of classical maps to be overcome.

The scientific justification of the study thus arises from the confrontation between two spatial realities: on the one hand, the existence of areas with high altimetric potential, clearly individualized hypsometrically; on the other hand, the manifestation of evident functional deficiencies in valley and slope spaces. This discrepancy calls for a GIS-based approach oriented toward the mathematical identification of altitudinal dominance and its valorization for the purpose of optimizing functional distribution within the territory.

Therefore, the study does not investigate relief height merely as a numerical value, but rather its structural role in the spatial organization of the territory, highlighting that altitudinal maxima become vectors of functionality, not just morphometric attributes.

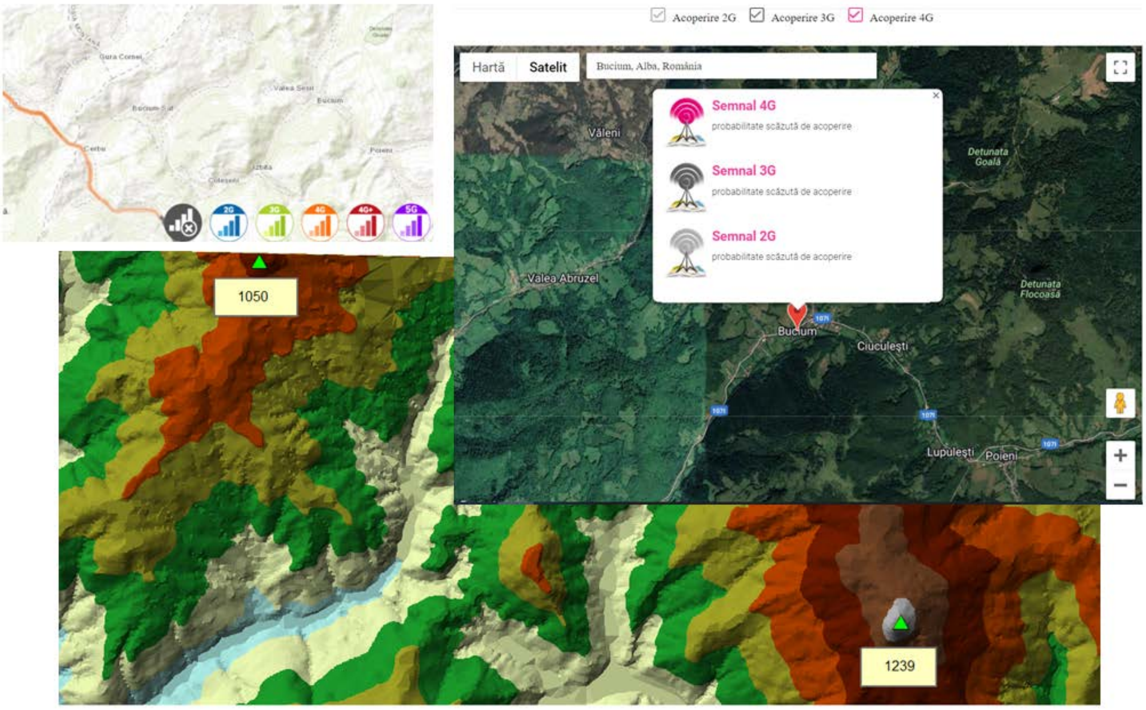

Fig. 1 The relationship between landform morphology and the spatial distribution of communication network coverage in the analyzed mountainous area (Bucium – Valea Abruzel)

3. Materials and methods

The analysis is based on the use of two essential categories of spatial data, which constitute the material support of the methodological approach. The first category is represented by the digital terrain model in TIN (Triangulated Irregular Network) format, used for the continuous representation of the real terrain morphology and for the faithful preservation of local altimetric variations. The second category consists of a two-dimensional reference surface, defined by a constant altimetric value of 1000 m, which functions as a threshold in the process of delineating areas situated at higher elevations.

