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Mapping drainage ditches in agricultural landscapes using LiDAR data

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Abstract. The aim of this study is to develop a method for identification of the drainage ditch network, which can be used for surface runoff modeling and to increase accuracy of estimation of greenhouse gas (GHG) emissions in croplands and grasslands, using remote sensing data. The study area consists of 11 objects throughout Latvia with a total area of 145 km^2. Digital elevation models (DEMs) in two resolutions, which were created using three different interpolation methods, were used for the analysis. Several multi-level data filtering methods were applied to identify ditch network, including flow patterns, which can be used in surface runoff process. The method we developed correctly identified 85–89% of ditches, depending on the DEM used, in comparison to the reference data. Mapped ditches are located within 3 m range of the reference data in 89–93% of cases. The elaborated model is robust and uses openly available source data and can be used for large scale ditch mapping with sufficient accuracy necessary for hydrological modelling and GHG accounting in the national inventories.

Key words: ditch, drainage, LiDAR, cropland, grassland.

INTRODUCTION

Most of the long-term operational infrastructure, including the drainage ditch network, has been developed before compliance with climate change was included in the planning process. Therefore it is essential to obtain accurate data on the location and condition of the ditch network in order to be able to assess its suitability for foreseeable conditions and the need for improvement measures. Ditches reduce the risk of flooding events during spring, as well as after heavy rainfalls, accumulating water and discharging it to downstream water bodies, where the opposite effect - overflow- can occur, if their capacity or runoff is limited. For this reason, ditches and their elements, such as culverts, need to be maintained and functioning (Moussa et al., 2002).

Recently, intensive agriculture, forestry and associated ditching have been identified to pose several complex environmental risks, particularly degradation of wetlands and soil, greenhouse gas emissions (Audet et al., 2017; Peacock et al., 2021), increased nutrient and sediment discharge to water bodies and biodiversity loss (Lidman et al., 2017; Lepistö et al., 2021). Identification of ditches and connections to the rest of the hydrographic network can help in decision making about water management, quality control, as well as risks, and the gathered data can be used to model environmental processes (Roelens et al., 2017).

In lowland agricultural lands of Western Europe, the density of the man-made ditch network has been estimated as 200–300 m ha^{-1}, but in Poland it reaches 150–350 m ha^{-1} (Bryndal & Kroczak 2019). Different research actions were implemented to evaluate and minimize environmental risks and to restore degraded or wet soils in the ditched agricultural and forest landscapes (Ivanovs & Lupikis, 2018; Hasselquist et al., 2018). However, such initiatives are significantly limited by the lack of accurate and site-specific data of ditch networks (Lidberg et al., 2017; Ivanovs & Lupikis 2018; Melniks et al., 2019).

Currently, remote sensing data and high-resolution laser scanning data are becoming increasingly important in environmental research. Therefore, the quality and suitability of a digital terrain model, as well as appropriate methodology are essential for identification of small-scale elements such as a ditch network (Anderson et al., 2006; Vaze at al., 2010).

Various studies have previously been carried out to identify ditches using laser scanning data, but they do not analyze the impact of the DEM interpolation method. Currently, most studies (Sofia et al., 2011; Passalacqua et al., 2012; Cazorzi et al., 2013) identify the ditch network using high-resolution (0.5 and 1 m) digital elevation models, which is considered to be the most widely used approach, because it requires a relatively low density of LiDAR points in comparison to requirements for raw LiDAR point cloud-based approaches. In a study carried out in Belgium (Roelens et al., 2016), classified LiDAR point clouds were used to identify agricultural ditches and their parameters. There are also studies based on different topographic indices, such as Topographic elevation index or Standardized elevation index combined (Passalacqua et al., 2012; Kiss et al., 2015). Most of the studies similar to ours regarding methodologyuse Relative Elevation Attribute or slope analysis, are focused on smaller study areas (up to 150 ha), and use individual laser scanning flight campaigns instead of countrywide assessments (Cazorzi et al., 2013; Rapinel et al., 2015; Roelens et al., 2018b, 2018a).

In our study we developed a method, applicable on large areas, which is based on the logistic approach and analysis of a digital elevation model with a focus on the DEM interpolation method and horizontal resolution.

