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Comparison of drainage network extracted from global digital elevation models with simple-flow and multi-flow direction

Comparação entre redes de drenagem extraídas de modelos digitais de elevação global com direção de fluxo simples e múltiplo

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Abstract

In 2022, the FABDEM model was released. Its developers used machine learning techniques to remove the height of forest canopy and buildings from the COPDEM digital elevation model (DEM). In this context, the objective of this study was to analyze and compare the drainage networks extracted from the SRTM, COPDEM and FABDEM global models using single and multiple flow direction methods, focusing on a floodplain area in the central-eastern region of the State of Paraná. Elevation and slope data from the three models were compared, and vertical accuracy was calculated from the root mean square error (RMSE) between each model and the reference data obtained from an official 1:50000 cartographic base. Drainage networks were extracted using different methods to define the flow direction and parameters of the algorithms implemented in GRASS GIS. The quality of the extracted drainage networks was analyzed by comparing them with the official 1:50000 hydrographic network and with topographic and longitudinal profiles. The results showed the higher vertical accuracy of FABDEM, as well as its better performance in extracting the drainage network when combined with the multiple flow direction method. However, the FABDEM model still has limitations when it comes to extracting drainage networks in floodplains, mainly because it was not successful to completely filter out the influence of vegetation in its altimetric data.

Keywords:
SRTM, COPDEM, FABDEM, Hydrological network, Floodplain.

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Resumo

No ano de 2022, foi disponibilizado o modelo FABDEM, o qual a partir do uso de técnicas de *machine learning* seus desenvolvedores removeram do modelo digital de elevação (MDE) COPDEM a elevação da vegetação e edificações. Neste contexto, este trabalho teve por objetivo: analisar e comparar as redes de drenagem extraídas a partir dos modelos globais SRTM, COPDEM e FABDEM, com métodos de direção de fluxo simples e múltiplo, tendo como foco uma área de planície de inundação na região centro-leste do estado do Paraná. Foram comparados os dados de elevação e a declividade oriunda dos três modelos, bem como calculada a acurácia vertical a partir do erro quadrático médio (EQM) entre cada modelo e os dados de referência obtidos em uma base cartográfica oficial na escala 1:50000. Foram extraídas as redes de drenagem usando diferentes métodos de definição da direção de fluxo e parâmetros a partir dos algoritmos implantados no GRASS GIS. A qualidade das redes de drenagem extraídas foi analisada a partir da comparação com a rede hidrográfica oficial que está disponível, na escala 1:50000, pela elaboração de perfis topográficos e de perfis longitudinais. Os resultados mostraram a maior acurácia vertical do FABDEM, bem como seu melhor desempenho na extração da rede de drenagem quando combinado ao método de direção de fluxo múltiplo. Entretanto, o modelo FABDEM ainda apresenta limitações na extração de redes de drenagem em planícies de inundação devido, sobretudo, a impossibilidade de filtrar por completo a influência da vegetação em seus dados altimétricos.

Palavras-chave:
SRTM, COPDEM, FABDEM, Rede hidrológica, Planície de inundação.

I. Introduction

In recent decades, the quantification of the Earth's surface using Digital Elevation Models (DEMs, which represent the surface with objects such as vegetation and buildings) and Digital Terrain Models (DTMs, which represent the surface without objects) has progressed and has become essential in fields of knowledge such as geomorphology, geology, hydrology, soil science, agronomy, oceanography, vegetation science, climatology, meteorology, and urban planning (El-Sheimy; Valeo; Habib, 2005; Hengl; Macmillan, 2009; Pike; Evans; Hengl, 2009).

Between the 1960s and 2000s, the development of computers, digital data processing techniques, and the availability of remote sensing techniques (e.g., photogrammetry, satellite imagery, and lasers) made it possible to extract elevation information from the Earth's surface. In addition, over the last 25 years the increase in data storage capacity, easier access to the Internet, and the development of machine learning and artificial intelligence techniques have made it possible to generate and make available high-resolution DEMs for large areas (Kidner; Smith, 2003; Lakshmi; Yarrakula, 2018; Hawker et al., 2022). In this context, global or quasi-global DEMs have been generated by satellite radar surveys, such as the Shuttle Radar Topography Mission (SRTM), Nasa Digital Elevation Model (NasaDEM), Advanced Land Observing Satellite - Phased Array type L-band

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Synthetic Aperture Radar (Alos PALSAR) and Copernicus Digital Elevation Model (COPDEM), or by stereoscopy, such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer - Global Digital Elevation Model (Aster GDEM).

Global or quasi-global DEMs are prominent in geoscience applications because of their low cost and wide geographic availability. However, the elevation estimated by orbital sensors includes the elevation of vegetation (with the contribution of the vegetation canopy) and buildings. To address this limitation, Hawker et al. (2022) used machine learning techniques to remove the contribution of forest and building surfaces to produce the first global DTM, called the Forest and Building Digital Elevation Model (FABDEM), with a spatial resolution of 30 meters. The authors compared this model to its source data (i.e., the COPDEM model) and to the Multi Error Removed Improved-Terrain Digital Elevation Model (MERIT DEM) in different environments (e.g., urban, forest, boreal forest, exposed soil, floodplain). The result of the comparison showed that FABDEM had the lowest statistical error.

