International Cartographic Association
Association Cartographique Internationale

Generalization of digital elevation models for military passability maps development

Wojciech Dawid [a,*], Krzysztof Pokonieczny [a]

[a] *Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland – wojciech.dawid@wat.edu.pl, krzysztof.pokonieczny@wat.edu.pl*

* Corresponding author

Abstract: This paper presents the methodology of the digital elevation model (DEM) generalization which aims to reduce the generation time of the military passability maps. The generalization is based on the local standard deviations of slopes on the analyzed area. It assumes that in areas, where the diversification of relief is low, the elevation points should be reduced, which may significantly increase the efficiency of the process of the military passability maps development. The generalization was performed on the LIDAR (Light Detection and Ranging) elevation data, which can be obtained with no charges from the Polish Head Office of Geodesy and Cartography. The data are in 1 m resolution and in an ASCII grid file, which contains all coordinates (X, Y and H) of elevation points. The conducted research shows that the modification of parameters used in the generalization process (shape and size of primary fields, number of classes and standard deviation threshold) influences the degree of generalization of obtained results. What is more, the generalized DEMs allowed to reduce the processing time of the passability maps by about 3.5 times compared to the non-generalized model. The parameters used for generalization can be adjusted by the user to individual needs which makes the tool universal.

Keywords: digital elevation model, generalization, military passability maps, microrelief, terrain

1. Introduction

Effective conduction of military operations requires appropriate planning. One of the most important aspects, which should be taken into account, is the availability, and in particular, the passability of the terrain. Pursuant to the military standardization document (Ministry of National Defence, 2012), passability is understood as the possibility of overcoming terrain by vehicles in all weather conditions, both on roads and cross country. As far as the road network is concerned, during military operations it can be destroyed and easily followed by the enemy, therefore the information whether the relocation of troops is possible through the terrain with no road infrastructure is indispensable. Such information is given by the maps of passability which show the classification of terrain into areas of various degrees of passability. The issue of developing the terrain passability has been investigated by numerous authors. Military passability map generation system was presented in publication (Pokonieczny, 2017) and it allows to generate military passability maps for various levels of detail on the basis of different spatial data. The application of image data to develop passability maps was shown in article (Rada et al., 2020). Moreover, in publication (Rybansky, 2020), the author analyzed the influence of vegetation on the possibility of movement. Another important aspect in investigating the passability, which is the impact of soil parameters, was raised in (Hubáček et al., 2016) where the authors conducted field measurements with use of cone penetrometer to determine the soil parameters and assess their influence on the passability.

Depending on the levels of conducted military operation, it is crucial to develop maps of passability in various detail. This research concerns the development of passability maps for the lowest operational level (tactical level), which is for single vehicle, or alternatively, for the small group of vehicles of the same kind. Such maps are created on the basis of very detailed digital elevation model (DEM) (Dawid and Pokonieczny, 2020) which can be obtained from the Polish governmental geoportal (Head Office of Geodesy and Cartography, 2022). The process of military passability maps development consists mainly of the microrelief analysis, which aims to detect the microrelief obstacles (such as bluffs, pits, drainage ditches, etc.), which are impassable for a given vehicle model. Due to the high resolution of DEMs, the analysis is very time consuming because each point of the model should be checked whether it is passable or not. In planning and conducting military operations, time is a crucial factor which may affect their result. This article proposes the methodology of DEM generalization which aims to reduce the time of the passability map generation.

DEM generalization issue has been investigated by multiple authors. The publication (Hu et al., 2009) discusses the principles of DEM generalization and proposes a way of digital generalization using Voronoi diagrams. The next DEM generalization method was proposed in (Zaksek and Podobnikar, 2005), where the authors extracted terrain skeleton and interpolated terrain

31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-6-2023

heights on the basis of it. The problem of DEM generalization created from the multi-source data was raised in (Podobnikar, 2017) and provided interesting results. Another noteworthy research concerns the heuristic DEM generalization method by detecting and combining catchments (Li et al., 2021). It uses the location of catchment basins in order to guide the generalization process. Moreover, some authors used the 3D Douglas-Peucker algorithm to generalize DEMs automatically (Fei and He, 2009; Shiqing et al., 2016).

The military passability maps for the tactical level of operation must provide accurate and, most importantly, quick information about the terrain. The process of their development based on the original (non-generalized) DEM, albeit slow, gives very accurate results (Dawid and Pokonieczny, 2021). The generalization of the DEM is in this case indispensable to reduce the computation time of the passability map. This paper proposes a method which, based on the local terrain characteristics, and more precisely the standard deviation of slopes, removes elevation points from areas with no or small relief diversification, which is a novelty in research related to the terrain passability. It enables generating the passability maps more meticulously in areas with bigger volatility of elevations, that is in potential locations of microrelief obstacles, and more generally in undiversified terrain. All the above allows to formulate the research question which is as follows: can the developed method speed up the military passability maps generation process while maintaining their accuracy and if so, by how much?

