Testing the quality of open-access DEMs and their derived attributes in Spain: SRTM, GDEM and PNOA DEM

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Abstract—**Digital Elevation Models (DEMs) are a valuable source of knowledge about relief and terrain characteristics. This paper presents an analysis of the accuracy of open-access DEMs in Spain: SRTM, GDEM and the recently released national DEM (known as PNOA DEM). The models were tested by computing the bias, the standard error and the Root Mean Square Error (RMSE) from elevation points gathered from the digital version of the 1:10,000 National Topographical Maps, and fitting the models using the classical linear regression analysis. In addition, the magnitude and pattern of errors in primary and secondary derived terrain attributes were explored by using a DEM generated ad hoc from elevation points and contour lines of the MTN (scale 1:10,000). The results showed the RMSE of terrain elevation ranging from 6.1 m for the SRTM to 33.0 m for the GDEM. Surprisingly, a RMSE of 31.2 m was estimated for the recently available PNOA DEM in Spain. Results also suggest that GDEM slightly underestimates altitudes in the study area, while this trend was not found in SRTM or PNOA DEM. The highest bias and squared error values showed by the PNOA DEM were particularly located in the roughest areas of steep slopes and high aspect variability. Finally, the exploration of the errors accounted by generating primary and secondary terrain attributes suggests that the utility of these models is strictly limited to description, visualization and representation of relief.**

I. Introduction

Several DEMs have been released to open access during the last decade, including two global models (extending over almost the whole earth surface): NASA/NGA Shuttle Radar Topography Mission (known as SRTM) and ASTER Global Digital Elevation Model (known as GDEM and produced by NASA and the Ministry of Economy, Trade and Industry of Japan: METI).On the other hand, local-national DEMs have also been released around the world (e.g. GEODATA DEM 9S by the Australian Government or NED by the United States Geological Survey). A few months ago, a new local DEM dataset known as PNOA DEM was released in Spain by the National Center for Geographic Information (CNIG[1]).

Global and local-national datasets are being used in a huge number of works to evaluate, analyze and produce relief information. The Accuracy of global models has been broadly tested [1,7]. However, there is a lack of information about the accuracy of local-national recently released DEMs. Furthermore, little is known about error propagation in open-access DEMs through the primary terrain derived attributes such slope, aspect, flow directions, specific catchment area, or the secondary ones such as topographic wetness index, stream power index, etc.

The main objectives of this article are i) to quantify the error of open-access DEMs in Spain and ii) to provide information about the magnitude of errors accounted by computing terrain attributes derived from these sources.

II. Study area

In order to evaluate the accuracy of the models over a wide range of relief landforms, the study area was selected to show a remarkable geomorphological diversity [3]. The Jerte Valley is located in the Center of the Iberian Peninsula (Fig. 1). It belongs to the Southwest foothills of the Central Mountainous System within the Iberian Hercynian Massif. Structurally it may be considered a complex graben with two fault systems of NE-SW and NW-SE direction.

III. Material and methods

Digital Elevation Models

A description of DEMs used in this paper is presented below:

[1] www.cnig.es

a) SRTM version 4.1: 90 m pixel size. In order to allow comparison between DEMs, the pixel size was resampled to 25 m (using nearest neighbor assignment).

b) GDEM version 2: 30 m pixel size, resampled to 25 m (using nearest neighbor assignment).

c) PNOA DEM: 25 m pixel size, generated by interpolation inframes of 4x4 DEMs of 5 m coming from the National Plan of Aerial Orthophotography in Spain (known as PNOA) and available for free download in[2]. The original model was obtained by automatic correlation and interactive stereoscopic debugging for the PNOA initiative (More information can be found in[3]).

d) MTN 1:10.000: A digital elevation model was constructed with features (contour lines and elevation points) extracted from the digital version of the National Topographic Map of Spain (MTN), scale 1:10.000. Topo to raster interpolation method implemented in ArcGIS 10 was used to obtain the DEM. This model was assumed as ground truth data when testing the derived terrain attributes. In addition, the MTN DEM accuracy was tested excluding 2,592 points during the interpolation process and using them later as control points to estimate the bias, the standard error and the Root Mean Square Error (RMSE) for MTN DEM, GDEM, SRTM and PNOA DEM. The elevation points used here comprises not only spots heights in peaks but also in other terrain locations.

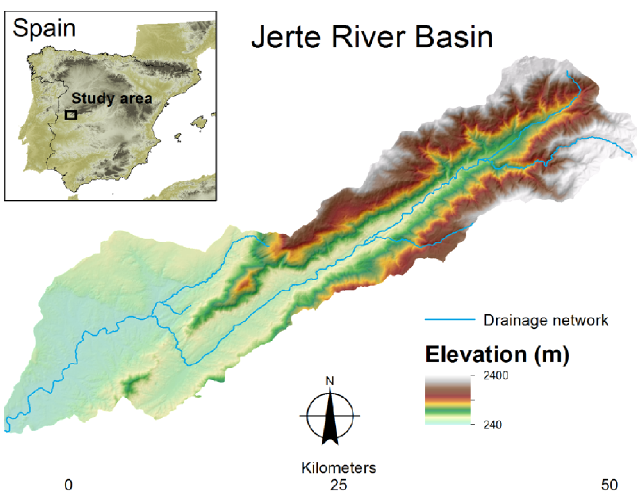

Figure 1. Location of the study area.