Study area

The study area (145 km^{-2} in total) consists of 11 regions in Latvia, where agricultural land dominates. The areas have been selected by experts to describe the overall landscape in as general way as possible. Areas are located in different quaternary sediments and are characterized by different types of land management and moisture regimes (Fig. 1).

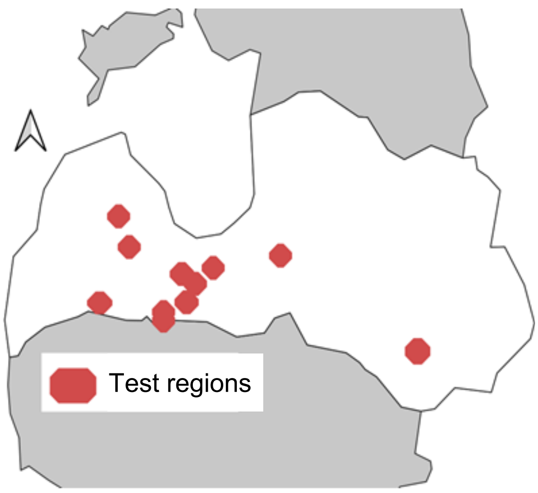

Figure 1. Locations of the digitized test regions, where red points indicate areas with dominating agricultural landscapes.

Reference and airborne LiDAR data

The LiDAR point cloud in LAS format, derived from Latvian Geospatial agencie's National ALS program, was used to create the digital elevation model. The LiDAR data we used, have a vertical accuracy of 0.12 m (2 sigmas with a 95% confidence level against the National Geodetic Network) and a horizontal accuracy of 0.36 m (2 sigmas with a 95% confidence level against the National Geodetic Network). The minimum point density is 4 points m^{-2}, and the average ground point density is 1.5 points m^{-2} (LGIA 2017).

In the study areas manual digitization of the ditch network as vector lines was performed using DEM 0.5 m resolution, which was obtained using the Binning interpolation method. When digitizing, DEM is depicted as a multidirectional hillshade.

MATERIALS AND METHODS

To perform the analysis, DEMs were first generated in horizontal resolutions of 0.5 m and 1 m using three different interpolation methods - Binning, Bilinear and Bicubic, which are implemented in open access GIS, for example GRASS GIS (Fig. 2).

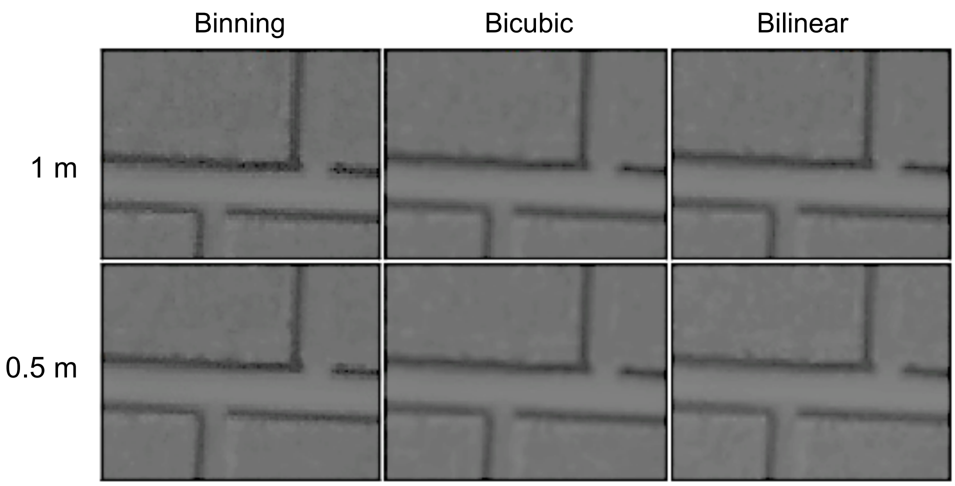

Figure 2. Example of raster images in 0.5 m and 1 m horizontal resolution and different interpolation methods.