2. Materials and methods

2.1 Study area

The tests were conducted based on area located in the east of Poland in Lublin Voivodeship in Parczew County between the latitude of 51°40’ to 51°40’15” and longitude of 23°12’10” to 23°12’35”. The terrain covers almost 0.12 km^2 and the altitude above mean sea level (MSL) ranges from 153.53 m to 154.87 m. The localization of the tested area is presented in Figure 1.

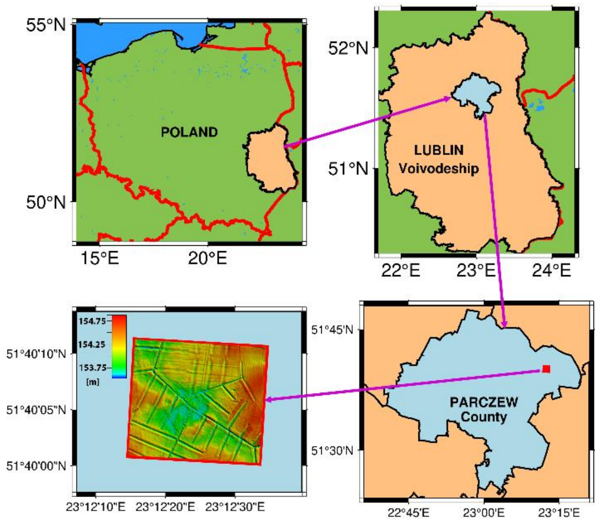


Figure 1. Localization of the study area.

This area was chosen because it contains a lot of visible microrelief objects, mainly drainage ditches, which are likely to be detected as impassable by the microrelief analysis. They are presented in Figure 2.

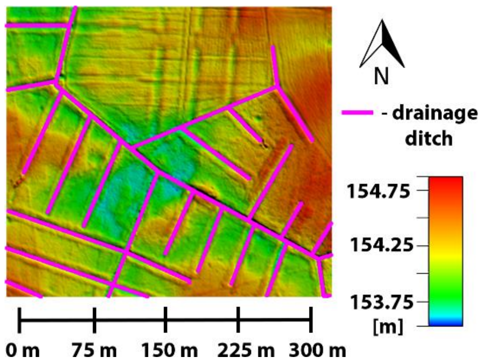


Figure 2. Characteristic microrelief objects on the study area.

2.2 Data used in the experimentation

This research was conducted on LIDAR (Light Detection and Ranging) elevation data which were obtained from the Polish Head Office of Geodesy and Cartography from National Geodesy and Cartography Resource. This repository contains all analogue and digital materials concerning geodesy and cartography which are used in different fields, such as national defence, economy, science, and culture (GUGiK, 2022). The data are distributed across the entire Poland’s territory and can be downloaded with no charges from the governmental website (www.geoportal.gov.pl) in ASCII grid file format. This format is both human-readable and hardware independent which makes it universal. The ASCII grid files are text files, which contain elevations of points distributed evenly in 1 m spacing in this case, and a header which describes the basic parameters of the file, such as the number of columns and rows, X and Y coordinates of the central elevation point, cell size (resolution of the model) and a value which is assigned as no data (ESRI, 2021). According to the data provider, the vertical accuracy of the data used in this research is 0.15 m.

The passability maps were developed for the Honker 2000 vehicle, which is widely used in Polish Armed Forces for various purposes. The crucial tractive parameters of this vehicle are as follows:

a) Wheelbase – 2.90 m;
b) Track width – 1.65 m;
c) Ground clearance – 0.22 m.

These parameters will be used by the algorithm to detect impassable places on the analyzed terrain.

2.3 Military passability maps development

To better understand the purpose of the research, it is crucial to get acquainted with the development process of the military passability maps on a high scale. These maps show impassable areas or areas, which significantly hinder the movement of a given vehicle. Their development is based on the microrelief analysis, which uses high-resolution digital elevation model and tractive parameters of a vehicle to check whether the analyzed elevation point can be passed by it. The whole process is performed automatically in an authorial tool developed by the authors in Python programming language (Dawid and Pokonieczny, 2021). How does it work? The microrelief analysis, in short, utilizes the coordinates (X, Y, H) of four wheel-ground tangency points to fit a plane into them using the least squares method. Subsequently, this plane is shifted vertically by the ground clearance value with the purpose of the approximation of the vehicle chassis. Then, there are created evenly spaced control points on the approximated chassis plane and the algorithm checks at each point whether the height of the terrain exceeds the height of the chassis in this exact location. If yes, the analyzed elevation point is classified as impassable. The process of the microrelief analysis has been thoroughly described and investigated in the publication (Dawid and Pokonieczny, 2020).

2.4 Generalization of the digital elevation model

The microrelief analysis is performed at each elevation point of the analyzed terrain. Due to the high resolution of the DEM (1 m), and consequently a huge number of elevation points to be analyzed, the process can be very time-consuming depending on the size of the analyzed area. The DEM generalization aims to reduce the number of elevation points while maintaining the detailedness of the model. The generalization assumes that the terrain, in places with insignificant diversification of relief, can be represented by fewer elevation points than in places where the diversification is bigger. The reduction of points allows for much faster generation of passability maps, which is of key importance e.g. in planning the military operation or the relocation of troops. This process has been fully automated in Python programming language and its workflow is presented in a form of block scheme in Figure 3.