[2] www.cnig.es
[3] www.ign.es/PNOA/

Derived Models

Terrain attributes of primary or secondary order are of particular interest in areas as geomorphology, hydrology or ecology. A large amount of information about overland and subsurface flow, soil water content, potential energy, soil erosion by flow, soil drainage rates, solar radiation, etc., can be provided with the help of these models. In this paper, we have tested the accuracy of terrain attributes derived from PNOA DEM, GDEM, and SRTM as compared to terrain attributes derived from the MTN DEM (considered as ground truth). Due to the large number of existing terrain attributes, only the most important ones have been tested in this work: slope; aspect (slope azimuth);specific catchment area (SCA: upslope area per unit width of contour, representing indirectly surface and subsurface runoff in a specific landscape location, calculated using D-Infinity algorithm by [8]); curvature [8], topographic wetness index (TWI: [2] TWI describes the spatial distribution and extent of zones prone to saturation); relative stream power index (SPI: [6], SPI estimates the erosive power of flowing water); and sediment transport capacity index (STCI: [6], STCI shows areas prone to deposition or erosion). Other useful indices as radiation or temperature ones were not considered here because authors' main concerns refer to geomorphology and hydrology. The slope, aspect and curvature attributes were calculated using ArcGIS software while SCA, TWI, SPI, STCI were obtained using Whitebox GAT software.

Statistical Procedure

The accuracy of DEMs was tested by a) using the RMSE (as described in section d) within DEM in the material and methods) and b) fitting a regression model between the MTN DEM (considered as ground truth) and GDEM, SRTM and PNOA DEM data. Fitting the model can be done if ground truth (MTN DEM) and target DEMs are available at all cells. However, the large amount of data cells necessary to represent the whole study area (more than a million) dissuaded us about using all the data. Instead of this, a random sample of 5,000 data cells was used to fit the models. A similar approach was used to test the derived terrain attributes.

IV. RESULTS

Table I presents general statistics for the different DEMs in the study area while Table II presents statistics for the 2,592 validation points in every DEM. Average RMSE for open-access DEMs in Spain was 23.44 m, being SRTM the most accurate with 6.10 m. A remarkable RMSE of 31.21 m was obtained for the new available Spanish dataset (PNOA DEM), similar to that obtained for the GDEM in the study area. A similar standard error was estimated for all the models, including MTN. However, important differences were found in the Average Bias with the highest values for GDEM.

TABLE I. SUMMARY OF GENERAL STATISTICS FOR EVERY DEM.

	MTN	PNOA DEM	GDEM	SRTM
Mean	742	746	736	743
Max.	2392	2398	2384	2387
Min.	239	240	224	240
Std. dev.	478	482	482	478

All the DEMs were linearly correlated with the MTN DEM, presenting in all cases high values for R coefficient. As respect to GDEM, Fig. 2 suggests that the model underestimates real altitudes in the study area. While this trend was not found in SRTM or PNOA DEM, another tendency was detected in the PNOA DEM (Fig. 3) to show the highest deviations from the ground truth (higher bias and square error) over rougher areas of steep slopes and high aspect variability. A similar performance of GDEM has been previously detected in a research developed in Australia [4]. Hirt et al. [4] also detected systematic errors in GDEM in Australia.

TABLE II. SUMMARY OF GENERAL STATISTICS FOR THE 2,592 VALIDATION POINTS IN EVERY DEM.

	MTN	PNOA DEM	GDEM	SRTM
Standard error	9.78	9.71	9.72	9.76
Average Bias	2.41	3.36	12.32	2.31
RMSE	4.90	31.21	33.00	6.10
Coefficient of Variation	68.51	68.11	69.02	68.39
Skewness	1.26	1.24	1.23	1.26
Kurtosis	0.52	1.23	0.43	0.52