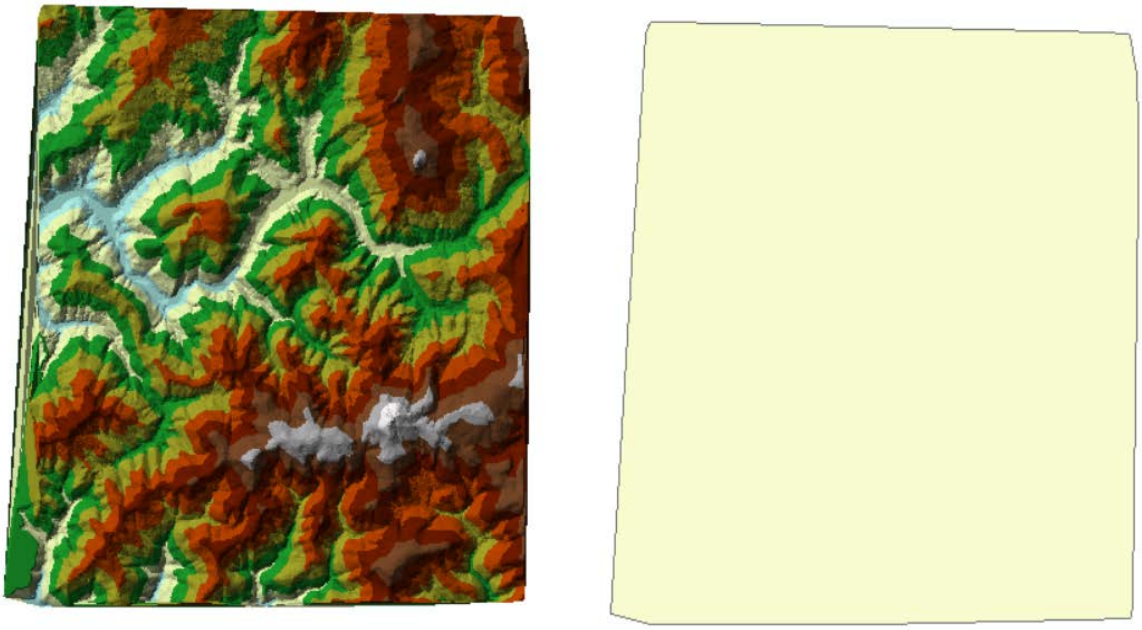

Fig. 2 Representation of the digital terrain model in TIN format (left) and the 2D reference surface with an imposed elevation of 1000 m (right)

The methodology applied in this research does not aim at the mere enumeration of technical procedures specific to GIS software, but is based on a coherent set of analytical objectives oriented toward the objective identification of surfaces with high potential for the placement of GSM stations.

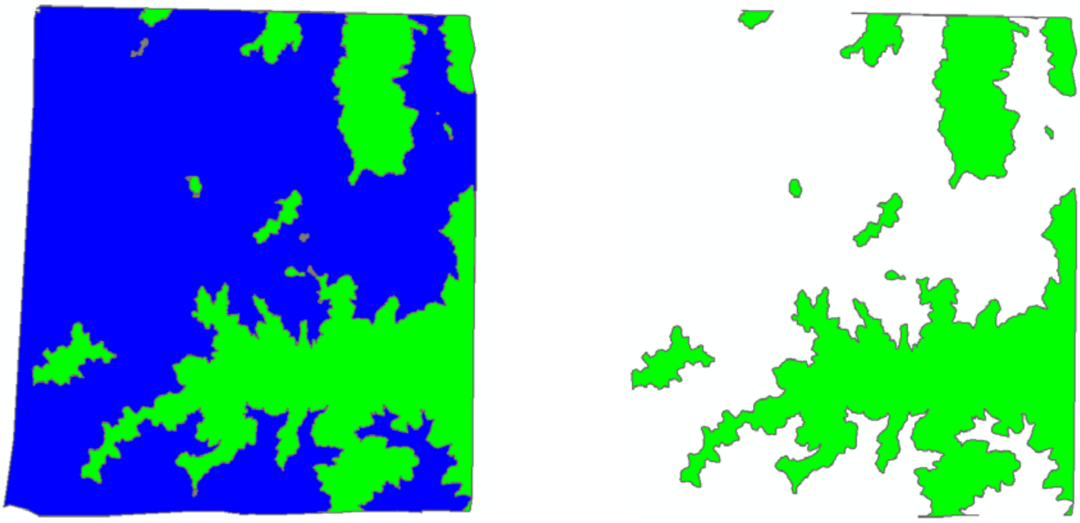

Fig. 3 Determination of the difference between the two surfaces in order to obtain the contact zones