The generalization process starts with the import of the DEM in ASCII grid file format (Figure 3, 1). It contains elevation points, which are distributed evenly with spacing 1 m. Subsequently, the slope map is generated based on the elevations (Figure 3, 2). Slopes allow detection of local variations of heights on the terrain. In the next step the additional grid with user-defined parameters is created (Figure 3, 3). It consists of primary fields, which can vary in shape and size. In the developed tool, there are 3 possible choices of shape: rectangle, diamond and hexagon and, as far as size is concerned, it can be set to any value. In this research there were used aforementioned three shapes and sizes of 5 m, 10 m and 15 m. A shape is determined for the rectangle and diamond primary field as a length of the edges and for the hexagon field as a long diagonal.

Having generated the grid, the process calculates the zonal statistics inside each primary field (Figure 3, 4). The DEM generalization is performed based on the local relief diversification, which means that in places where the fluctuations of elevations are high, the generalization must be performed in a lesser degree, and inversely.

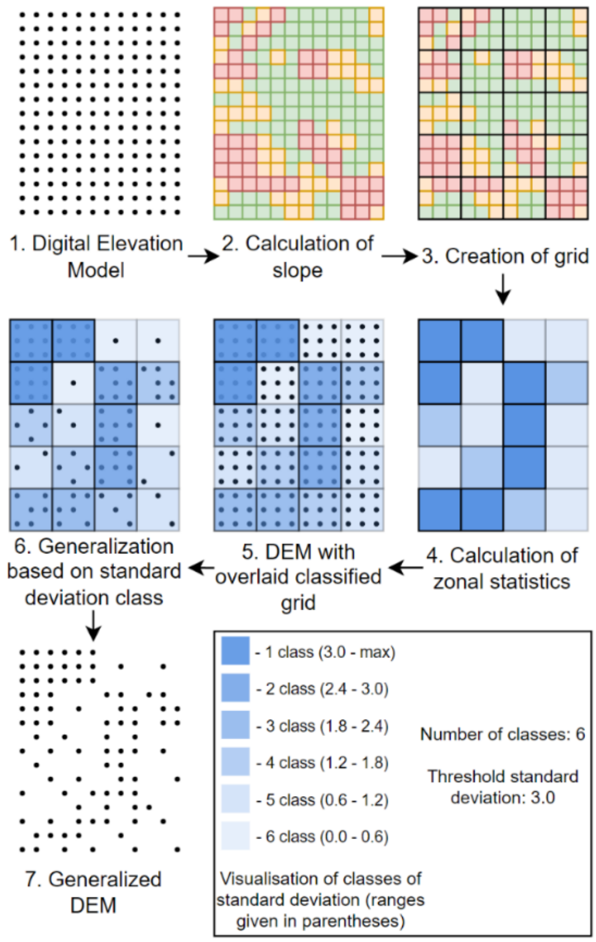


Figure 3. Digital elevation model generalization process.

The statistic which shows best the diversification of terrain heights is the standard deviation (Ayeni, 2014). Based on this value, the classification of primary fields is performed. The number of classes are also a definable parameter and in case of this research, the generalization was performed based on 6, 8 and 10 classes. The classification also uses the threshold standard deviation value. All primary fields with the standard deviation above the threshold are classified into one class (in Figure 3 – 1 class) and rest values from 0 to the threshold value are divided into equal ranges (in Figure 3 – classes from 2 to 6). The threshold parameter can also be adjusted by the user and in this research there were used values 3 m, 4.5 m and 6 m.

Part 5 of Figure 3 shows the DEM with overlaid classified primary fields. Based on these classes, the removal of excessive elevation points is performed. The generalization process removes elevation points inside each primary field proportionally to the class represented by it (Figure 3, 6). As far as possible, it gets rid of points distributed regularly within the primary field. One may see that with the decrease of the standard deviation values, the number of maintained elevation points drops.

However, in the first class (with the standard deviations above the threshold value) no elevation points were removed. As a result, the generalized DEM is obtained (Figure 3, 7).

To sum up, the generalization process requires to define four parameters: shape and size of the primary field, number of classes and threshold standard deviation value. In this research they were set to the following values:

a) shape – square, diamond and hexagon;
b) size – 5 m, 10 m, 15 m;
c) number of classes – 6, 8, 10;
d) standard deviation threshold – 3 m, 4.5 m, 6 m.

Such configuration of parameters allows to generate 81 generalized DEMs in total. They will be analyzed in the further part of the article.

