Topography and Hydrology Modeling and Influence on Soil Erosion Simulation, at Small Basin Scale

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Abstract. Diffuse pollution from agricultural activities is a major environmental problem. The extent of the impacts is driven, e.g., by local topography due to the influence on hydrological processes. This study aims to investigate the use of different scale topographic data in assessing runoff-erosion processes. The TopAGNPS module, a component of the AnnAGNPS model (Annualized Agriculture Nonpoint Source), was used to assess the impact of the vertical resolution of the Digital Elevation Model (DEM) on the topographic and hydrological configuration of a basin, and on the simulation of soil erosion. The study focuses on a small agro-forestry basin (190 ha) located in the municipality of Idanha-a-Nova, Portugal. A georeferenced survey of the basin's surface drainage network was carried out and then compared with the results of the simulated drainage networks generated by the TopAGNPS module using two DEMs with vertical resolutions of 1 m and 5 m. The DEM with a 5 m vertical resolution produced unsatisfactory results, as evidenced by significant discrepancies between the simulated and observed natural drainage networks. On the other hand, the drainage network generated with the DEM of 1 m resolution was very similar to the observed drainage network. The use of distinct topographic configurations modeled based on different vertical resolution DEMs on the estimation of soil erosion by water using the RUSLE model (Revised Universal Soil Loss Equation), resulted in significant differences considering the values of 5.85 and 4.17 ton/ha.year for the DEM with 1 m and 5 m vertical resolution, respectively. Considering that soil erosion by water and other processes, such as the transport of pollutants, are distributed processes, it is of great relevance to consider good topographic and hydrologic configurations to achieve more reliable simulations and better support decision-making.

Keywords: Digital Elevation Model · data resolution · AnnAGNPS model · soil erosion · agroforestry basin

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1 Introduction

The simulation models designed for the scale basin, combined with Geographic Information Systems (GIS), simplify the integration process of the basin conditions, and present themselves as indispensable tools for the simulation of geographically distributed processes, such as the water erosion process, due they allow the configuration and comparison of alternative land use solutions aimed at sustainable use [1]. The use of hydrological models normally includes a first phase of topographic configuration of the basin, based on the Digital Elevation Model (DEM) with a certain vertical resolution, which will be related to the study area. One of the parameters frequently used to compare this configuration is the simulated natural drainage network, which should be as similar as possible to that observed in the study area [2]. The model AnnAGNPS (Annualized Agricultural Nonpoint Source), integrated with GIS [3], is one of the existent models that simulate the process of non-point source pollution in agricultural areas, including soil water erosion, and giving daily results of runoff, yield, and load of sediments and other pollutants [4]. This model includes the module (FlowNet Generator), which, based on the DEM, simulates the limits of the basin and hierarchizes the stream network. The most important generated parameters are the limits of the basin and sub-basins, and, inside these, the limits of the cells, the natural drainage network, and the topographic factors (LS) da RUSLE (Revised Universal Soil Loss Equation) for each cell [2]. The vertical resolution of the DEM influences the basin division in sub-basins, and, as a consequence, in the topographic parameters that characterized it, interfering in the simulation of runoff and sediments and other contaminants load outside the basin [5].

Considering the referred above, the main goal of this study is to analyze the influence of the DEM with different vertical resolution (1 m and 5 m), using the AnnAGNPS module FlowNet Generation, in the topographic and hydrologic configuration in a small basin, and the simulation of soil water erosion with RUSLE model.

2 Materials and Methods

2.1 Characterization of the Study Basin

The study basin is located in the southeast of Portugal (Idanha-a-Nova county), with an area of 190 ha and gently sloping, with a maximum slope of 10% and the most representative between 2 and 4%. The hierarchy order is 3, and the maximum length of the mainstream is 2300 m (Fig. 1c) [6]. It is an agro-forestry basin included in the Irrigation District of Campina da Idanha, where the most important crops are oat, maize, and pasture, and an area occupied by a young forest of holm and cork oaks (31% of the total area) (Fig. 1b). The climate is typically Mediterranean, with a hot summer and dry winter that is not very cold and an annual rainfall average of 600 mm, but it is very irregular in both amount and distribution. The soils are majority Cambisols and Luvisols, with a small area of Fluvisols near the borders of the main stream (Fig. 1a).

