Enhancing DEMs for geomorphometric research through digital filtering

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Abstract— **Currently, Digital Elevation Models (DEMs) are the main source for representing Earth's surface and have been an integral part of any geospatial analysis, in particular, geomorphometric research. Among existing techniques, photogrammetry is considered as a common method for obtaining high-resolution elevation data, especially over large or/and inaccessible areas. However, this DEMs are disposed to a severe amount of uncertainty. The aim of this research is to provide an optimal filtering strategy that can remove possible errors and improve the quality of raw photogrammetric DEMs for geomorphometric research over regions with relatively low relief. Results reveal that a combination of three digital filters, namely Gaussian filter, Median filter, and Slope Based filter, is able to reduce different sources of errors and improve the elevation accuracy of DEM by more than 5%, resulting in improved quality of the derived geomorphometric parameters.**

I. Introduction

Topography is one of the main factors controlling processes taking place at or near the Earth's surface [1]. Hence, Earth scientists, geographers and cartographers have recognized the significance of topographic parameters for studying, modeling and mapping landscape [2]. Consequently, digital Earth's surface representation has become an important and inevitable focus for many decades. Nowadays, Digital Elevation Models (DEMs); with their digital and 3D format, became the main source for representing Earth's surface and have been an integral part of any geospatial analysis. Other than they are indispensable for 3D surface terrain representation, they provide in combination with other products an essential base dataset for further terrain analysis and modeling, orthorectification of additional remote sensing datasets used in geospatial analysis and mapping applications [2]–[5].

In digital photogrammetry, errors of elevation measurements can account for 5 to 20% of the total measurements, depending on the image quality [6]. The presence of such error results in very noisy DEM and injects uncertainty in the derived geomorphometric parameters. Several studies have indicated that derived geomorphometric parameters; such as average terrain slope, are positively correlated with the increase in the global error of the modeled surface [7], [8]. It is clear that such DEMs need editing and filtering in order to enhance their quality before they can be used for geomorphometric analysis [9]. Nowadays, filtering errors on DEMs is an area of active research and variety of filtering algorithms have been developed and studied for decades [9], [10]. However, the impact of filtering on elevation data is poorly studied and nobody can really claim that any of the existed filters is absolutely the chosen one for all datasets and study areas.

In order to find an optimal filtering approach that can remove all possible errors and improve the quality of raw photogrammetric DEM, a suite of three filtering algorithms have been applied, both individually and in combination. Filtering algorithms include a Gaussian filter (GF), a median filter (MF) and slope based filter (SBF).

II. Material and methods

Sahel-Doukkala region is located in Moroccan Atlantic coast between latitudes 33°20'N and 33°15'N. The topography of the area includes two most significant units, which are the Sahel and the Doukkala. The general topography of the Sahel consists of ridges, oriented NE-SW, low in height (80 to 160 m) and of variable wavelength. Moreover, the Sahel include a sub-unit called the Oulja which consists of big depression containing wetlands and agricultural fields. The second main

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geomorphological unit is the Doukkala, and it remains as wide plain characterized by very low topographic variation.

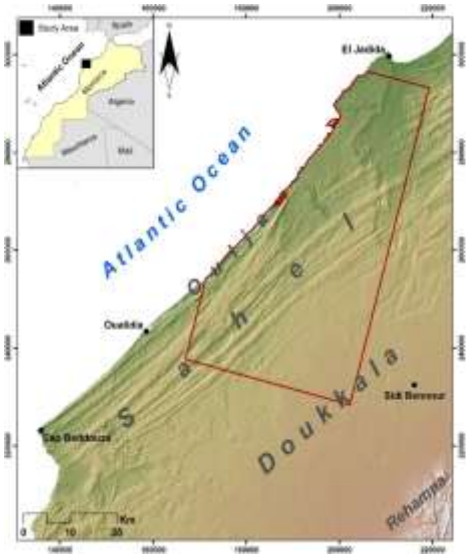

Figure 1. The location of the study area

In this research, we tried to find an optimal filtering approaches that can removes all possible errors and improve the quality of photogrammetric DEM, hence, a suite of three filtering algorithms has been applied, both individually and in combination, on the Open Source software package SAGA-GIS (System for Automated Geoscientific Analyses) [11]. The Gaussian filter was applied with standard deviation (σ) ranging from 1 to 8 intervals for each DEM, while the median filter was tested with kernels ranging from 3x3 to 33x33. On the other hand, several attempts involving different terrain slope values and search radius were being tested for the slope based filter.