To identify the preliminary ditch network using DEM, a logical query based on the identification of local depressions was used, depending on the minimum depth and width of the ditch set by the user (Eq. 1). This type of raster processing has some similarities with Relative Elevation Attribute, which is used in several other studies (Cazorzi et al., 2013; Rapinel et al., 2015; Roelens et al., 2018b). The same analysis was done to all DEM's in both 0.5 m and 1 m resolution. The output of this algorithm is a binary image, where the value of 1 indicates a local reduction corresponding to the set parameters.

$$\text{If}\,((DEM + X < DEM\,[-Y,0]\ \&\&\ +X < DEM\,[Y,0])\ \|\ (DEM + X < DEM\,[0,Y]\ \&\&\ DEM + X < DEM\,[0,-Y])\ \|\ (DEM + X < DEM\,[Y,Y]\ \&\&\ DEM + X < DEM\,[-Y,-Y])\ \|\ (DEM + X < DEM\,[-Y,Y]\ \&\&\ DEM + X < DEM\,[Y,-Y]), 1, 0) \qquad (1)$$

where DEM – digital elevation model; X – minimal depth of the ditch; Y – minimal width of the ditch, both in raster cells.

The resulting binary image contains both the ditch network and various supplementary data sets that have met the specified criteria. The higher resolution DEM is used for the analysis and the smaller the minimum depth of the ditch as well as the wider its width, the more we are exposed to pixels that contain 'noise'. Further processing of the preliminary ditch network was performed using ESRI ArcMap automated vectorization tools.

Multi-level filtering of elements was performed by vectorizing the binary image. First, noise pixel filtering, creation and generalization of linear objects were performed. Vectors are designed considering their length, the distance between the ends, as well as the connection angle for connecting small gaps.

In the next processing step, final filtering was performed. In this step a complex analysis of the ditch network takes place considering the number of its constituent elements, the total length, and the possibility of connectivity in the 15 m buffer zone. In this way elements that do not form a network of ditches consist of objects shorter than 30 m individually or form systems with a total length of less than 100 m are disposed of (Fig. 3).