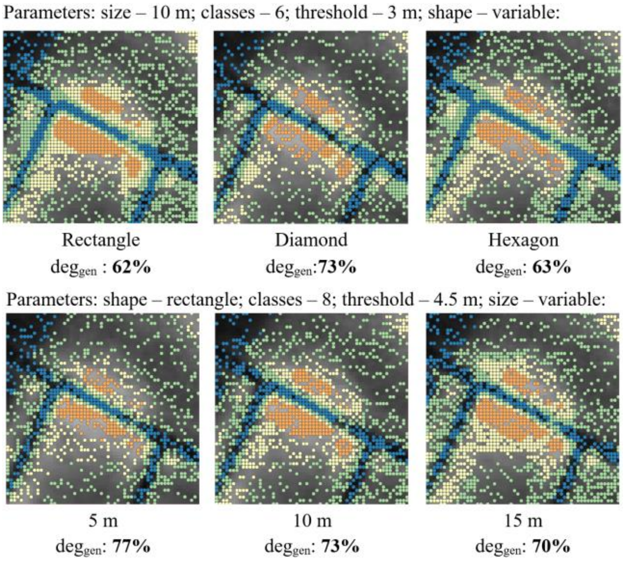
3. Results

This section shows the results of the generalization process. Due to the large amount of results, only some of them will be shown, which present best the dependencies between various settings. To demonstrate differences between the obtained results, the degree of generalization coefficient was calculated with use of equation 1.

$$deg_{gen} = \left(1 - \frac{N_{gen\_DEM}}{N_{DEM}}\right) * 100\% \qquad (1)$$

where deg_{gen} = degree of generalization
N_{gen_DEM} = number of elevation points in the generalized DEM
N_{DEM} = number of elevation points in the original non-generalized DEM (in case of this research it was 111,260)

Results of the generalization are presented in Figure 4.



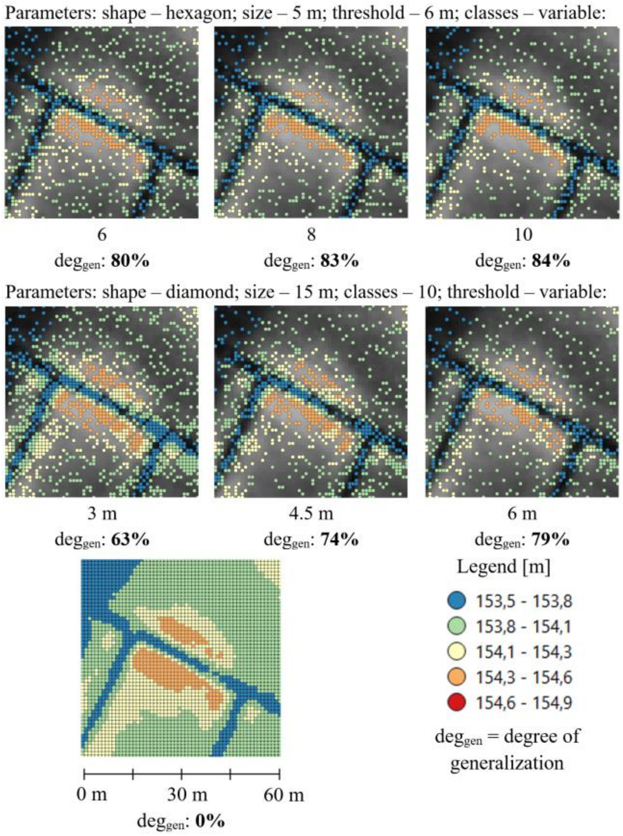


Figure 4. Visualisation of the selected results of the DEM generalization.

One may see that the degree of generalization values vary in the DEMs generalized with different parameters. The juxtaposition of all degrees is presented in Table 1.

deg_{gen} [%]		6 classes			8 classes			10 classes		
		3 m	4.5 m	6 m	3 m	4.5 m	6 m	3 m	4.5 m	6 m
Rectangle	5 m	68	75	79	69	77	81	69	78	82
	10 m	62	72	76	62	73	78	62	73	79
	15 m	58	69	75	58	70	76	58	70	76
Diamond	5 m	71	77	80	72	79	83	72	80	84
	10 m	73	80	83	74	81	84	74	81	85
	15 m	62	72	77	63	73	79	63	74	79
Hexagon	5 m	71	78	80	72	79	83	72	80	84
	10 m	63	73	77	64	74	79	64	74	80
	15 m	60	71	76	60	71	78	61	72	78

Table 1. The degrees of generalization in dependence of used parameters (shape and size of the primary field – on the left; number of classes and threshold value – at the top).

4. Discussion

4.1 The degree of generalization

The obtained results showed that the degree of generalization of the analyzed terrain is in range from 58% to 84% with a mean of 73%. It means that the number of elevation points was reduced from 118,260 (in the non-generalized DEM) to about 32,000 points on average. The degree of generalization depends mainly on the terrain which is to be generalized. The more diversified the terrain, the lower the degree of generalization because more primary fields will be classified into higher class (with greater standard deviation value), and consequently less points will be removed from inside it. Moreover, one may see in Table 1 that the degrees of generalization varies depending on different parameters applied to the generalization. Those dependencies are shown in the form of charts in Figures 5-8.