To evaluate the impact of filtering algorithms on geomorphometric parameters, we calculated shaded relief map, slope, plan curvature, profile curvature and topographic roughness index (TRI) from each filtered DEM.

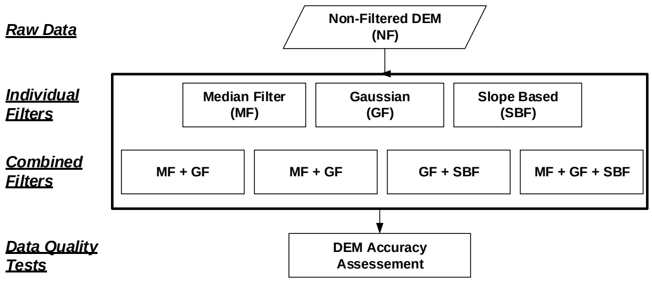

Figure 2. Flowchart of the methodology

III. Results and Discussion

To define the optimum size of each filter, different sizes have been applied for each dataset. Then, the RMSE and SD for each filter size was calculated using 143 well-distributed checkpoints extracted from 1: 25,000 topographic maps with a planimetric accuracy of 5 m and altimetric accuracy of 2.5 m. After several tries it was decided to go further by using GF with a filter size of 3σ, and a size of 15x15 has been chosen for MF. Concerning SBF, a combination of TSA75 and SR3 has been chosen. After finding the optimal parameters for each filter, they were applied individually and in combination to DEM extracted from ALOS PRISM data with a spatial resolution of 10 m [7].

It can be observed from Fig. 3 that errors in DEM are sensitive to filtering and all filters provide some enhancement in accuracy relative to the raw DEM, where the combination of all tested filters shows the best improvement with the lowest RMSE (5.2% reduction in RMSE).

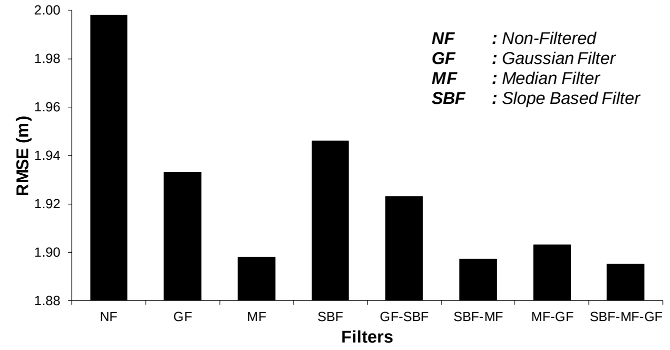

Figure 3. Effect of filtering algorithms on DEM accuracy

Fig. 4 extends these results to the case of the full error distribution. It is obvious that GF, SBF, SBF&MF and SBF&GF perform poorly and have a little effect on DEM. However, MF, MF&GF, and SBF&MF&GF return steep cumulative frequency curves with relatively sharp inflections accompanied by movement toward zero, compared to unfiltered DEM, which indicates a reduction in errors. Looking at the results of SBF&GF, it can be seen that they produce more deterioration (increased negative errors) than improvement, so it should definitely be avoided. MF&GF, with increased errors between 0 and +2, does not produce as much improvement as does MF alone. The application of MF individually achieves good results for error reduction by reducing negative errors, and positive errors except between 0 and +1. However, the combination of all 3 filters performs better, with decreased errors between 0 and ±2, suggesting that they can handle a greater amount of error within the surface.

