EVALUATING THE SUITABILITY OF AIRBUS WORLDDEM FOR FLOOD MODELLING IN DATA-SCARCE REGIONS: THE CASE STUDY OF THE MEGARUMA RIVER, MOZAMBIQUE

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ABSTRACT
The provision of good topographic data is critical to the application of flood inundation models. However, high resolution accurate Digital Elevation Models (DEMs), such as those obtained by LiDAR, are currently unavailable in many regions of the world. Satellite-derived DEMs can thus constitute a suitable alternative. The open access SRTM DEM, with horizontal resolutions of 90 or 30 m, has received much attention from hydraulic modellers. These data, if appropriately treated, can support large-scale flood inundation modelling, providing reasonably accurate risk assessments. Nonetheless, commercial DEMs of higher resolution and accuracy, such as Airbus WorldDEM (12 m resolution), have recently become available worldwide. Their potential for hydraulic modelling has been less explored, but they might eventually replace SRTM data for large-scale modelling, while allowing for more detailed local flood studies worldwide. In this study we evaluate the utility of Airbus WorldDEM topographic data for flood modelling in data-scarce regions. A 3.5-km reach of the Megaruma River in Mozambique is used as a test case. A shallow water model is developed for the reach, based on Airbus WorldDEM data. The hydrological consistency of the DEM is analyzed, and the need for hydrological conditioning for realistic hydrodynamics. The suitability with respect to flood frequency is also evaluated, the hypothesis being that the limitations of the DEM would be less relevant for the modelling of very high flows. The results show that, in spite of the higher resolution and the hydrological editing to which it is subject, WorldDEM dataset still presents limitations that prevent it from being directly used without further processing in local flood modelling studies.
Keywords: digital elevation model, flood modelling, flood wave propagation, hydraulics, Mozambique.

1 INTRODUCTION

Flood inundation models are essential tools for flood risk management. They provide information on flood extent and timing, as well as on flow characteristics that serve as a basis to develop flood hazard maps. Hydrodynamic models which solve the two-dimensional shallow water equations are a well-established approach in cases where flows can be strongly two-dimensional, such as river confluences [1], flows over extensive flat floodplains [2] or urban areas [3].

The provision of good topographic data is critical to the application of such models. Current computational resources allow us to set up flood inundation models of river reaches at very small spatial scales [4], [5]. However, this requires adequate topographic data at such scales. High resolution accurate Digital Elevation Models (DEMs), such as those obtained by LiDAR, are currently unavailable in many regions of the world.

Satellite-derived DEMs can thus constitute a suitable alternative. The open access Shuttle Radar Topography Mission (SRTM) DEM, with horizontal resolutions of 90 or 30 m, has received much attention from hydraulic modellers. These data, if appropriately treated, can support large-scale flood inundation modelling, providing reasonably accurate risk assessments [6], [7]. Other existing open access online digital elevation models, such as the

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Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM have also been applied in flood modelling [8]. However, STRM has emerged as the favoured choice in comparative studies due to its greater feature resolution, reduced number of artifacts and lower noise [9].

Commercial DEMs of higher resolution and accuracy, such as Airbus WorldDEM (12 m resolution), have recently become available worldwide. Their potential for hydraulic modelling has been less explored, but they might eventually replace SRTM data for large-scale modelling, while allowing for more detailed local flood studies worldwide.

This study is part of the work of the Water and Environmental Engineering Group of the University of a Coruña (Spain) on cooperation projects aimed at institutional strengthening of the Regional Water Management Administration in Northern Mozambique. In this data-scarce region, the SRTM DEM has been successfully used as main source of topographic data for dam-break flood analysis [10]. However, a terrain reconditioning procedure was needed to improve its accuracy and to ensure that it was hydrologically consistent. The possibility of having an alternative or complementary source of topographic data that requires less preprocessing effort is very attractive for future practical studies.

In this study we evaluate the utility of Airbus WorldDEM topographic data for flood modelling in the data-scarce region of Cabo Delgado, Mozambique. A 3.5-km reach of the Megaruma River is used as a test case. A two-dimensional shallow water model of the reach is set up. The hydrological consistency of the DEMs is analysed, and the need for hydrological conditioning for realistic hydrodynamics.