First, the establishment of a geometric reference framework was pursued in order to allow the spatial discrimination between topographic units located below and above the imposed altimetric threshold. The real relief, represented by a TIN digital terrain model, was analyzed in relation to a conceptual surface with a constant elevation of 1000 m. In this way, the identification of areas where the altitude exceeds the established threshold becomes a logical operation, formulated as a relationship between two continuous spatial entities, rather than as a simple point-based measurement.

Subsequently, the process involved the construction of an ideal observation network in the form of a grid uniformly projected over the studied surface. This approach serves to transform a continuous phenomenon (altitude) into a discrete set of comparable points, to which selection, classification, and verification criteria can be applied. The grid thus becomes a statistical tool for geospatial sampling, intended to identify the distribution of altitudes across geometrically equivalent sectors.

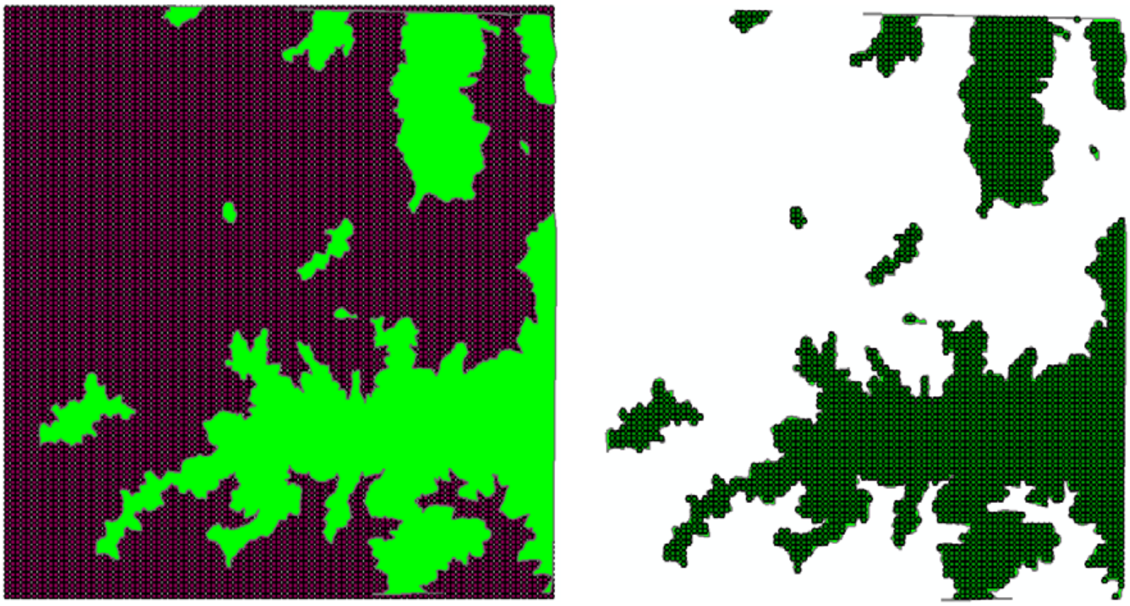

Fig. 4 Design of the regular point network (grid) over the surfaces located at elevations above the imposed threshold

The points subsequently retained in the analysis were only those whose spatial position coincides with the over-threshold zones, which corresponds to a topological inclusion operation. In this context, the selection is neither random nor manual, but governed by the explicit rule of spatial contiguity between the point and the geographic surface characterized by higher altitudes. This approach eliminates subjectivity and transforms the decision into a deterministic and fully reproducible one.