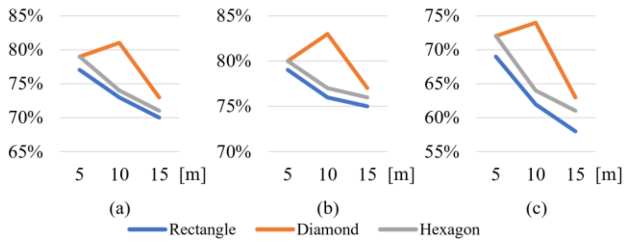


Figure 5. Dependence between the degree of generalization and size of primary fields for various shapes of primary fields in DEMs with the following parameters: (a) 8 classes and 4.5 m threshold; (b) 6 classes and 6 m threshold; (c) 10 classes and 3 m threshold.

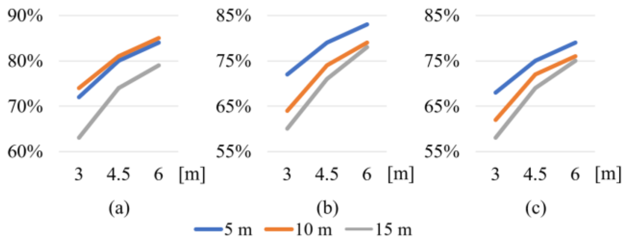


Figure 6. Dependence between the degree of generalization and standard deviation threshold for various sizes of primary fields in DEMs with the following parameters: (a) 8 classes and diamond shape; (b) 8 classes and hexagon shape; (c) 6 classes and rectangle shape.

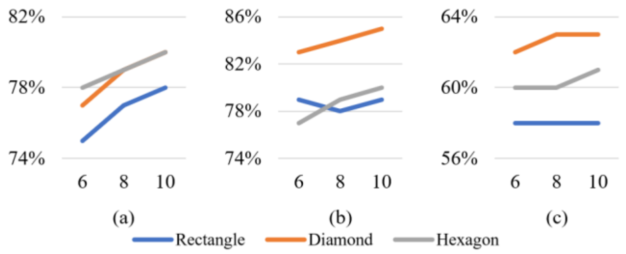


Figure 7. Dependence between the degree of generalization and number of classes for various shapes of primary fields in DEMs with the following parameters: (a) 5 m size and 4.5 m threshold; (b) 10 m size and 6 m threshold; (c) 15 m size and 3 m threshold.

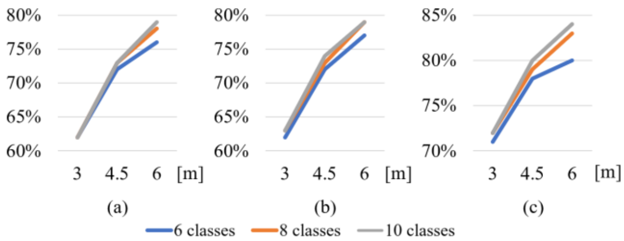


Figure 8. Dependence between the degree of generalization and standard deviation threshold for various numbers of classes in DEMs with the following parameters: (a) 10 m size and rectangle shape; (b) 15 m size and diamond shape; (c) 5 m size and hexagon shape.

On the basis of these charts, one may notice that with the increase of the size of primary fields, the degree of generalization drops in almost every case (Figure 5). Microrelief objects reach mainly several meters in size and even if they occupy a small part of the 15 meters primary field, they have an influence on the standard deviation of slopes in this field. The consequence of that is the classification of this field to the class with higher standard deviation, and consequently the removal of lower number of elevation points, which decreases the degree of generalization. The one exception of this dependence is diamond shape which has the biggest degree of generalization in resolution of 10 m.

What is more, the rise of the standard deviation threshold causes the growth of the degree of generalization in every analyzed size of the primary fields. Figure 6 shows only some examples but this principle applies in all cases, as can be concluded from the Table 1.

As far as the dependence between shape of primary fields and number of classes is concerned (Figure 7), the differences between the degrees of generalization are inconsiderable and do not exceed 4% in any case. It means that the number of classes has insignificant influence on the obtained results.

Figure 8 showed that with the growth of the standard deviation threshold there is a significant increase of the degree of generalization. The charts for each number of classes are very similar to each other and they start to differentiate in the threshold of 6 m.

4.2 Digital elevation models differences

On the basis of the obtained generalized DEMs, the computation of differences between them and the reference (non-generalized) DEM has been performed. Its aim was to assess the influence of generalization on the accuracy of the DEM. The results are presented in the form of histograms in Figure 9.