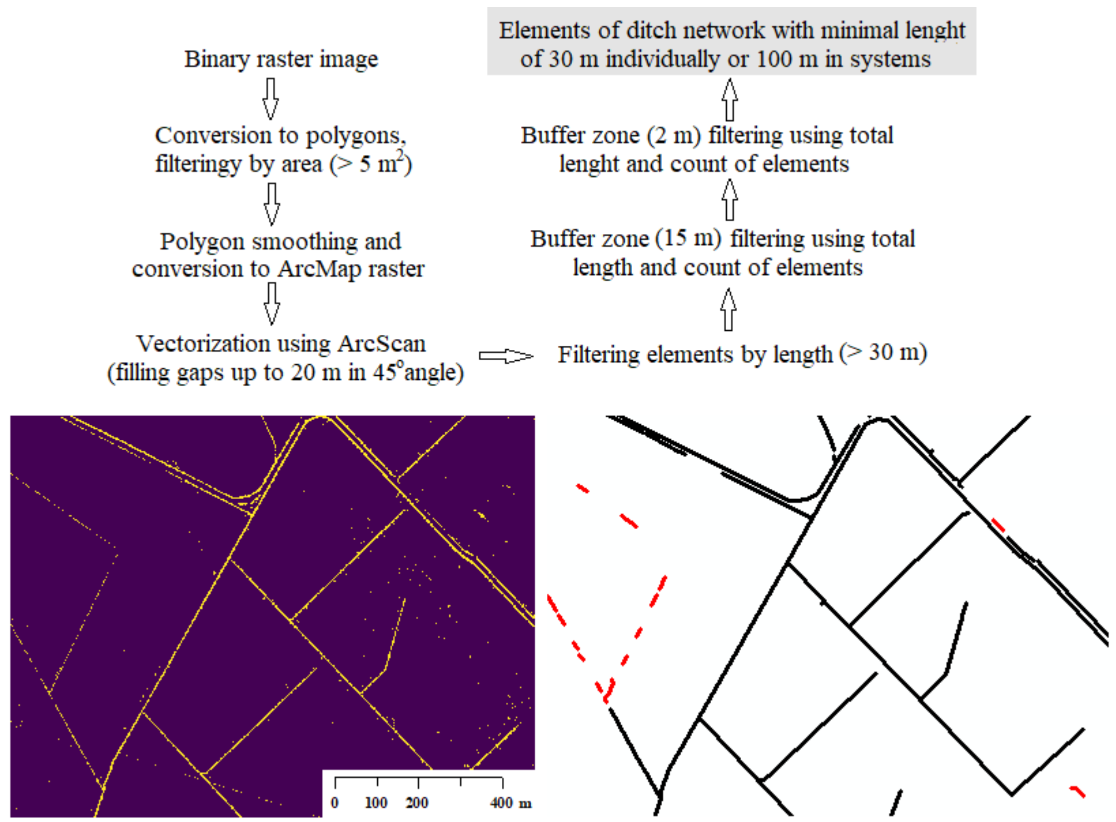

Figure 3. Diagram of data filtering workflow and example of binary image (left), where yellow pixels are representing preliminary ditch data and vectorized data (right) before (red) and after (black) multi-level filtering was performed.

RESULTS

For the analysis we used a minimum ditch depth of 0.3 m and maximum width of 8 m. Only the final data of the model after filtering was used for data analysis. The preliminary ditch data in binary images were not analyzed. Buffer zones of 2 m were created for both reference and modeled data, which were analyzed by converting them to raster format. Accuracy of the modeled ditch data is evaluated by comparison of modeled pixels with reference pixels in the test areas using a confusion matrix (Fig. 4). The confusion matrix is made for each resolution as well as for each interpolation method. Several metrics, such as recall, precision, errors of omission and commission were calculated using the confusion matrix (Tables 1, 2).

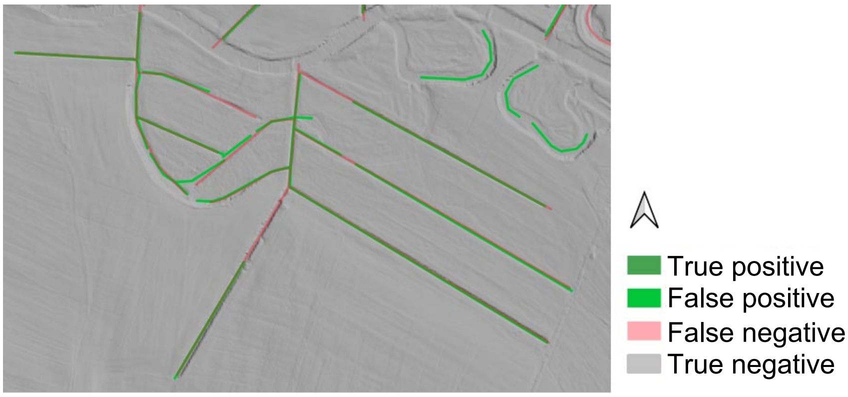

Figure 4. Example of area, where confusion matrix analysis was done.

Given that the confusion matrix is more suitable for raw raster pixel comparison and that our chosen method of analysis should be considered with caution when comparing results with other studies of this type, the Jaccard index was also used to assess the accuracy of the model (Real & Vargas 1996). In this case, 3 m buffer zones are created around the reference ditch vector data and the total length of modeled ditches in the sample areas that overlap with the reference data in the given deviation is determined.

Table 1. Evaluation of the model performance of mapping drainage ditches using DEM in 1 m resolution and 3 different interpolation methods

1 m resolution	Binning	Bicubic	Bilinear
Recall, %	85	86	85
Accuracy, %	98	99	98
Precision	0.77	0.78	0.77
Error of omission, %	15	14	15
Error of commission, %	23	22	23
Jaccard index for overlapping lines in 3 m distance	0.89	0.9	0.89

The results show small but considerable differences in the performance of the model in identifying ditches at both DEM resolutions and the chosen interpolation method. The highest model recall and precision, as well as the smallest errors of omission and commission, using DEM in 1 m horizontal resolution is obtained, when Bicubic interpolation method is applied (Table 1). There is no considerable difference in performance between Binning and Bilinear interpolation methods, where all measures, including Jaccard index, are identical.

When DEM with 0.5 m resolution is used, all metrics have higher accuracy regardless of the interpolation method applied. However, the Bicubic interpolation method shows a significant difference between all parameters in comparison to other methods. The values of the error of omission and error of commission, as well as Jaccard index approves that in Latvia, taking in account the defined drainage ditch morphometric parameters in agricultural lands, this method offers the highest performance from those compared in this study.

