Impact of Data Processing and DTM Resolution on Determining of Small Erosional Landforms

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Abstract. Small erosional landforms are characterised by a dynamics closely related to the occurrence and changes in precipitation and water flowing down the slopes. Triggered by water, the erosion processes are controlled by the other environmental conditions like slope gradient, lithology, land cover and land use. Studying the changes in the topography gives information about the spatiotemporal dynamics of erosion and can contribute to a more effective assessment of erosion susceptibility and mitigation measures at the earliest stage of the process development. Usually in the initial stages, the changes in the topography are hardly noticeable and using high resolution digital terrain models (DTMs) is of high importance. In this relation, the aim of the current research is to determine to what extent the resolution of the models influences the results of delineating the flow lines, rills and gullies. For this purpose, a terrain survey was carried out and data was acquired by UAS (uncrewed aerial system) DJI Phantom 4RTK. DTMs in horizontal resolution of 0.05, 0.1, 0.2, 0.5 and 1 m are created and analysed. Special attention is given to the analysis of surface curvature as an indicator for flow convergence and divergence. The research is done on a slope area covered mainly by grass and some rare bushes and trees. Despite the observed variations, the results show a general trend of decrease in the flow length with decreasing DTM resolution. Considering the plan curvature and concave areas, the differences are smallest between the models with cell size 0.1 and 0.2 m.

1. Introduction

Small erosional landforms like rills and gullies are ones of the most widespread. Studying of these landforms gives an information about the development of erosion processes that can help in elaborating measures to prevent the soil degradation. Until present days, a number of methods have been developed and used to assess soil erosion, as well as the spatial and temporal dynamics of the process. Among these methods, most commonly used is modeling, which requires processing of a significant volume of information. Many publications in the world literature show that the developed models for assessment of the erosion in the plain areas are not applicable in mountains, which, regarding the sensitivity of these territories, directs research to new approaches in erosion research. This, as well as the spatial nature of the data, determine the widespread use of geoinformation technologies in erosion investigations, including wider use of remote sensing. Despite the gained experience in integration of different models for calculating soil erosion and automatic mapping erosional landforms using UAS and TLS (terrestrial laser scanning) data [1, 2], there...
is still a need to clarify what is the optimal DTM resolution to delineate rills and gullies and to quantify erosion processes. It is a challenge to create a reliable DTM when different types of vegetation as forest, shrubs and grass cover the area. Some critical issues can be determined in close-range remote sensing of erosional landforms such as the choice of point spacing that is necessary to detect surface features and their changes [3].

Regarding to the above, the aim of the current research is to determine to what extent the resolution of the models influences the results of delineating the flow lines, rills and gullies. For this aim, DTMs statistics and two main morphometric parameters (flow lines length and topographic curvature) are analysed.

2. Study area
The area of interest is located in the Eastern Rhodopes, Bulgaria (Figure 1), in the middle part of the river Mashkuleva watershed, near to village Bogatino. The region as a whole is susceptible to water erosion because of the peculiarities of rocks, topographic surface and land cover. The current study was done on a low mountain slope covered by rare vegetation, mainly grass and single trees and shrubs. The test area is around 0.31 ha with a mean slope gradient of 18°. It is a subject of shallow surface erosion. At the northern end of this area a small gully (26 m long) is developed. Highly weathered gneisses build the upper and middle parts of the catchment, which favors erosion processes.

3. Data and methods
The aerial survey was taken in April 2021. An uncrewed aerial vehicle (UAV) - DJI Phantom 4 RTK with 20 Mpix color digital camera was used for data acquisition. The camera was equipped with 1" CMOS sensor of micro 4:3 (3:2) standard with resolution of 4864×3648 pixels (5472×3648). The plan mission was realized automatically with the GS RTK app. 2D photogrammetry planning mode was used where an image heading and side overlap were set at 80%. The average flight altitude was 50 m. The multirotor Phantom 4 RTK provided centimeter-accurate data, while requiring fewer ground control points. In the studied area six well-distributed ground control points (GCPs) have been set. They were measured with a survey-grade GNSS receiver CHCNAV i50 in a WGS84 UTM 35 North coordinate system (EPSG: 32635). Photogrammetric processing of the UAV imagery was performed with Agisoft PhotoScan professional software. As a result of the data processing, a point cloud was generated to be used for a deriving of digital elevation model. In order to satisfy research aim, the dense point cloud was classified automatically. All the points were divided into two classes - ground points and others. The classification procedure consists two steps. Firstly, the dense cloud is divided into cells of a certain size.
In each cell the lowest point is detected. Triangulation of these points gives the first approximation of the terrain model. At the second step new point is added to the ground class if the new point satisfies the definite conditions. The process is repeated while there still are points to be checked.