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Fig. 5 indicates the spread of the influence of tested filtering algorithms on geomorphometric parameters calculated from filtered DEMs. They show that a significant amount of error dominates the geomorphometric parameters derived from unfiltered DEM, which disturb the shape of the modeled topographic surface and increase the variability in the corresponding cumulative frequency curves. Note that maps of shaded relief, slope, and TRI derived from unfiltered DEM are quite readable and can be used as an illustration. However, it can be clearly seen that maps of plan and profile curvature derived from unfiltered DEM are almost unreadable, and therefore, they can't be used for geomorphometric analysis. This is because the unfiltered DEM holds both low- and high-frequency noise which is increased by calculation of derivatives.

The application of filters enhances the overall quality of plan and profile curvature maps; among other derived parameters. However, the analysis of filters applied in combination shows better results, where the best results were obtained for the combination of GF&MF&SBF. It can be clearly observed from derived geomorphometric parameters maps that a considerable amount of error was reduced. Moreover, they show a considerable reduction in the hummocky error pattern making the surface more smoothed and realistic. On the other hand, the combination of filters illustrates the strong influence of the GF on geomorphometric parameters, where only the GF removes surface noise and gives smooth pattern at the same time. Hence, the application of GF at the end of filtering operation is recommended for getting more realistic DEM.

IV. CONCLUSION

Using a combination of filtering algorithms, we were able to eliminate different sources of errors and to improve the elevation accuracy in our DEM by 5% resulting in improved quality of the derivative geomorphometric parameters. The gain in the representativeness of such improved high-resolution DEM will allow more detailed studies in the near future.

Our main findings are that, for our case example, intelligent selection of filtering strategy can improve the quality of DEM and consequently can produce more reliable geomorphometric information. Depending on the goals of a study, our findings could be used to guide the choice of appropriate filtering strategy by discussing the advantages and disadvantages of each, for many landscapes and collected datasets.