2 MATERIALS AND METHODS

2.1 Study site and cartographic information

The Megaruma River flows through Cabo Delgado province in northeastern Mozambique (Fig. 1). It has a length of approximately 201 km and an average slope of 2.24‰. The Megaruma River basin is an internal basin of Cabo Delgado, with an extension of 5065 km^2. Its average annual precipitation (P) reaches 927 mm, while the potential evapotranspiration (PET) is 1346 mm. The aridity index (P/PET) shows that the climate is humid.

The studied reach has a length of 3.517 km and an average river width of 0.146 km (Fig. 1). The mean annual flow (Qo) is estimated to be 357.5 m^3/s (Fig. 2) [11], [12]. The reach is located in the lower part of the basin, which is frequently affected by flooding. It is estimated that around 7000 people and 1700 buildings are exposed to the 500-year flood event (Fig. 3) [12].

The source of topographic data for this study was the Airbus WorldDEM. This product is based on the radar satellite data acquired during the TanDEM-X Mission, with 0.4 arc-second resolution (about 12x12 m at the equator). This DEM is a consumer-ready product that has been hydrologically edited to reduce the effect of radar-specific artifacts [14]. Water bodies are identified and delineated and set to a plausible elevation. In the case of rivers, monotonic flowing elevations are enforced.

2.2 Hydraulic modelling

In order to evaluate the hydrological consistency of the DEM, a flood inundation model of the reach was set up using the software Iber [15], [16]). The model solves the 2D depth-averaged shallow water equations by means of a finite volume method.

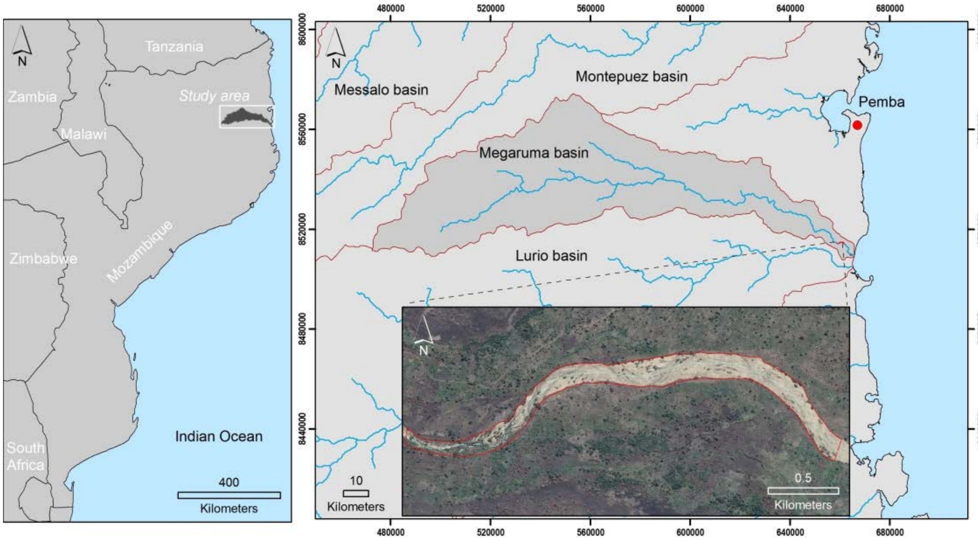

Figure 1: Location of the Megaruma River basin and the analysed river reach. Aerial image of the reach (inset figure).