A DTM in a horizontal resolution of 0.05 m was generated of points that have been classified as ground. This model is further processed in ArcGIS Pro environment and resampled to models in 0.1, 0.2, 0.5 and 1 m resolution using bilinear interpolation. In order to analyse the impact of DTM resolution on determining small erosional landforms we considered the main morphometric parameters as length of the flow lines and curvature of the generated surfaces. The flow lines are derived of flow accumulation raster by D8 algorithm (Hydrology tools in ArcGIS Pro) and using a threshold value for the area of which a stream (rill) could be initiated. Determining the threshold value is of high importance for the results of flow lines delineation and it is closely related to the drainage density. Analysing the influence of DEM resolution on drainage network extraction Ariza-Villaverde et al. [4] consider a threshold value in percent of maximum flow accumulation. The authors state that at dense drainage network the appropriate threshold value is lower than 1% of maximal flow accumulation. In the current study, the threshold value is determined as an area that could form flows/streams. Taking into account the topographic properties of the area of test site, the field observations and measurements, we choose a value of 20 m². The topographic curvature is considered as an indicator for the distribution of erosion and deposition, and for flow convergence and divergence. Profile and planform curvature are analysed. The profile curvature is calculated on the direction of maximal slope gradient and allow determining convex and concave parts of the slope. Convex parts are associated with areas of deposition and concave ones with erosion and sediment transport. Planform (plan) curvature shows changes in the slope aspect. The positive values of the plan curvature indicate that the surface is convex and flows divergence. When the values are negative, the surface is concave and flows convergence.

4. Results and discussion

4.1. DTMs statistics

Comparison of the DTMs in different resolution shows larger differences between the values of maximal elevation (29 cm larger for the 0.05m DTM of the whole test area in comparison to 1m DTM) while the values of minimal elevation slightly increase with increasing the cell size (Table 1). These results are consistent with the results presented in [3, 4, 5]. Considering only the area of the gully, the differences between the minimal values are larger (38 cm between 0.05m and 1m DTMs), while at the maximal values the largest difference is 16 cm between the models with a cell size of 0.05 m and 0.5 m. These differences can be explained by the effect of vegetation and the weaker erosion out of the gully area, as well as by the absence of vegetation in the gully and smoothing out the convex parts of the gully in increasing cell size of the models. Despite the observed differences the results show a common trend of increasing the minimal and decreasing the maximal values of the elevation with increasing cell size of the DTMs. The smallest, almost negligible are the differences between the models with a horizontal resolution of 0.05 and 0.1 m.

The impact of the DTMs resolution on morphometric properties of the landforms can be seen on the cross-section graphs (Figure 2). The comparison of the cross-section lines shows larger difference when cell size becomes 0.5 m and larger. In this regard when the task is to delineate flow lines models with cell size of 0.2 m and even 0.5 m could give appropriate results and can be used instead a very detailed 0.05 m DTM that will speed the data processing. However, a special attention has to be given to using 0.5 m DTM, regarding the properties of the topographic surface and the size of erosional landforms. For calculating the volume of the sediment transport and change detection, high resolution DTM (0.05 cell size) is needed.
Table 1. DTM statistics

| Cell size | 0.05 | 0.1  | 0.2  | 0.5  | 1   |
|-----------|------|------|------|------|-----|
| Min       | 639.48 | 639.48 | 639.54 | 639.54 | 639.62 |
| Max       | 659.33 | 659.33 | 659.27 | 659.11 | 659.04 |
| Mean      | 648.59 | 648.59 | 648.59 | 648.59 | 648.59 |
| Median    | 648.27 | 648.27 | 648.27 | 648.28 | 648.27 |
| Std.Dev.  | 4.27  | 4.28  | 4.28  | 4.28  | 4.28 |

The whole test area

| Cell size | 0.05 | 0.1  | 0.2  | 0.5  | 1   |
|-----------|------|------|------|------|-----|
| Min       | 641.36 | 641.36 | 641.40 | 641.32 | 641.74 |
| Max       | 649.80 | 649.83 | 649.78 | 649.65 | 649.70 |
| Mean      | 644.43 | 644.43 | 644.42 | 644.39 | 644.39 |
| Median    | 644.27 | 644.28 | 644.26 | 644.27 | 644.23 |
| Std.Dev.  | 1.96  | 1.97  | 1.95  | 1.98  | 1.86 |

The gully area

Figure 2. Cross-sectional profile at different resolution DTMs
4.2. Flow lines

There is a variety in the results of flows delineation in the gully and inter-gully erosion on one side, and the other part of the slope that is covered by grass, and where erosion is less visible. While in the inter-gully area the lines derived from 5, 10 and 20 cm DTMs fit better to the orthoimage, at the other part of the test area 5 and 10 cm models give better results (Figure 3).