To ensure that the altimetric values associated with each point faithfully reflect the real morphology of the terrain, the process integrated a conversion of the TIN model into a raster structure. This transformation allows the continuous extraction of values from a regular model, providing a numerical basis for verifying potential interpolation errors or topological inconsistencies. By reference to this raster, each point becomes the carrier of a validated elevation value. The raster structure, by organizing space in the form of a grid of equidistant cells, facilitates the assignment of a unique altimetric value to each discrete element of the surface, eliminating ambiguities generated by the discontinuities between TIN faces. In this way, each point of the projected grid can be directly correlated with a precise numerical elevation value extracted from a continuous and homogeneous altimetric field.

This stage strengthens the quantitative character of the research and transforms the analysis from a predominantly geometric approach into a rigorous morphometric one, based on measurable and statistically verifiable values.

Table — EXTRACT_Intersect

OBJECTID *	Shape *	FID_EXTRACT	Id	RASTERVALU
1600	Point	1599	0	1340
1599	Point	1598	0	1332
1532	Point	1531	0	1330
1531	Point	1530	0	1329
1459	Point	1458	0	1325
1530	Point	1529	0	1325
1664	Point	1663	0	1316
1598	Point	1597	0	1315
1665	Point	1664	0	1309
1460	Point	1459	0	1302
1458	Point	1457	0	1298
1533	Point	1532	0	1297
1388	Point	1387	0	1296
1461	Point	1460	0	1296
1529	Point	1528	0	1296
1597	Point	1596	0	1293
1387	Point	1386	0	1281

(0 out of 2942 Selected)

EXTRACT_Intersect

ArcToolbox | Table

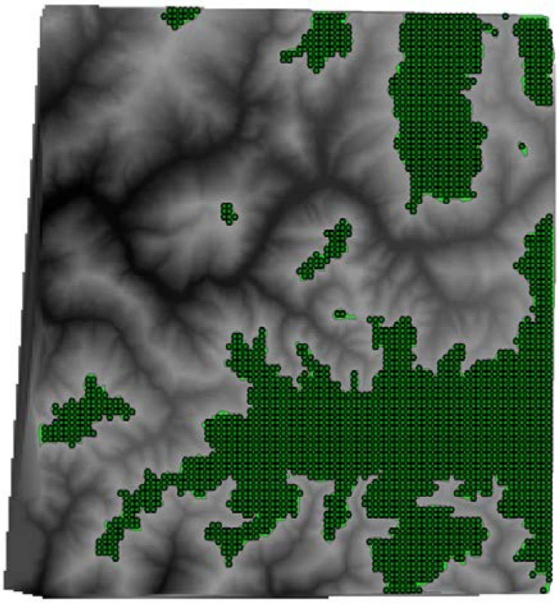

Fig. 5 Extraction of the elevation values on the raster background obtained through TIN to Raster conversion and error verification

Subsequently, the points were spatially classified not only according to altitude, but also in relation to the surfaces to which they belong. Through this mechanism, the potential locations for GSM stations are not treated as isolated elements, but are integrated into a logical structure that specifies their relationship with the original morphological unit.

Table — EXTRACT_Intersect

OBJECTID *	Shape *	FID_EXTRACT	Id	RASTERVALU	FID_DIF_TIN	Volume	SArea	Code
1600	Point	1599	0	1340	34	2027573276.32	24108396.8361	-1
1599	Point	1598	0	1332	34	2027573276.32	24108396.8361	-1
1532	Point	1531	0	1330	34	2027573276.32	24108396.8361	-1

(0 out of 2942 Selected)

EXTRACT_Intersect

Fig. 6 Spatial intersection between the elevation-attributed points and the zones with altitudes above 1000 m in the context of vector overlay