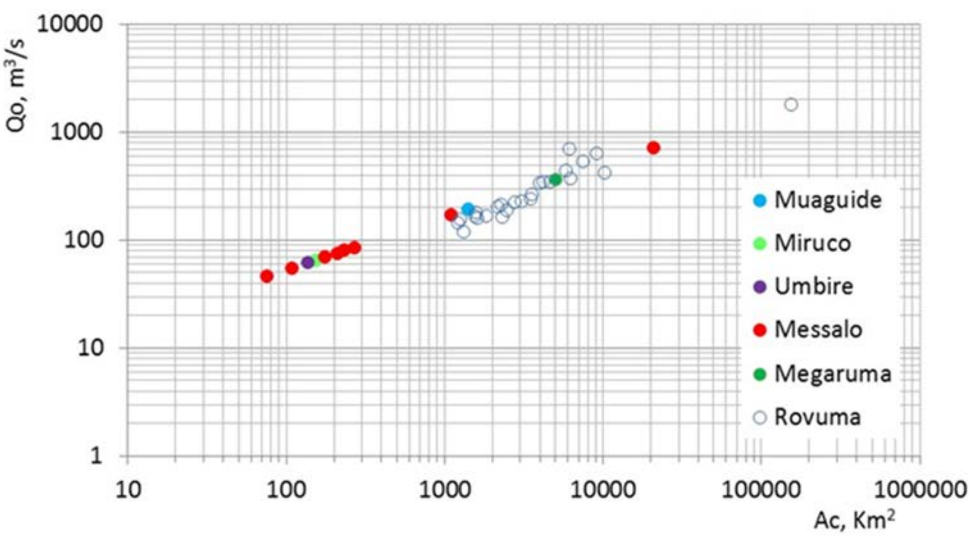

Figure 2: Mean annual flow (Qo) vs basin area (Ac) for sub-basins in the region. *(Source: Results obtained in the framework of the project SIXHIARA [12] and obtained by SWECO in the Rovuma catchment [13].)*

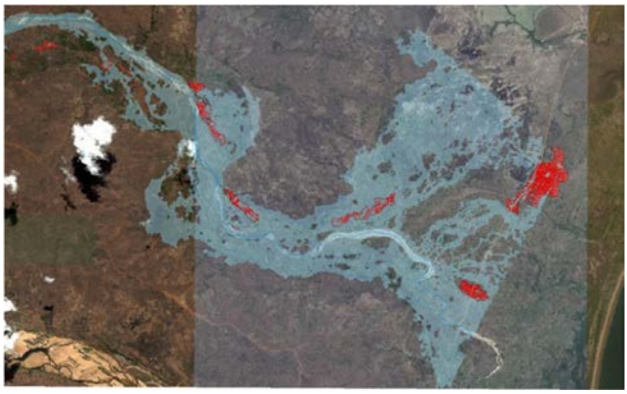

Figure 3: Location of rural settlements in the lower part of the Megaruma River (in red) within the 500-year flood extent. *(Source: Numerical model results obtained in the framework of the project SIXHIARA [12].)*

Two model configurations were set-up. In the first one, the original WorldDEM data was used to define the model topography. In the second one, a terrain conditioning process was applied to the DEM data. The reconditioning process is based on the so-called stream burning procedure, which is used to correct surface drainage patterns derived from DEM [17]. The vector river network derived from an aerial image is converted into a raster river with the same spatial resolution as the DEM. This raster river network is burnt into the un-conditioned DEM, so that the elevation values are artificially lowered at cells that are part of this raster drainage. The burning depth is variable along the longitudinal profile of the river, considering the envelope of the minimum elevations of the original DEM, as shown in Fig. 4.

In both configurations, typical physical values were selected for the Manning roughness coefficient, which is the only parameter of the model. Water depth maps for constant flows of different magnitude (up to 400 m^3/s) were computed.

3 RESULTS AND DISCUSSION

Fig. 5 shows the predicted water depth field for a discharge of 50 m^3/s. In spite of the low discharge value, well below the mean annual flow, significant flooding occurs if the original digital elevation model is used (Fig. 5(a)). This is a first indicator that non-physical elevation variations might be resent in the original DEM, affecting flow predictions.

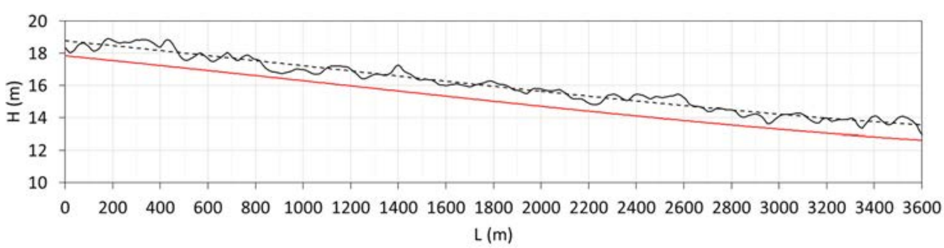

Figure 4: Longitudinal profile along the river thalweg with the original digital elevation model (black) and the hydrologically-conditioned digital elevation model (red). The average slope of the reach is plotted in a dotted line.