![Flow lines derived of DTM with different resolution](image)

**Figure 3.** Flow lines derived of DTM with different resolution

Considering the length of the flow lines the total length of the derived lines decreases with the increasing the cell size of the DTMs. This common trend is presented also in other publications considering the impact of DEM resolution [3, 6]. In the current study, an exception of this trend is observed in comparison of 0.5 and 1 m cell size models where the length is slightly increased at the model with larger cell size. Regarding the gully where erosion is more visible, the common trend of decreasing the length of the flow lines with decreasing of the DTMs resolution is also observed. The terrain models, analysed in the current case, can be divided in two groups according to the differences in the total length of the derived flow lines. The first one consists 0.05, 0.1 and 0.2 m DTMs and the models with 0.5 and 1 m cell size form the second group (Table 2). The change in the total length of the
flow lines with the successive change in the resolution of the models shows largest difference at the passing from 0.2 to 0.5 m cell size. Regarding the whole study area, the smallest difference in the flow lines length is calculated between the lines derived of 0.5 and 1 m DTMs, despite the large difference between the cell sizes. This shows that in the case of shallow erosion the changes of the topographic surface are more smoothed out in decreasing the models resolution. In the gully area resampling the models from 0.05 to 0.1, 0.2, 0.5 and 1 m leads to increasing the difference between the total lengths of the flow lines. This indicates that in a more dynamic conditions and erosion of the surface, using DTMs with a cell size of 0.05 to 0.1, 0.2 m gives better results than 0.5 and 1 m models.

**Table 2.** Total length of the flow lines and differences in the length at different resolution of the DTMs*

| Cell size | 0.05 | 0.1 | 0.2 | 0.5 | 1     |
|-----------|------|-----|-----|-----|-------|
| Total length of the flow lines | 624.77 | 604.22 | 592.20 | 543.21 | 550.75 |
| 624.77    | 0.00  | **20.55** | 32.58 | 81.56 | 74.02 |
| 604.22    | -20.55 | 0.00  | **12.02** | 61.01 | 53.47 |
| 592.20    | -32.58 | **-12.02** | 0.00  | 48.99 | 41.45 |
| 543.21    | -81.56 | -61.01 | -48.99 | 0.00  | **-7.54** |
| 550.75    | -74.02 | -53.47 | -41.45 | **7.54** | 0.00  |

| Cell size | 0.05 | 0.1 | 0.2 | 0.5 | 1     |
|-----------|------|-----|-----|-----|-------|
| Total length of the flow lines | 45.42 | 47.17 | 46.72 | 33.50 | 36.86 |
| 45.42    | 0.00  | -1.75 | **-1.30** | 11.92 | 8.56 |
| 47.17    | 1.75  | 0.00  | **0.45** | 13.67 | 10.31 |
| 46.72    | 1.30  | **-0.45** | 0.00  | 13.22 | 9.86 |
| 33.50    | -11.92 | -13.67 | -13.22 | 0.00  | **-3.36** |
| 36.86    | -8.56 | -10.31 | -9.86  | **3.36** | 0.00  |

*Values in the table show the difference between the flow lines length given in the row and the respective length in the column

**Minimal differences (in absolute values) for the given resolution of the DTM are shown in bold.

4.3. Curvature

The distribution of flow lines on the topographic surface is related to the surface curvature. This parameter is one of the most often used for quantitative measure for flow line divergence, delineating channel network and characterizing erosion process [7, 8, 9]. A high-resolution DTM is able to detect the divergence/convergence areas related to unchannelized/channelized processes [10]. The planform curvature allows tracing the lines of the flows at the concave parts, divided by the convex ones (Figure 4). Profile curvature indicates erosion and deposition in the direction of maximal slope gradient.

The analyses of curvature rasters show that high-resolution topography is not very suitable for calculating curvature that to be used for delineating flow lines. Smoother curvature maps are more appropriate for the extraction of channel network [10]. In the current study, DTMs were smoothed before generating the curvature rasters, having regard the meaning of the curvature parameters and their geomorphological interpretation. The smoothing was done by Focal Statistics tool in ArcGIS Pro using moving window (neighbourhood type) in a size of 1 m² for 0.05, 0.1, 0.2 and 0.5 m DTMs and 2 m² for
DTM with a cell size of 1 m, statistics type “Mean”. Despite the 3x3 neighbourhood size often used in publications [11] we used a different smoothing range depending on the DEM resolution to obtain comparable rasters representing the curvature in one and the same size of 1 m².

![Surface curvature derived of 0.5 m DTM](image)

**Figure 4.** Surface curvature derived of 0.5 m DTM

Comparison of the curvature rasters and analysing the size of convex and concave areas show that profile curvature is more sensitive to the changes in the cell size of DTMs (Figure 5).