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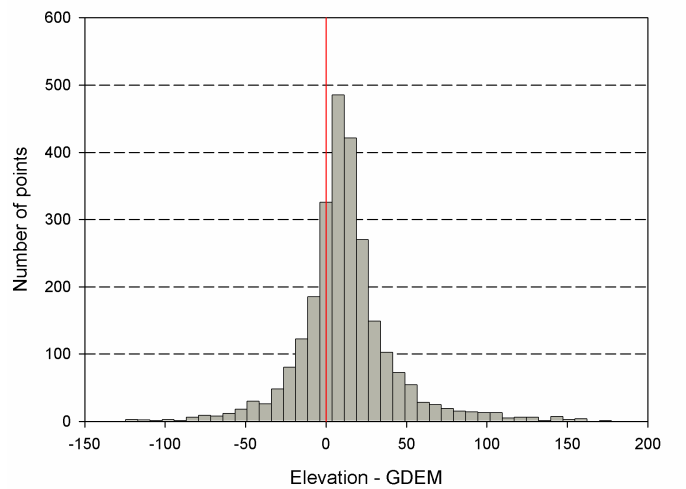

Figure 2. Histogram of control points heights minus GDEM heights. Some statistics for this distribution: D of Kolmogorov-Smirnov test=0.1165; p<0.01, Lilliefors-p<0.01; number of elements=2592; Mean=12.33; Standard deviation=30.62; Maximum=177.47; Minimum=-124.45 and Shapiro-Wilk test W=0.91; p=0.00.

The Correlation coefficients between terrain attributes derived from the different models are shown in table III. In spite of the R values observed in table III; only slope, $curvature_{SRTM}$ and $STCI_{SRTM}$ were undoubtedly correlated. The comparison between slope azimuth (aspect) histograms derived from every model did not show any significant difference. Table III also illustrate the inaccuracy of the secondary terrain attributes performed, mainly those directly related to a previous delineation of the specific catchment area.

In order to clarify whether low values in correlation coefficients (Table III) were influenced by outliers, histograms and cumulative curves for terrain attributes derived from the DEMs were elaborated. The resulting graphs showed important discrepancies between terrain attributes derived from MTN DEM and those derived from the other DEMs.

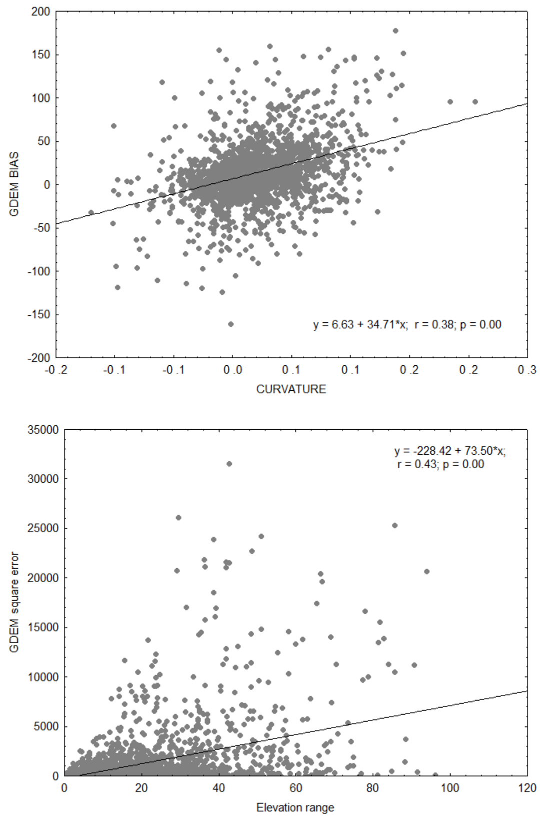

Figure 3. Relationship between GDEM bias-curvature (upper plot) and GDEM square error-elevation range (lower plot). Curvature was calculated with Zevenbergen and Thorne method [9] while elevation range was calculated as the difference between the highest and lowest elevations in a window of 5x5 cells. Both of them, curvature and elevation range, were calculated from the MTN DEM and then related to control points estimated bias and square error.

TABLE III. R CORRELATION COEFFICIENTS BETWEEN TERRAIN ATTRIBUTES DERIVED FROM THE STUDIED MODELS AND THOSE OF THE MTN DEM.

	PNOA	**GDEM**	**SRTM**
Slope	**0.77**	**0.96**	**0.77**
Curvature	-0.01	-0.02	**0.58**
SCA	**0.16**	0.00	**0.08**
TWI	**0.26**	**0.24**	**0.41**
SPI	**0.06**	0.00	**0.01**
STCI	**0.25**	**0.39**	**0.85**

Significant relationships are highlighted (p<0.05).

V. CONCLUSIONS

Results demonstrate that GDEM and PNOA DEM are still not more accurate and useful than SRTM, the utility of the former being highly limited to the description, visualization and representation of the relief of large areas. In a similar way to previous studies developed in Australia, important systematic errors were found in GDEM in SW Spain. The selected terrain attributes derived from GDEM, SRTM or PNOA DEM proved to be highly inaccurate, with the exception of some primary or first derived attributes, such as slope or aspect. The lack of precision of the secondary terrain attributes seem to be related to the inaccurate calculation of the SCA, although deeper research should be done in the future in order to test this hypothesis. In addition, further research is being done in order to test PNOA DEM with LIDAR data in other regions of Spain.

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