International Cartographic Association
Association Cartographique Internationale

Relief classification using artificial neural networks

Małgorzata Wieczorek [a,*], Wojciech Przybył [b]

[a] *Department of Geoinformatics and Cartography, University of Wroclaw, Malgorzata Wieczorek – malgorzata.wieczorek@uwr.edu.pl,*
[b] *Prof. Józef Kosacki's Military Institute of Engineer Technology, Wojciech Przybył – przybyl@witi.wroc.pl*

* Corresponding author

Keywords: relief classification, geomorphometry, geological context, artificial neural networks, machine learning

Abstract:

The intricate complexity of Earth's surface topography has long posed significant challenges for researchers in geomorphology and geoinformation sciences. Landform classification is a non-trivial task, as it requires careful consideration of both diverse quantitative (morphometric) factors and the geological or lithological context in which these landforms occur. The challenge is further exacerbated by scalability issues: while certain methods may perform effectively at smaller spatial scales (e.g., analysing localized terrain sections), their accuracy often diminishes when applied at macro-scales, where the number of variables and observations grows exponentially.

Previous studies have demonstrated that unsupervised methods—such as k-medians or other clustering algorithms—can partially identify terrain features. However, these approaches typically require expert interpretation to assign meaningful labels to the resulting clusters.

At the same time, reliance on geomorphometric indicators—such as the Topographic Position Index (TPI) or measures of slope shape—can streamline analysis by concentrating primarily on quantitative data. However, it often becomes evident that TPI and similar metrics alone are insufficient for accurate landform classification, as they fail to account for qualitative factors such as lithology and geological structure.

To address this limitation, a proposed solution involves the integration of lithological features as qualitative complements to standard morphometric indicators. In this study, a raster dataset was analysed, incorporating elevation data and derived parameters, including relative height, slope, aspect, and both planar and vertical curvature. Additionally, a qualitative lithological variable was incorporated into this dataset to complement the quantitative attributes. This integration aimed to achieve a more comprehensive characterization of the terrain, extending beyond the numerical attributes typically derived from elevation data alone.

The study area, located in the Bystrzyckie Mountains in Poland (a 9 km × 7 km section with a 25 m resolution), served as an ideal testing ground due to its diverse geological conditions and landforms shaped by various geomorphological processes. A total of ten landform classes were identified by an expert, based on terrain morphology, the geomorphological processes shaping the relief, and lithological information (Wieczorek, Migoń, 2014). Then, the primary objective of the research was to reproduce these classes using artificial neural networks (ANN). During the experimental phase, various network parameters were systematically tested, including the number of layers, the number of neurons per layer, regularization techniques (e.g., dropout), the number of training epochs, learning rate, and the influence of specific morphometric variables on classification outcomes. Particular emphasis was placed on incorporating Moore's neighbourhood, which accounts for spatial context by evaluating each pixel (cell) in relation to its surrounding points, rather than in isolation.

The results of the automated classification were compared with the manual geomorphological classification, which served as the expert standard. The quality of the outcomes was evaluated using an agreement index. The findings indicated that well-tuned neural networks, when provided with carefully selected data (including lithological information), can achieve satisfactory agreement with expert-based classifications.

Regularization was not found to be crucial for reducing overfitting, particularly considering the complexity of the problem, which involved a large number of samples and high terrain variability. The selection of an appropriate network architecture, learning rate, and number of epochs played a more significant role in preventing the model from "memorizing" specific training cases, thus preserving its clustering capabilities.

https://doi.org/10.5194/ica-abs-10-300-2025

In summary, integrating quantitative morphometric indicators with qualitative data—particularly lithological information—is both feasible and significantly improves the performance of artificial neural networks in landform classification. Proper network architecture design and the inclusion of Moore's neighbourhood data enhance the identification of geomorphological classes. These findings represent progress toward automating tasks that have traditionally relied on expert supervision, potentially supporting geologists, geomorphologists, and spatial planners in future systems. While expert knowledge remains essential for interpreting final results, AI-based methods, such as neural networks, can substantially increase the efficiency and speed of recognizing complex landforms.

Acknowledgements

The authors would like to thank Dr. Milena Różycka for providing her work on the lithology of the Bystrzyckie Mountains.

References

Wieczorek M., Migoń P., 2014. Automatic relief classification versus expert and field based landform classification for the medium-altitude mountain range, the Sudetes, SW Poland, 2014. *Geomorphology*, Vol. 206, pp. 133–146.

https://doi.org/10.5194/ica-abs-10-300-2025