2.2 Digital Elevation Models and Streams Network

To concretize the objectives of this study, two DEMs with vertical resolutions of 1 m and 5 m were based on existing topographic information. The base data were topographic

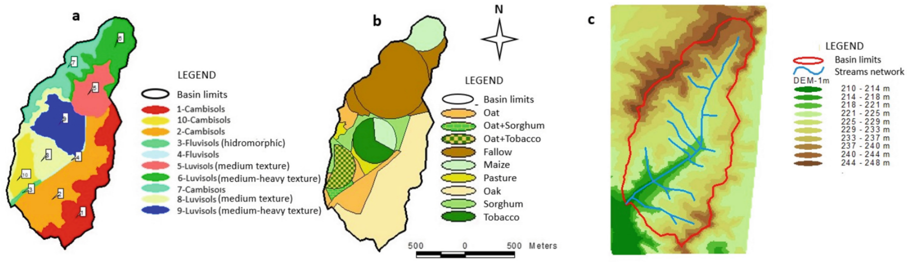

Fig. 1. Soil categories in the study basin (a), agro-forestry uses (b), and Digital Elevation Model (MDT) with basin limits and streams network (c).

maps with a scale of 1:2500, surveyed and elaborated when the building of the Irrigation District of Campina da Idanha. The DEMs were obtained by digitalization of the level curves with vertical resolution of 1 m and 5 m and georeferenced with the UTM coordinates in the GIS environment [7]. It also elaborated a map in GIS with the natural drainage network inside the study basin, having been necessary to survey all of the network and register the coordinates with a GPS device (Global Position System; GeoExplorer3 da TRIMBLE). This equipment was used in the field with signal reception and triangulation at least five satellites, and after the data was corrected (differential correction) with data captured by a fixed station located at the School of Agriculture/Polytechnic Institute of Castelo Branco, and proper software (GPS Pathfinder Office). This software also allowed the export of the data, corrected and validated, to shapefile format, to be used in GIS environment and compatibilized with other data generated in the same environment.

2.3 Module FlowNet Generator of the Model AnnAGNPS

The module FlowNet Generator is constituted by the operational programs TopAGNPS (**Top**ographic **AGNPS**), AgFlow (**Ag**ricultural watershed **Flow**net), and by a program that is a graphical interface VbFloNet (**V**isual **B**asic Network). The program TopAGNPS uses the same principles of the program TOPAZ (**To**pographic **Pa**rameteri**Z**ation), with some modifications to run integrated in the AnnAGNPS model [8]. The first to be executed, according to Fig. 2, is the program TopAGNPS, which, obtained from the DEM topographic information, allows the calculation of the basin limits, simulated stream network, and the division in sub-basins and respective cells, which collects the runoff to certain stream. The subprograms Dednm, Raspro, and Rasfor of the program AgFlow, are controlled by control files that can be changed by the user according to the more adequate for a certain simulation.

The file Dednm.inp, which controls the sub-program Dednm.exe, allows the introduction of the pair of values CSA (Critical Source Area) and MSCL (Minimum Source Channel Length), respectively, the minimum area and length necessary to establish a stream where the runoff is sufficiently concentrated that easily allows the identification in the field. It's evident that the pair of values CSA/MSCL determines the level of division of the basin in sub-basins and the stream network. In a sequence of a great number of simulations with different combinations of pairs of values CSA/MSCL, and comparison with the stream network identified in the field, the values with the best results were CSA