Table 2. Evaluation of model performance of mapping drainage ditches using DEM in 0.5 m resolution and 3 different interpolation methods

0.5 m resolution	Binning	Bicubic	Bilinear
Recall, %	88	89	87
Accuracy, %	98	98	98
Precision	0.79	0.81	0.79
Error of omission, %	12	11	13
Error of commission, %	21	19	21
Jaccard index for overlapping lines in 3 m distance	0.91	0.93	0.91

DISCUSSION

The main difference between our study and research results published earlier is the focus area; earlier studies have mainly focused on relatively small and specially selected sample areas (Sofia et al., 2011; Cazorzi et al., 2013; Kiss et al., 2015; Rapinel et al., 2015; Roelens et al., 2018a). To the date we have not found any studies, where national-level LiDAR data sets have been used, covering large areas for automated decryption of the ditch area. The above mentioned studies mostly use laser scanning data from individual missions implemented specially for these studies, which have a higher density of bare ground points. In our case the focus is on the LiDAR data sets acquired within the scope of the National scale program, with relatively low bare ground point density of 1.5–2.0 points m^{-2}, as well as larger and more robust testing area is used. The study implemented in Belgium (Roelens et al., 2018b) used DEM, as well as the point cloud approach, resulting in significantly different results between both methods; however, the error of omission and error of commission in this study are similar those obtained in our study.

The accuracy and consistency of the obtained results comparing with the reference data in our study are significantly higher compared to other studies. It should also be noted that different methods have been applied in the compared studies to assess the performance of the models, so this is not an unambiguous aspect to evaluate.

Performing individual flights with an unmanned aircraft provides an opportunity to obtain a higher density of points, as well as multispectral and RGB images, thus resulting in a wider range of interpretations in the assessment of the overgrowth and technical condition of ditches. This approach provides a wide range of possibilities for classification and monitoring of ditches, as multispectral scenes allow the calculation of different vegetation and moisture indices (Rapinel et al., 2015; Roelens et al 2017).

Acquisition of such data would allow to calculate vegetation and moisture indices. It would be important for the continuation of our study to integrate national scale and local data sets, as they, in combination with LiDAR data, provide a wide range of options for data interpretation. The combination of these data would be valuable within the scope of further studies on the development of a tool for automatic classification of ditches and assessment of their technical condition to be used on a country or local scale analysis.

The assessment of the technical condition of ditches using combined remote sensing data would be very useful, given that the ditch networks have basically unknown, but potentially significant effects on the greenhouse gas (GHG) balance, which EU countries will have to report in the National GHG inventories (Peacock et al., 2021).

CONCLUSIONS

1. The elaborated methodology for identifying drainage ditch network using LiDAR data can be used to map ditches over large areas.
2. In agricultural landscapes the elaborated method demonstrated very high accuracy, similar to the studies, where smaller, individual flight campaign-based sample areas were analyzed.
3. The highest metric parameters were obtained using DEM in 0.5 m resolution, when Bicubic interpolation method was applied.
4. Threshold values should be considered seriously to improve model performance, especially, when mapping is done outside agricultural lands.
5. Further studies with the aim to identify natural stream networks, classify drainage ditch networks and analyze their impact on hydrological regime, and to assess the potential usage for ditch area and volume calculations, which can be used for GHG emission inventory, must be done to extend the field of application of the elaborated method.

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REFERENCES

Anderson, E.S., Thompson, J.A., Crouse, D.A., Austin, R.E. 2006. Horizontal resolution and data density effects on remotely sensed LIDAR-based DEM. *Geoderma*, **132**(3–4), 406–415.

Audet, J., Wallin, M.B., Kyllmar, K., Andersson, S. & Bishop, K. 2017. Nitrous oxide emissions from streams in a Swedish agricultural catchment. *Environmental science, Agriculture Ecosystems. Environment* **236**, 295–303.

Bryndal, T. & Kroczak, R. 2019. Reconstruction and characterization of the surface drainage system functioning during extreme rainfall: the analysis with use of the ALS-LIDAR data - the case study in two small flysch catchments (Outer Carpathian, Poland). *Environmental Earth Sciences* **78**, 215.

Cazorzi, F., Fontana, G.D., Luca, A.D., Sofia, G. & Tarolli, P. 2013. Drainage network detection and assessment of network storage capacity in agrarian landscape. *Hydrology Processes* **27**, 541–553.