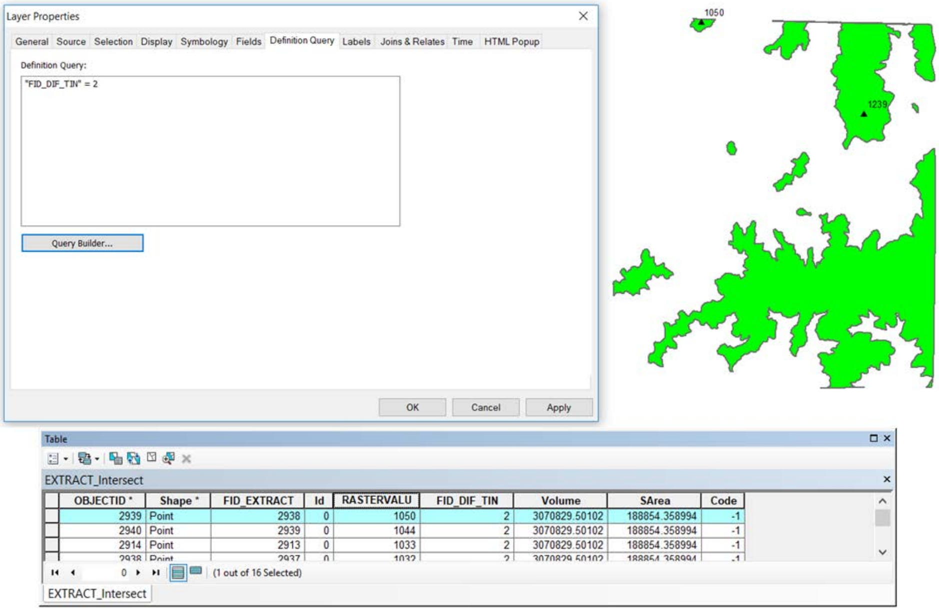

Fig. 7 Classification of points into distinct layers according to their membership in the contact surfaces (inclusion) and determination of maximum values

In the final stage, the results were subjected to a process of morphological validation. Their 2D overlay allowed the verification of topographic relationships, while the three-dimensional analysis contributed to confirming their dominant character within the landscape. The 3D visualization thus becomes not a mere graphic device, but a method of control, since a high altitude does not automatically equate to usefulness in signal propagation if it is located within a concavity or behind an orographic barrier.

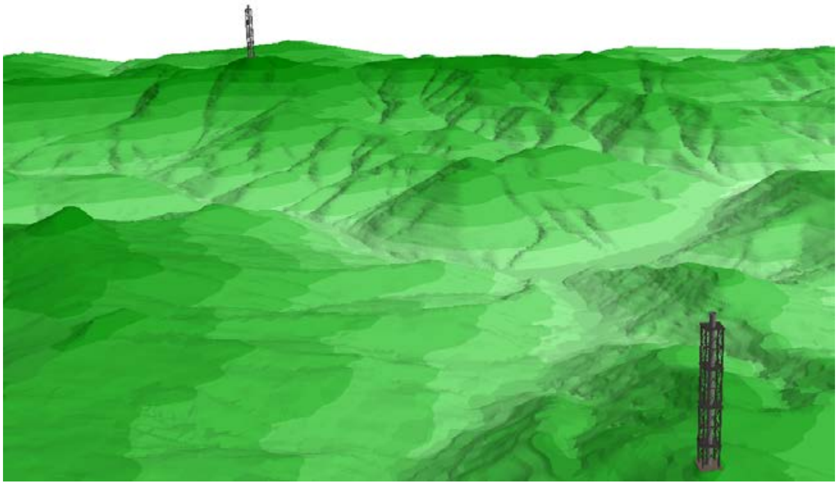

Fig. 8 Verification and validation of the results through their overlay on the morphological content

4. Results and discussions

The application of the methodology based on the integration of TIN and raster models, correlated with the use of a regular point grid, made it possible to highlight the morphometric differences within the surfaces located above the imposed altitudinal threshold. The raster obtained through conversion provided a continuous field of elevation values, based on which point elevations were extracted for each element of the spatial sampling. This stage generated a homogeneous numerical database, indispensable for statistical analysis and value comparison.