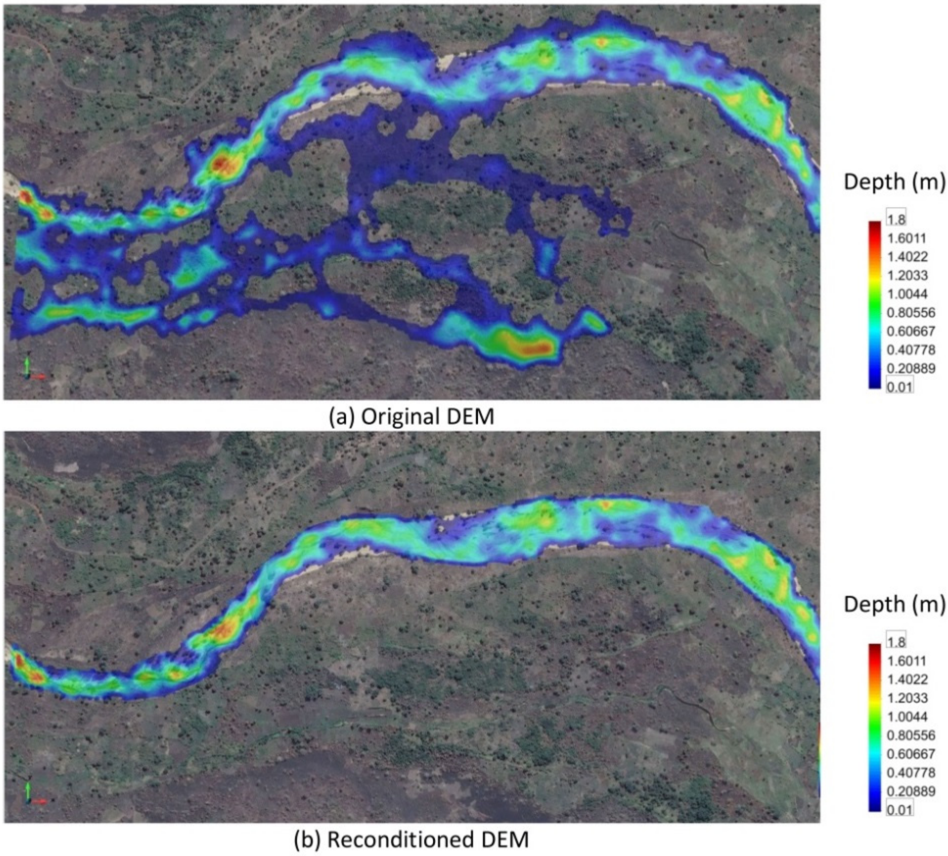

Figure 5: Predicted water depth map in the reach with the original DEM and the conditioned DEM for a discharge of Q=50 m^3/s.

In a second step, the average reach characteristics obtained with the two model configurations were compared. The average mean depth vs. discharge relationships in the reach are shown in Fig. 6. In order to derive estimates of bankfull width and depth for the reach, the relationships obtained by Moody and Troutman [18] between this variables and the discharge were used. The mean annual flow Qo can be considered representative of bankfull discharge [19]. For a Qo of 357 m^3/s, a bankfull width of 136 m and a bankfull depth of 1.57 m were obtained. This value of width is consistent with the width estimated from the aerial image, which is 146 m of average in this reach. As can be seen in Fig. 6, the average depth values obtained with the original DEM never reach the most likely estimate of bankfull depth of 1.57 m. The average depth is only in the order of 1 m for the mean annual flow. The average depth vs. discharge curve becomes practically horizontal from flows higher than 100 m^3/s. This suggests that the bankfull capacity of the stream is considerably underestimated when the original DEM is used. On the contrary, the average depth vs. discharge curve obtained with the hydrologically-conditioned DEM is consistent with the above estimates.

The average depth for the mean annual flow is 1.73 m.