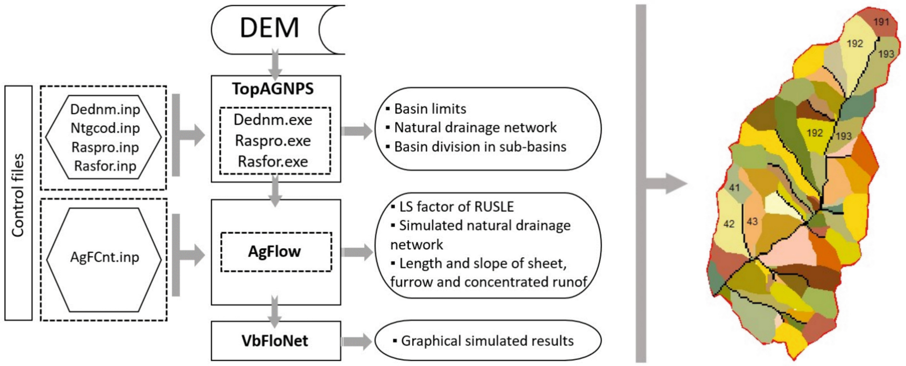

Fig. 2. Execution sequence of the programs included in the module FlowNet Generator, and form how this module divides the basin into sub-basins and cells, applied to the study basin (ex: cells 191, 192, 193 are part of sub-basin 19).

equal to 3.0 ha and MSCL equal to 80 m, to both DEMs with different vertical resolutions. The results of the program TopAGNPS are transferred to the program AgFlow (Fig. 2) and reordered in stream or hillside pixels. The program AgFlow also calculates the LS factor of the RUSLE equation, and the length and slope of the laminar runoff (first 50 m in the line of runoff), furrow runoff (the following 50 m in the same line), and concentrated runoff (remaining part of the same line) [9]. The program VbFloNet is a graphical interface run optionally because the results can be seen in the GIS environment.

3 Results and Discussion

3.1 Topographic Configuration of the Study Basin

The joint analysis of Fig. 3a and b allows inferring that, relative to the streams of order 3, significant differences between the streams network observed in the field and the simulated for the two DEMs with vertically different resolutions. However, relative to the remaining streams of order 1 and 2, we can see significative differences in the figure with the DEM 5 m (Fig. 3b), related to different paths in the basin and the absence of some streams of order 1, results that were obtained by other authors [5]. The simulated results based on the DEM 1 m (Fig. 3a), the stream network is practically equal to the one observed. Another way to analyze the different topographic and hydrologic configurations generated with the two DEMs used is by observation of Fig. 3c and d, referent to the basin division in sub-basins, which are quite different, mainly in the downstream zone of the basin.

3.2 Simulation of Soil Erosion by Water

The simulation of soil erosion by water was performed with the methodologies of RUSLE model [10]. In the sequence of topographic and hydrologic configuration of the study basin and its division into sub-basins and cells, the attribute values of the RUSLE factors

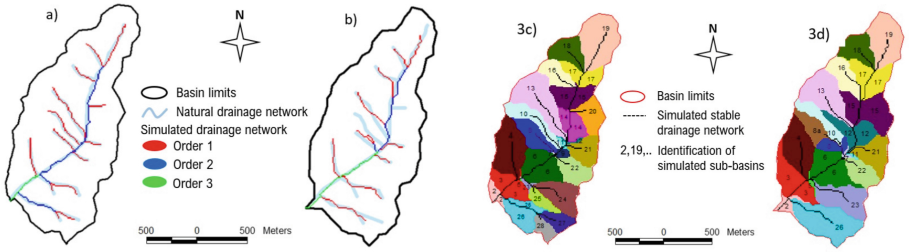

Fig. 3. Natural drainage network simulated and observed in the field, and simulation of the basin division in sub-basins, by the module FlowNet Generator – 3a) and 3c) DEM 1 m, 3b) and 3d) DEM 5 m, with values of CSA equal to 3.0 ha and MSCL equal to 80.0 m, for both DEMs.

in each cell were the most representative in each one. Since the area of the basin is relatively small, it is considered the value of the rainfall erosivity equal in all of the areas (1279 MJ.mm/ha.h.year). By analysis of Fig. 4, complemented with the information in Table 1, we can find that the topographic factor (LS factor) is the one that presents a great difference between the two DEMs used.