The distribution of the obtained elevation values indicates significant internal variability even within the same over-threshold topographic units. This finding demonstrates that the altitudinal threshold functions as a general filter, but does not capture the internal complexity of the relief. Within the same polygonal surface, differences of several tens of meters can be identified between points, which confirms the fragmented character of mountain ridges and interfluves.

The analysis of point classification according to their membership in the contact surfaces highlighted the existence of nuclei of maximum value concentration, arranged along linear structures corresponding to the main ridgelines. This spatial organization of maxima reveals that the relief is not composed of isolated extremes, but of coherent systems of geomorphological dominance. Therefore, the maximum values should not be interpreted as mere point peaks, but as expressions of a continuous morphological architecture.

Quality control of the results through the overlay of the elevation-attributed points onto the altimetric raster indicated good concordance between the extracted values and the real structure of the relief. Minor deviations identified in sectors with steep slopes suggest the influence of raster resolution and the density of the source points used in generating the TIN. However, these discrepancies do not significantly affect the overall interpretation of the altitudinal maxima, but rather emphasize the need to adjust resolution according to the local complexity of the terrain.

Three-dimensional validation of the results enabled a much more rigorous morphological interpretation of the maximum points. In the 3D representation, it was observed that the selected points are, in most cases, positioned along ridge edges or in areas of pronounced positive slope, confirming their role as dominant elements within the relief volume. By contrast, some points with high numerical values but located on relatively flat surfaces exhibit reduced visual dominance, which demonstrates that altitudinal maxima should not be automatically equated with maxima of morphological dominance.

From a methodological perspective, the obtained results confirm the usefulness of the approach based on space discretization through a regular grid, while also highlighting its limitations. Point density directly influences the degree of analytical detail: a grid that is too sparse may omit relevant micro-relief features, whereas a very dense grid significantly increases data volume and processing time. Therefore, the choice of optimal resolution represents a compromise between fidelity and computational efficiency.

Compared to classical empirical methods of peak identification, GIS-based analysis allows not only the localization of extremes, but also their integration into a coherent system of spatial relationships. The results demonstrate that the automatic selection of maxima provides a much more objective image of relief dominance, reducing the risk of errors generated by the subjective interpretation of hypsometric maps.

From an applied perspective, the numerically validated altitudinal maximum constitutes a robust indicator for subsequent visibility, viewshed, or landscape organization analyses. At the same time, the results emphasize that relief must be understood as a dynamic three-dimensional system, in which extreme values acquire meaning only through their relation to the surrounding morphological context.

In conclusion, the results show that the applied methodology not only identifies altitudinal maxima, but also contributes to the understanding of the internal structure of the relief and the way in which morphological dominance is spatially distributed. This opens perspectives for extending the analysis toward visibility studies, landscape modeling, or complex spatial assessments.

5. Conclusions

The conducted study demonstrates the effectiveness of using GIS technologies in the morphometric analysis of relief and in the rigorous determination of altitudinal maxima through the complementary integration of TIN and raster digital models. The conversion of the TIN structure into a raster model enabled the transition from an adaptive geometric representation to a homogeneous numerical framework, facilitating the precise validation of the altimetric values associated with the analyzed points.

The obtained results confirm that the areas situated above the imposed altitudinal threshold are not homogeneous units, but exhibit a complex internal structure with clearly differentiated nuclei of dominance. The identification of maximum elevation points, numerically validated through the raster support and confirmed by 2D and 3D analysis, highlights the hierarchical character of the relief and demonstrates that altitudinal extremes represent the expression of the spatial organization of positive landforms.

By applying the regular point grid and topological inclusion relationships, the selection of maxima was carried out within an objective framework. This approach confirms that GIS is not merely a cartographic representation tool, but a genuine environment for the analysis of geographic space.

The three-dimensional validation of the results demonstrated that the maximum points are not merely extreme statistical values, but correspond to real structures of morphological dominance (ridges, interfluves, crests), with high potential for visual control over the surrounding territory. Thus, the altitudinal maximum acquires not only numerical significance, but also functional and perceptual meaning.

6. References

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