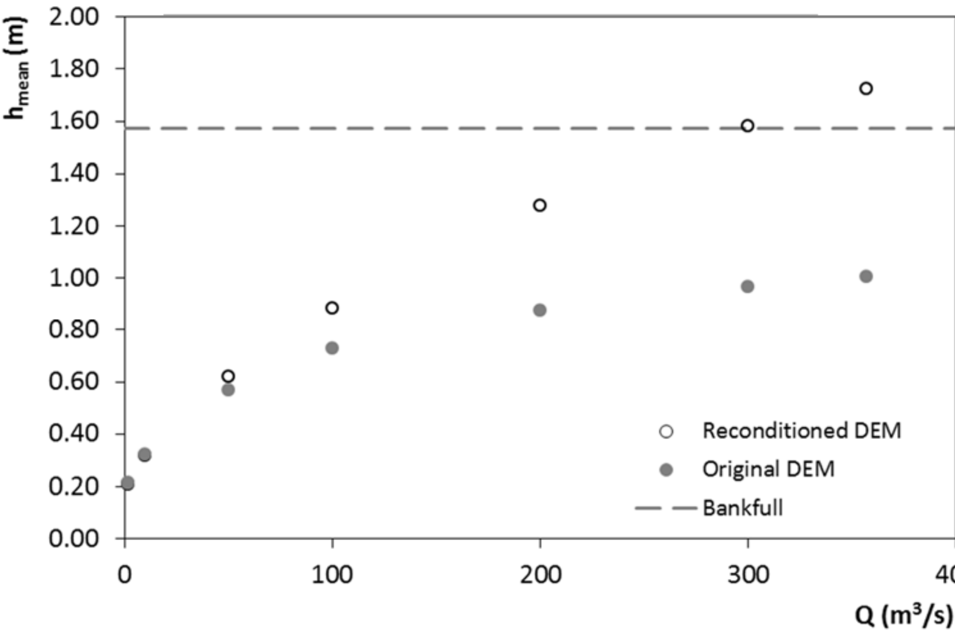

Figure 6: Average mean depth in the reach with the original DEM and the conditioned DEM for different flow discharges. The most likely estimate of bankfull depth based on empirical regressions [18] is plotted in dotted line.

Fig. 7 shows the predicted water depth field for a discharge of 300 m^3/s, which is close to the mean annual flow. Major flooding is predicted by the model which relies on the original DEM, whereas minor flooding is predicted with the reconditioned DEM. Very low water depths are predicted along the main channel in the first case, which results in low average depths values in the reach, as illustrated in Fig. 6. This unrealistic flow patterns seem to be due to non-physical elevations present in the DEM, which result in flow blockages and channel overflows.

4 CONCLUSIONS

In this study we evaluate the utility of Airbus WorldDEM topographic data for flood modelling in the data-scarce region of Cabo Delgado, Mozambique. A shallow water model of a 3.5-km reach of the Megaruma River was developed based on Airbus WorldDEM data.

The results show that the bankfull capacity of the stream is considerably underestimated when this DEM is used. This results in an overestimation of flood extents, with flooding occurring at very low flows. The application of a terrain reconditioning process that enforces realistic channel elevations into the original DEM data significantly improves model predictions. The results suggest that, in spite of the hydrological editing to which it is subject, WorldDEM dataset still presents limitations that prevent it from being directly used without further processing in local flood modelling studies.

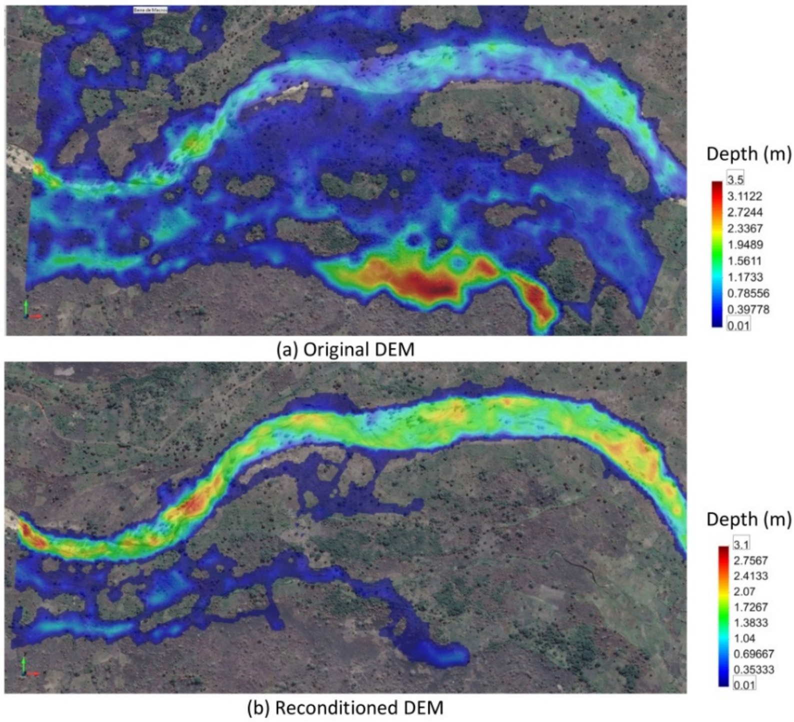

Figure 7: Predicted water depth map in the reach with the original DEM and the conditioned DEM for a discharge of Q=300 m^3/s.

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