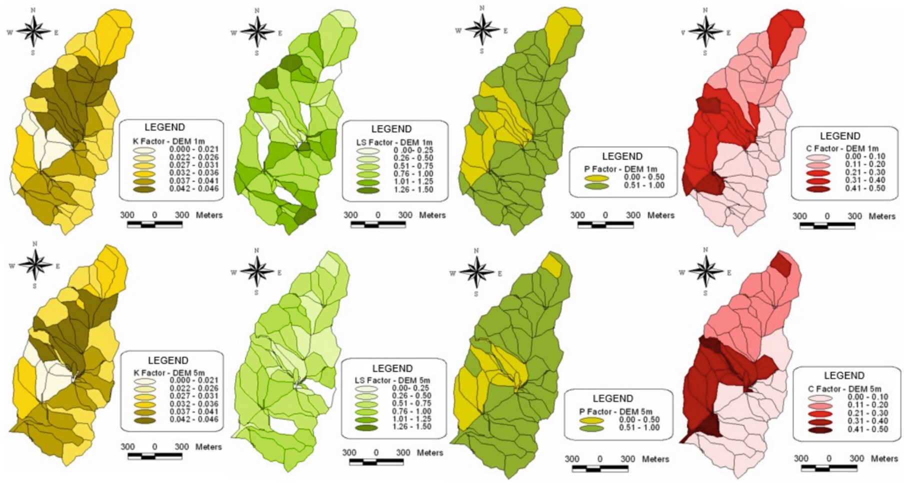

Fig. 4. Distribution by cells in the study basin of the K, LS, C, and P RUSLE factors, for the DEMs with vertical resolutions 1 m and 5 m.

We can find that the factor of soil cover (C factor) presents the greatest values in the cells where the predominant soil use is oat, having consequently higher values of soil loss in those cells (Fig. 5).

The values of soil loss are 5.85 and 4.17 tons/ha.year, respectively, for the DEM 1 m and DEM 5 m vertical resolution, show clearly the influence of the different topographic and hydrologic configurations of the basin in the simulation of the soil erosion process. Considering the values average of the factors LS, K, C, and P of the RUSLE model, respectively equal to 0.861, 0.034, 0.208 e 0.888 (DEM 1 m) and 0.611, 0.034, 0.214 e

Table 1. Average values of slope and slope length of laminar, in furrows, and concentrated runoff for all of the cells generated by the DEMs 1 m and 5 m, and average of LS factor of RUSLE model.

DEM	Sheet runoff		Furrow runoff		Concentrated runoff		LS Factor
	Slope (m/m)	Slope length (m)	Slope (m/m)	Slope length (m)	Slope (m/m)	Slope length (m)	
DEM 1 m	0,038	49,4	0,060	45,2	0,038	129,0	0,861
DEM 5 m	0,028	49,4	0,048	48,1	0,030	211,4	0,611

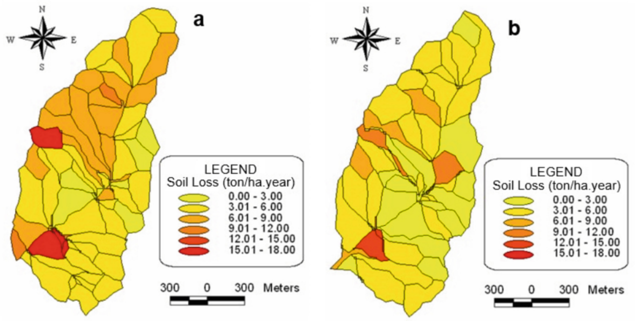

Fig. 5. Distribution by cells in the study basin of the soil loss calculated by RUSLE model, for the DEMs with vertical resolutions 1 m and 5 m.