![Distribution of convex and concave areas at different cell size DTMs](image)

**Figure 5.** Distribution of convex and concave areas at different cell size DTMs (in % of the total area for the respective resolution of the model)

The variations in the profile curvature at different resolution of the DTMs indicate that determination of erosion and deposition areas is more dependent on the resolution of the model than the delineation of the flow lines.

5. Conclusions

The horizontal resolution of DTMs have a significant impact on the results of studying erosional landforms. This effect is smoothed out or occurred in a different way due to the vegetation cover. The analysis of the properties of the models with cell size of 0.05, 0.1, 0.2, 0.5 and 1 m shows consistent change when cell size become 0.2 m or larger. The cross-sectional profile through the gully and the adjacent slope indicate negligible difference between 0.05, 0.1 and 0.2 m DTMs, particularly regarding the position of the bottom lines of the gully and rills. For delineating small erosional landforms models
in a resolution of 0.1 m is recommended. DTM with a cell size of 0.2 or even 0.5 m could also give good result in determining the flow lines but the depth of the erosional landforms and vegetation cover have to be thoroughly analyzed. The incremental change in the cell size of the DTMs shows a general tendency to decrease the length of the flow lines with decreasing model resolution. In the current study an exception are the lines derived using 1 m DTM. Analysis of the surface curvature displays that determination of areas of erosion and deposition, and in this relation volume calculation, are more sensitive to the resolution of the models than delineating the flow lines.

The results, presented in this paper give some insights about the impact of the DTMs cell size in studying small erosional landforms but they are closely related to the particular landscape. Despite the general compliance with the findings in other publications, the interpretation of the DTMs and the derivative models have to be done taking into account the landscape conditions.

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References
[1] S. D'Oleire-Oltmanns, I. Marzolff, K. D. Peter, J.B. Ries, “Unmanned Aerial Vehicle (UAV) for Monitoring Soil Erosion in Morocco”. Remote Sensing, 4(11):3390-3416, 2012. https://doi.org/10.3390/rs4113390
[2] J. Šašak, M. Gallay, J. Kaňuk, J. Hofierka, J. Minár, “Combined Use of Terrestrial Laser Scanning and UAV Photogrammetry in Mapping Alpine Terrain”. Remote Sensing, 11(18):2154, 2019, https://doi.org/10.3390/rs11182154
[3] Xiaoyu Lu, Yingkui Li, R. A. Washington-Allen, Yanan Li, Haidong Li, Qingwu Hu, “The effect of grid size on the quantification of erosion, deposition, and rill network”, International Soil and Water Conservation Research, Vol. 5, Issue 3, pp 241-251, ISSN 2095-6339, 2017, https://doi.org/10.1016/j.iswcr.2017.06.002.
[4] A. B. Ariza-Villaverde, F. J. Jiménez-Hornero, E. Gutiérrez de Ravé, “Influence of DEM resolution on drainage network extraction: A multifractal analysis”. Geomorphology 241, 243–254, 2015, http://dx.doi.org/10.1016/j.geomorph.2015.03.040
[5] M. Nazari-Sharabian, M. Taheriyoun, M. Karakouzian, “Sensitivity analysis of the DEM resolution and effective parameters of runoff yield in the SWAT model: a case study”, Journal of Water Supply: Research and Technology-Aqua, 69 (1): 39–54, 2020, https://doi.org/10.2166/aqua.2019.044
[6] H. Zhang, Z. Li, M. Saifullah, Q. Li, X. Li, “Impact of DEM Resolution and Spatial Scale: Analysis of Influence Factors and Parameters on Physically Based Distributed Model”, Advances in Meteorology, vol. 2016, Article ID 8582041, 10 pages, 2016, https://doi.org/10.1155/2016/8582041
[7] E. Tcherkezova, A. Sarafov, “Applying GIS and Erosion Response Units to derive erosion processes in the Tsaparevska river watershed, Bulgaria”. Compt. rend. Acad. bulg. Sci., 68, 12, 1559-1556, 2015
[8] A. Vinci, R. Brigante, F. Todisco, F. Mannocchi, F. Radicioni, “Measuring rill erosion by laser scanning”, Catena 124 (2015) 97–108, 2015. http://dx.doi.org/10.1016/j.catena.2014.09.003
[9] I. Florinsky, “Digital Terrain Analysis in Soil Science and Geology”. Elsevier Science, ISBN 409 9780128046333, 2016
[10] F. Pirotti, P. Tarolli, “Suitability of LiDAR point density and derived landform curvature maps for channel network extraction”. Hydrol. Process. 24, 1187–1197, 2010
[11] P. Bazzoffi, “Measurement of rill erosion through a new UAV-GIS methodology”, Italian Journal of Agronomy; vol. 10(s1):695, 2015