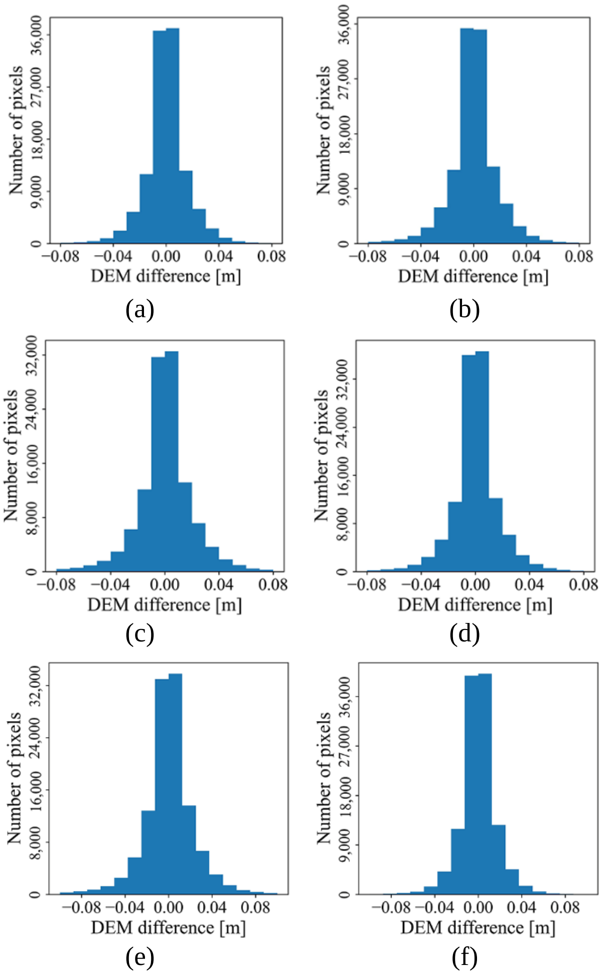


Figure 9. Histograms of the differences between the non-generalized DEM and the DEMs generalized with the following parameters: (a) size: 5 m, shape: diamond, classes: 6, threshold: 3 m; (b) size: 10 m, shape: rectangle, classes: 8, threshold: 4.5 m; (c) size: 15 m, shape: hexagon, classes: 10, threshold: 6 m; (d) size: 15 m, shape: rectangle, classes: 10, threshold: 4.5 m; (e) size: 10 m, shape: diamond, classes: 6, threshold: 6 m; (f) size: 5 m, shape: hexagon, classes: 3, threshold: 3 m.

The created histograms clearly show that the differences between the reference and the generalized DEMs are slight. The histograms resemble the normal distribution and their major part is accumulated within the range of -0.08 m to 0.08 m, which is a satisfying result because the vertical accuracy of the elevation data is 0.15 m (according to the data provider) and the differences of the generalized DEMs almost wholly fall within the range of this error. Taking into account the differences in all generalized DEMs, 99.9% of their values were below 0.15 m and there were only some single pixels which slightly exceeded this value. Such results proclaims that the generalization process of DEMs did not have an influence on their accuracy and generalized models can be used instead of original ones, what significantly increases the performance of the analyzes conducted on them.

To better show the quality of the DEM generalization, contour lines have been generated. They are shown in Figure 10.

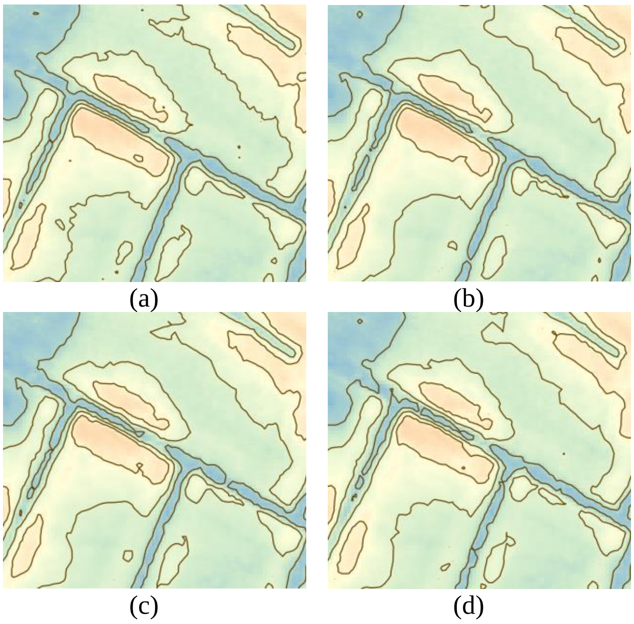
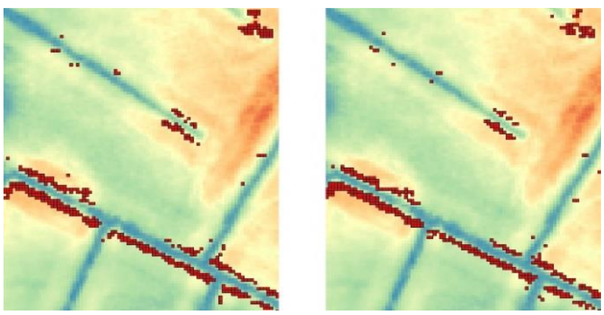


Figure 10. Contour lines (interval: 0.25 m) created from the non-generalized DEM (a) and from the DEMs generalized with the following parameters: (b) size: 5 m, shape: rectangle, classes: 8, threshold: 4.5 m; (c) size: 10 m, shape: diamond, classes: 6, threshold: 3 m; (d) size: 15 m, shape: hexagon, classes: 10, threshold: 6 m.

One may see that despite the slight differences in courses of the contour lines, comparing to the original ones, their character and location is quite similar. It proves that the generalization does not cause a relevant decrease in the quality of the elevation models.