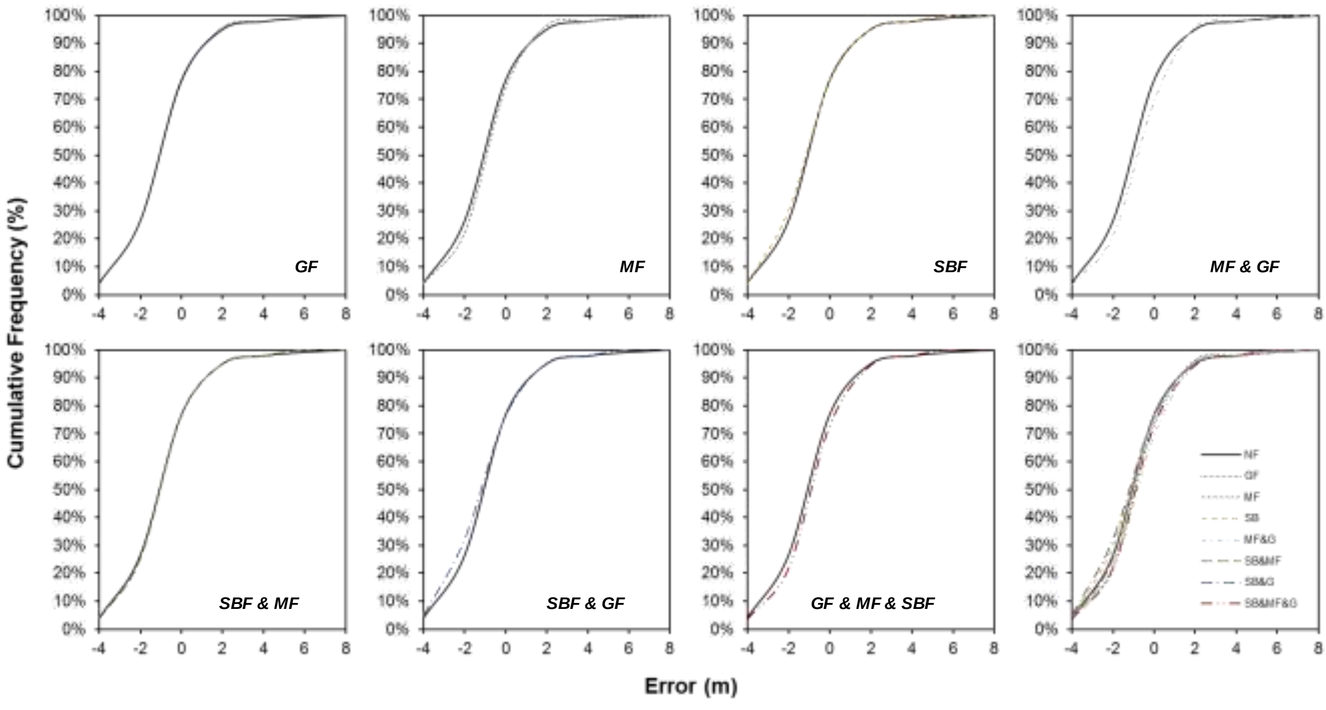

Figure 4. Cumulative frequency of elevation errors of filtered DEMs

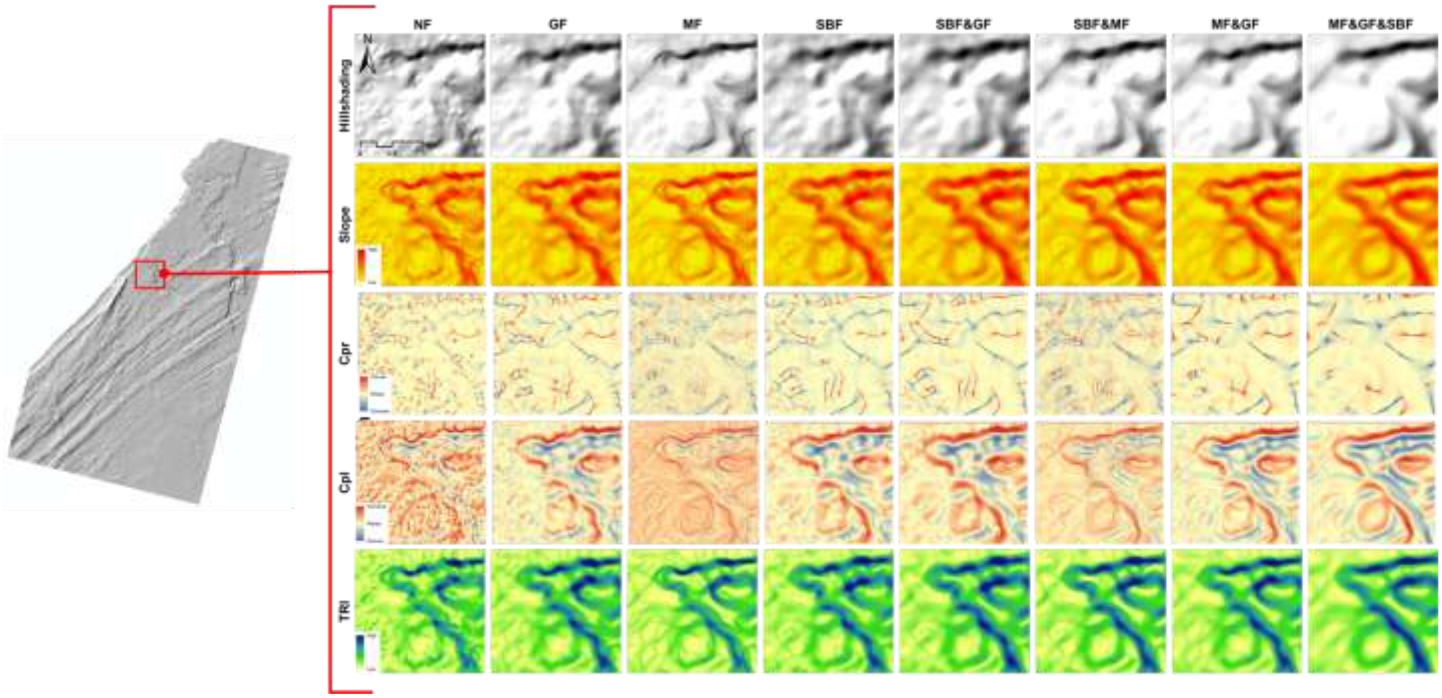

Figure 5. Maps of geomorphometric parameters derived from filtered DEMs

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