Hasselquist, E.M., Lidberg, W., Sponseller, R.A., Ågren, A. & Laudon, H. 2018. Identifying and assessing the potential hydrological function of past artificial forest drainage. *Ambio* **47**, 546–556.

Ivanovs, J. & Lupiķis, A. 2018. Identification of wet areas in forest using remote sensing data. *Agronomy research* **16**(5), 2049–2055.

Kiss, K., Malinen, J. & Tokola, T. 2015. Forest road quality control using ALS data. *Can. J. Forest Research* **45**, 1636–1642.
Latvian Geospatial information agencie (LGIA). 2017. ALS data, and its processing. *Fotogrammetrijas diena 2017*.
Lepistö, A., Räike, A., Sallantaus, T. & Finér, L. 2021. Increases in organic carbon and nitrogen concentrations in boreal forested catchments – Changes driven by climate and deposition. *Science on The Total Environment* **780**, 146627.
Lidberg, W., Nilsson, M., Lundmark, T. & Ågren, A.M. 2017. Evaluating preprocessing methods of digital elevation models for hydrological modelling. *Hydrological Processes* **31**(26), 4660–4668.
Lidman, F., Boily, Å., Laudon, H. & Köhler, S.J. 2017. From soil water to surface water-how the riparian zone controls element transport from a boreal forest to a stream. *Biogeosciences* **14**, 3001–3014.
Melniks, R., Ivanovs, J. & Lazdins, A. 2019. Method for shallow drainage ditch generation using remote sensing data. *Proceedings of the 9th International Scientific Conference Rural Development 2019*, 149–154.
Moussa, R., Voltz, M. & Andrieux, P. 2002. Effects of the spatial organization of agricultural management on the hydrological behaviour of a farmed catchment during flood events. *Hydrological Processes* **16**, 393–412.
Passalacqua, P., Belmont, P. & Foufoula-Georgiou, E. 2012. Automatic geomorphic feature extraction from lidar in flat and engineered landscapes. *Water Resources* **48**, 1–18.
Peacock, M., Audet, J., Bastviken, D., Cook, S., Evans, D., Grinham, A., Holgerson, M.A., Högbom, L., Pickard, A.E., Zieliński, P. & Futter, M.N. 2021. Small artificial waterbodies are widespread and persistent emitters of methane and carbon dioxide. *Global Change Biology* **00**, 1–15.
Rapinel, S., Hubert-Moy, L., Clément, B., Nabucet, J. & Cudennec, C. 2015. Ditch network extraction and hydrogeomorphological characterization using LiDAR-derived DTM in wetlands. *Hydrology Research* **46**, 276.
Real, R., Vargas, J.M., 1996. The Probabilistic Basis of Jaccards's Index of Similarity. *Systematic Biology* **45**(3), 380–385.
Roelens, J., Dondeyne, S., Van Orshoven, J., Diels, J. 2016. Extracting cross sections and water levels of vegetated ditches from LiDAR point clouds. *International Journal of Applied Earth Observation and Geoinformation*. **53**, 64–75.
Roelens, J., Höfle, B., Dondeyne, S., Van Orshoven, J. & Diels, J. 2018a. Drainage ditch extraction from airborne LiDAR point clouds. *ISPRS Journal of Photogrammetry and Remote Sensing* **146**, 409–420.
Roelens, J., Rosier, I., Dondeyne, S., Van Orshoven, J. & Diels, J. 2018b. Extracting drainage networks and thei connectivity using LiDAR data. *Hydrological Processes* **32**(8), 1026–1037.
Roelens, J., Van Orshoven, J., Dondeyne, S. & Diels, J. 2017. Extraction and connection of artificial drainage networks in agricultural areas using LiDAR data. *Communications in agricultural and applied biological sciences* **82**(1). National Symposium on Applied Biological Sciences. Leuven, Belgium, pp. 19–19.
Sofia, G., Tarolli, P., Cazorzi, F., Dalla Fontana, G. 2011. An objective approach for feature extraction: distribution analysis and statistical descriptors for scale choice and channel network identification. *Hydrology and Earth System Sciences* **15**, 1387–1402.
Vaze, J., Teng, J. & Spencer, G. 2010. Impact of DEM accuracy and resolution on topographic indices. *Environmental Modelling & Software* **25**(10), 1086–1098, ISSN 1364-8152.