4.3 Generating passability maps

The generalized DEMs were used to perform the microrelief analysis which generates impassable fields for the analyzed vehicle creating the map of passability. Figure 11 presents obtained passability maps based on the non-generalized DEM and DEMs with the minimum, mean and maximum degree of generalization.



(a) (b)

31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-6-2023

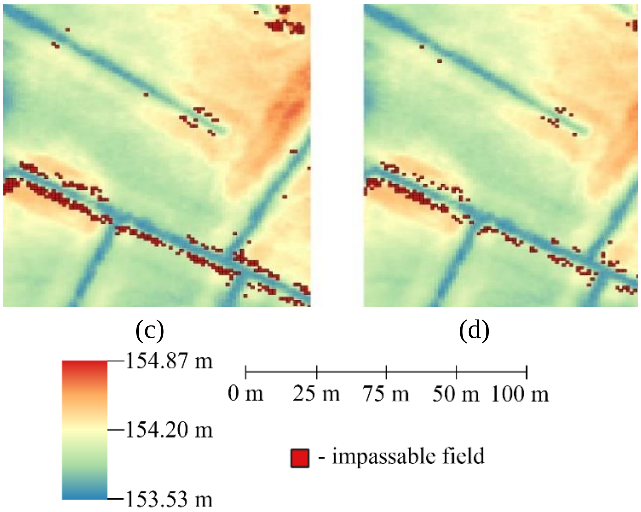


Figure 11. Passability maps created from the non-generalized DEM (a) and from the DEMs generalized with the following parameters: (b) size: 15 m, shape: rectangle, classes: 8, threshold: 3 m – 58% degree of generalization; (c) size: 10 m, shape: diamond, classes: 6, threshold: 3 m – 73% degree of generalization; (d) size: 10 m, shape: diamond, classes: 10, threshold: 6 m – 85% degree of generalization.

The passability maps show that the number of impassable points visibly decreases with the growth of the degree of generalization. The exact number of these points in dependence of the used DEMs is juxtaposed in Table 2.

Kind of DEM	Number of impassable points
non-generalized	1398
58% degree of generalization	1188
73% degree of generalization	980
85% degree of generalization	560

Table 2. Number of impassable points on the passability maps generated with use of different kinds of DEMs.

One may see that the degree of generalization strongly affects the obtained passability maps. The number of impassable points was reduced by almost 60% in the most generalized DEM (85% degree) and by 15% in the least generalized (58%). Mean reduction of impassable points totaled 30%. However, taking into account the location of impassable points, one may see in Figure 11 that it is very similar for all cases. The microrelief analysis indicated impassable points in the same areas or on the microrelief obstacles and, despite their significant reduction, the character of the terrain has been maintained. What is more, the generalization of the DEMs significantly improved the performance of the microrelief analysis, and consequently the duration of the passability maps generation process. Performance tests were conducted on a computer of the following parameters:

a) Processor – 2 x Intel® Xeon® Gold 6230;
b) Base speed – 2.10 GHz;
c) RAM – 192 GB;
d) Number of CPUs – 80.

A chart presenting the generation time of the passability maps in relation to the degree of generalization of DEMs (0% - non-generalized DEM) is shown in Figure 12.

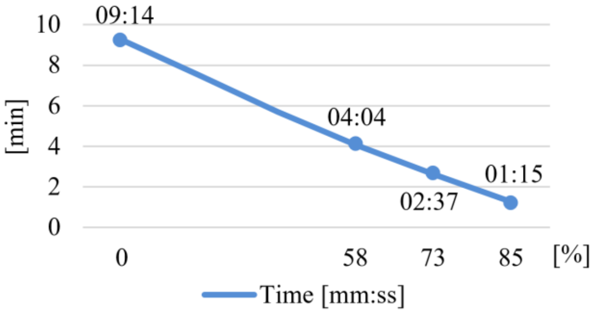


Figure 12. The dependence between the time of the passability maps development and the degree of generalization of the DEMs they were generated from.

The chart clearly shows that with the increase of the degree of generalization, the computation time decreases. All this is due to the reduced number of elevation points which undergo the microrelief analysis. The chart resembles the linear function and the decrease of the processing time is in direct proportion to the growth of the degree of generalization. The utilization of the computer of the aforementioned parameters allowed to perform the microrelief analysis at an average rate of 214 elevation points per second. The generalization process allowed to reduce the generation time of the passability maps has by about 3.5 times.

5. Conclusions

The conducted analyzes demonstrate clearly that the digital elevation model generalization significantly accelerates the military passability maps generation, which is of great importance for planning and conducting military operations. As it was shown in Figure 4, the results of the generalization differ from each other depending on the parameters used in this process. Their analysis showed that the number of classes parameter has little influence on the degree of generalization while the other parameters (size and shape of primary fields, standard deviation threshold) intensify or reduce it. A big advantage of the developed tool, making it universal, is that the user can define these parameters to individual needs.

The analysis of the differences between obtained generalized DEMs and the non-generalized DEM showed that the generalization does not affect the accuracy of the elevation model. The differences are mostly (99.9%) within the 0.15 m range, which is a value provided by the data distributor.

