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How to mitigate flood events similar to the 1979 catastrophic floods in the lower Tagus

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Supplement

Accuracy of the Digital Elevation Models:

Spatial resolution and spatial accuracy are two of the most important issues in scientific disciplines that deal with geographical data, and therefore, need accurate cartographic results that fit the purposes of a particular study. In this sense, the quality of global DEMs has been frequently studied to assess their wide range of applications. Most of these studies consist of comparing the obtained data from DEMs and a set of reference data generally called control points. To evaluate DEM precision in the area under scope, 206 leveling benchmarks from the official high accuracy altimetric network of the Portuguese Geodetic System (RNGAP), located in the study area or in the immediate vicinity, were used as control points. This network is referred to the mean sea level in Cascais until the last day of 1938 (Cascais Helmert 38). In terms of accuracy, its relative error is rated at 0.1mm/100m (1ppm). Direção Geral do Território (DGT) provides, through a web feature service (WFS), all data related to the RNGAP (http://mapas.dgterritorio.pt/geodesia/geodesiamarcasnivelamentowms.html).

As it is shown in Table S1, where the main general characteristics of the freely available DEMs under consideration are presented, the horizontal and vertical references differ for some of them. To ensure consistency in the analysis of multiple data sets, it was necessary to convert them to a common reference frame. The WGS84 and EGM96 were chosen as the horizontal and vertical reference systems, respectively, to accomplish this goal. On the other hand, the altitudes of the leveling benchmarks are referred to the geoid model for Portugal mainland (GeodPT08) (https://www.dgterritorio.gov.pt/geodesia/modelo-geoide) (Catalao and Sevilla, 2009).

DEM	*Type of Coordinate System*	*Elipsoid*	*Height datum*	*Spatial Resolution*	*Absolute Vertical Accuracy*	*Absolute Horizontal Accuracy*	*Reference source*
ESRI-DEM	Cartographic	GRS80	ETRS89	30 m	± 20 m	< 30 m	ESRI Portugal (2009)
ASTER GDEM	Geographic	WGS84	EGM96	30 m	± 20 m	< 30 m	ASTER (2009)
SRTM DEM	Geographic	WGS84	EGM96	30 m	±16 m	< 20 m	Farr and Kobrick, (2000)
COP DEM GLO-30	Geographic	WGS84	EGM2008	30 m	< 4 m	< 6 m	Fahrland et al., (2020)

Table S1. Characteristics of the evaluated Digital Elevation Models.

Since the leveling benchmark altitudes provide the most precise vertical data available, a set of statistical analyzes were performed to assess which is the best DEM, in terms of vertical accuracy, to be selected for the flood simulation process. For this purpose, several statistical indicators were calculated to assess the differences between the benchmark altitudes and the corresponding pixel values in each DEM. These indicators include the Mean Absolute Error (MAE), which is calculated by determining the average of the absolute differences between the DEM and the benchmarks. Additionally, the Standard Deviation (SD) was computed to measure the spread of the differences between the DEM and the benchmarks. The Root Mean Squared Error (RMSE) was also computed by taking the square root of the average of the squared differences between the DEM and the benchmarks. Moreover, the Mean Error (ME) was computed as a measure of the bias between the DEM and the benchmarks, which is determined by averaging those differences. A positive ME indicates that the DEM is overestimating the elevation, while a negative ME indicates that the DEM is underestimating the elevation. This information is summarized in Table S2.

DEM / ***STATISTICAL INDICATOR***	ESRI	ASTER	SRTM	Copernicus
MAE (m)	*3.56*	*4.74*	*3.10*	*2.12*
SD (m)	*4.71*	*4.90*	*3.94*	*3.81*
RMSE (m)	*4.81*	*5.91*	*4.42*	*3.81*
ME (m)	*-1.00*	*3.30*	*2.01*	*0.17*

Table S2. Statistical analysis of the altitude difference between leveling benchmarks and analyzed DEMs.

Considering all the statistics that evaluate the error it is possible to state that Copernicus DEM is consistently the best model, presenting always lower values and as such it was the altimetric model assumed as the most accurate for the study area.

While the evaluation conducted thus far provides insight into the suitability of the chosen DEM, the authors further investigated by analyzing the spatial distribution of the standard deviation of the absolute error (Figure S1). This analysis aimed to identify whether any spatial randomness or systematic pattern was present among the most disparate values of the difference between leveling benchmarks and the DEM, which could indicate potential systematic errors in the DEM under investigation.

Figure S1 reveals that overall, the study area displays low error values. Moreover, the most anomalous values are sporadically distributed and limited in number, representing only about 10 of 206 values. These findings confirm the conclusions of the previous evaluation and support the selection of the Copernicus DEM for further use.

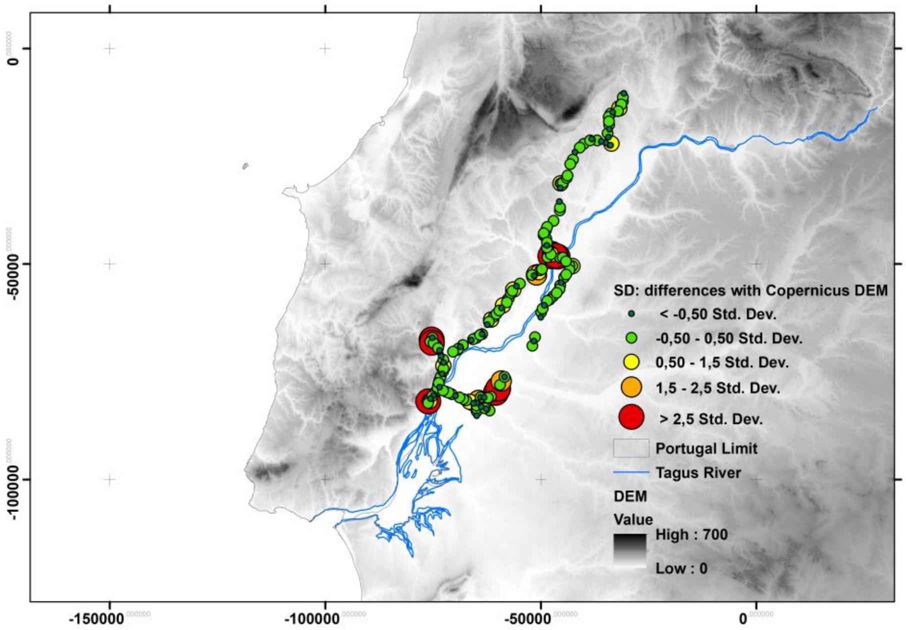

Figure S1. Spatial distribution of the Standard Deviation of the absolute errors, computed here through the differences of the benchmarks' altitudes and the Copernicus DEM, for each benchmarks' location. (Map: EPSG:3763 – ETRS89 / Portugal TM06).

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