0.868 (DEM 5 m), it's evident that the great influence in the difference of the simulated soil loss is due to the LS factor.

4 Conclusions

By considering the objectives that we proposed to reach with this study, i.e., testing the influence of the vertical resolution of the DEM in the topographic and hydrologic configuration of a small basin and its interference in the soil erosion simulation, it was possible to extract the following conclusions.

The simulation of processes which is important to hydrology, like non-point source pollution in general and, in particular, soil erosion, is crucial to the existence of detailed topographic information related to the area of the territorial unit. So, it was demonstrated the significative interference of the accuracy of topographic information, not adequate to the area of basin study, on the division in sub-basins, and, as a consequence, in the values of the topographic and hydrologic factors related and simulation of the soil erosion. This influence is mainly verified in the LS factor of the RUSLE model, with the values of 0.861 and 0.611, reflected in 5.85 and 4.17 ton/ha.year of soil loss, respectively, for the DEM 1 m and DEM 5 m.

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References

1. Duarte, A.C., Ferreira, C., Vitali, G.: Use of simulation models to aid soil and water conservation actions for sustainable agro-forested systems. In: Jhariya, M.K., Meena, R.S., Banerjee, A., Meena, S.N. (eds.) Natural Resources Conservation and Advances for Sustainability, pp. 389–412. ELSEVIER, Amsterdam, Netherlands (2021). https://doi.org/10.1016/B978-0-12-822976-7.00006-5
2. Bingner, R.L., Theurer, F.D.: Topographic factors for RUSLE in the continuous-simulation, watershed model for predicting agricultural, non-point source pollutants (AnnAGNPS). In: Ascough II, J.C., Flanagan, D.C. (eds.) Proceedings of the Soil Erosion Research for the 21st Century, pp. 619–622. ASAE, Honolulu, HI, USA (2001)
3. Cronshey, R.G., Theurer, F.G.: AnnAGNPS non-point pollutant loading model. In: Proceedings First Federal Interagency Hydrologic Modelling Conference, pp. 19–11, Las Vegas, NV, USA (1998)
4. Abdelwahab, O.M., Ricci, G.F., De Girolamo, A.M., Gentile, F.: Modelling soil erosion in a Mediterranean watershed: Comparison between SWAT and AnnAGNPS models. Environ. Res. **166**, 363–376 (2018). https://doi.org/10.1016/j.envres.2018.06.029
5. Bingner, R.L., Garbrecht, J., Arnold, J.G., Srinivasan, R.: Effect of watershed subdivision on simulation runoff and fine sediment yield. Trans. ASAE. **40**(5), 1329–1335 (1997)
6. Duarte, A.C., Mateos, L.: How changes in cropping intensity affect water usage in an irrigated Mediterranean catchment. Agric. Water Manag. **260**, 107274 (2022). https://doi.org/10.1016/j.agwat.2021.107274
7. Duarte, A.C.: Non-point source pollution originated by irrigated agriculture, at basin scale. PhD Thesis. Córdoba, University of Córdoba, Spain (2006)
8. Garbrecht, J., Martz, W.: Advances in automated landscape analysis. In: Espey, W.H., Combs, P.G. (eds.) Proceedings of the First International Conference on Water Resources Engineering, vol. 1, pp. 844–848. American Society of Engineers. San Antonio, Texas, USA (1995)
9. Theurer, F.D.; Cronshey R.G.: AnnAGNPS – Reach routing processes. In: Proceedings of the First Federal Interagency Hydrologic Modelling Conference. 1-25 to 1-32. Las Vegas, Nevada, USA, (1998)
10. Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C.: Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA-ARS., Ag. Handbook 703, Washington (1997)