What is more, the usage of the generalized DEMs in the military passability maps generation process has an impact on the number of indicated impassable points (Figure 11). Due to the increase of the degree of generalization, the number of impassable points drops. However, this drop does not affect the character of the analyzed terrain. Impassable points are located in the same areas where they are in the reference passability map created based on the non-generalized DEM. That behavior results directly from the reduction of the elevation points in the generalized DEMs and does not affect the accuracy of the obtained results.

The performance analysis proved that the DEM generalization can significantly speed up the process of the military passability maps development (Figure 12). It is worth noting that, in this research, the analyzed terrain covered almost 0.12 km^2. While planning the military operations, the area of interest can be a way more greater, and consequently, the time of the analysis will be longer. Nevertheless, the generalization process allows to reduce the time of the analysis by about 3.5 times what may be critical to the success of any military operation.

Finally, the proposed DEM generalization methodology can be applied to any analysis, which requires the high detailed digital elevation model, to reduce its time. Further research should focus on the implementation of routing algorithms to the obtained military passability maps, which would cover another important, from a military perspective, aspect.

6. Acknowledgements

This work was supported by Military University of Technology in Warsaw, Faculty of Civil Engineering and Geodesy, Institute of Geospatial Engineering and Geodesy: [Grant Number UGB/22-816/2023/WAT].

7. References

Ayeni, A., 2014. Empirics of Standard Deviation. https://doi.org/10.13140/2.1.1444.6729

Dawid, W., Pokonieczny, K., 2021. Automation of the Terrain Classification Process due to Passability Taking the Microrelief Shapes into Consideration, in: 2021 International Conference on Military Technologies (ICMT). Presented at the 2021 International Conference on Military Technologies (ICMT), pp. 1–8. https://doi.org/10.1109/ICMT52455.2021.9502821

Dawid, W., Pokonieczny, K., 2020. Analysis of the Possibilities of Using Different Resolution Digital Elevation Models in the Study of Microrelief on the Example of Terrain Passability. Remote Sensing 12, 4146. https://doi.org/10.3390/rs12244146

ESRI, 2021. Esri ASCII raster format [WWW Document]. URL https://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/esri-ascii-raster-format.htm (accessed 10.20.22).

Fei, L., He, J., 2009. A three-dimensional Douglas–Peucker algorithm and its application to automated generalization of DEMs. International Journal of Geographical Information Science 23, 703–718. https://doi.org/10.1080/13658810701703001

GUGiK, 2022. PZGiK Data [WWW Document]. Head Office of Geodesy and Cartography. URL https://www.gov.pl/web/gugik/dane-pzgik4 (accessed 10.18.22).

Head Office of Geodesy and Cartography, 2022. Geoportal [WWW Document]. URL https://www.geoportal.gov.pl/ (accessed 11.28.22).

Hu, H., Gao, J., Hu, P., 2009. The digital generalization principle of digital elevation model 7492, 749221. https://doi.org/10.1117/12.838546

Hubáček, M., Rybansky, M., Cibulova, K., Brenova, M., Ceplova, L., 2016. Mapping the passability of soils for vehicle movement. KVÜÕA Toim 5–18.

Li, J., Shen, Y., Gao, A., Chen, K., Zhang, Y., Ai, T., 2021. A heuristic DEM generalization by combining catchments. Geocarto International 0, 1–16. https://doi.org/10.1080/10106049.2021.2017019

Ministry of National Defence, 2012. Defence Standard NO-06-A015:2012, Terrain—Rules of Classification—Terrain Analysis on Operational Level 58.

Podobnikar, T., 2017. Semantic generalization of the multi-source digital elevation model (DEM).

Pokonieczny, K., 2017. Automatic military passability map generation system, in: 2017 International Conference on Military Technologies (ICMT). Presented at the 2017 International Conference on Military Technologies (ICMT), IEEE, Brno, Czech Republic, pp. 285–292. https://doi.org/10.1109/MILTECHS.2017.7988771

Rada, J., Rybansky, M., Dohnal, F., 2020. Influence of Quality of Remote Sensing Data on Vegetation Passability by Terrain Vehicles. ISPRS International Journal of Geo-Information 9, 684. https://doi.org/10.3390/ijgi9110684

Rybansky, M., 2020. Determination the ability of military vehicles to override vegetation. Journal of Terramechanics 91, 129–138. https://doi.org/10.1016/j.jterra.2020.06.004

Shiqing, D.O.U., Xuesheng, Z., Chengjun, L.I.U., Yawen, L.I.N., Yanqin, Z., 2016. The Three Dimensional Douglas-Peucker Algorithm for Generalization between River Network Line Element and DEM. Acta Geodaetica et Cartographica Sinica 45, 450. https://doi.org/10.11947/j.AGCS.2016.20140584

Zaksek, K., Podobnikar, T., 2005. An effective DEM generalization with basic GIS operations. 8th ICA Workshop on Generalization and Multiple Representation, A Coruña, Spain.