Since the release of this new DTM, several of works have been carried out and published to compare the quality of FABDEM with other global models. Some of them focus on comparisons in specific geographic areas (Dandabathula et al., 2023; Iqbal et al., 2023; Krdžalić et al., 2024) and others in different areas worldwide (Bielski et al., 2024; Meadows; Jones; Reinke, 2024). Most of these works use models generated from Light Detection and Ranging (LiDAR) surveys as reference data. In general, these works have demonstrated the superiority of FABDEM as the most reliable model to represent the terrain surface (i.e., excluding vegetation and buildings) in different environments.

In the context of geoscience, drainage networks derived from DEMs/DTMs are one of the main products of digital terrain modeling. Several drainage network extraction algorithms have been developed and are available in software or applications such as GRASS GIS (Grass Development Team, 2017) and TopotoolBox (Schwanghart; Scherler, 2014). In geomorphology, for example, the extraction of drainage networks is essential for morphometric analyses based on Horton's Laws (Horton, 1945), the SL index (Hack, 1973), the ks index (Snyder et al., 2000), and the χ index (Perron; Royden, 2013). It is also fundamental in fields such as hydrological modeling (Giannoni; Roth; Rudari, 2005) and urban planning (Duarte et al., 2013).

Over the last decade, the process of automatically extracting drainage networks has continued to be the subject of research (Ahmadi et al., 2014; Lindsay; Yang; Hornby, 2019; Borgohain et al., 2023), particularly on the extraction of drainage networks in floodplains (Chen et al., 2024). There has also been work aimed at comparing drainage networks extracted from different elevation data sources. For example, Ahmadi et al.

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(2014), working in a mountainous watershed in Iran, found that the drainage network derived from the Aster DEM (29 m resolution) was more accurate than the one derived from the SRTM (90 m resolution) and two topographic bases at 1:25000 and 1:50000 scales. Borgohain et al. (2023), working in a flat area of the Indian Himalayas, found that the drainage network derived from the MERIT DEM showed lines that appeared more natural when compared to the results derived from FABDEM. However, the drainage network derived from FABDEM was more detailed due to its higher spatial resolution. Gaida et al. (2024), in a forested area in the state of Rio Grande do Sul, found that the drainage network derived from FABDEM showed greater spatial correspondence with the existing drainage when compared to the drainage networks derived from SRTM and Aster GDEM. In general, the main limitations of automated drainage network extraction are related to the accuracy of the results, topological errors and unnatural visual appearance (e.g. straight lines) (Ahmadi et al., 2014; Lindsay; Yang; Hornby, 2019; Borgohain et al., 2023).

Since the development and availability of FABDEM, the opportunity has arisen to explore the potential of this new model for the automatic extraction of drainage networks. As the FABDEM data, at least in theory, do not consider the height of vegetation and buildings, we hypothesize that drainage networks derived from FABDEM will have a more natural delineation compared to drainage networks derived from DEMs with the same spatial resolution, such as SRTM or COPDEM.

Therefore, the objective of this study was to analyze and compare the drainage networks extracted from FABDEM with those extracted from two other global DEMs. COPDEM and SRTM were selected as the two DEMs. The former was chosen because it is the original data source of FABDEM, and the latter because it is the most widely used global DEM. The analysis included the use of single and multiple flow direction methods to extract the drainage networks, focusing mainly on the floodplain of the Iapó River (central-eastern region of Paraná). For this purpose, their altimetric data were compared by calculating their respective vertical accuracies, using as reference data the elevations from digitized topographic maps

II. MATERIALS E METHODS

ELEVATION DATA AND REFERENCE DATA

The global digital elevation/terrain models were obtained, with their respective characteristics:

- Shuttle Radar Topography Mission v. 3 (SRTM): horizontal resolution of 1 arc second (~30 meters). The data were acquired between February 11 and 22, 2000 by the C-band radar (National Aeronautics and Space Administration, 2024). Available in: www.earthdata.nasa.gov/;

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- Copernicus DEM (COPDEM): horizontal resolution of 1 arc second (~30 meters). The data was acquired between 2011 and 2015 by the TanDEM-X mission (Copernicus, 2024). Available in: panda.copernicus.eu/;
- Forest and Building DEM v. 1.2 (FABDEM): horizontal resolution of 1 arc second (~30 meters). Data from the COPDEM model (Hawker et al., 2022). Available in: data.bris.ac.uk/data/dataset/25wfy0f9ukoge2gs7a5mqpq2j7;

All three models were preprocessed by filling depressions using the Wang & Liu algorithm available in SAGA GIS 2.3.2 (Conrad et al., 2015).

Elevation and hydrography data from IBGE/DSG 1:50,000 scale topographic maps, digitized and vectorized by the *Águas do Paraná* Institute (now part of the *Água e Terra* Institute), were used. The elevation points and the points of intersection between the drainage network and the contour lines were chosen as reference points for calculating the vertical accuracy of each model.

COMPARISON BETWEEN MODELS AND CALCULATION OF VERTICAL ACCURACY

The comparison between the global models partially followed the methodological steps of Silveira and Silveira (2015). The maximum, mean, and standard deviation of the difference between the elevation and slope data from the comparison between the models were calculated. Vertical accuracies were calculated using the root mean square error (RMSE) (Equation 1) between the elevation of each model and the points used as reference data. The RMSE was calculated without considering the different classes of land use in the area.

$$RMSE = \frac{\sqrt{\Sigma(z_m - z_r)^2}}{n} \text{ (Equation 1)}$$

where z_m is the elevation of the model, z_r is the elevation of the reference data point, and n is the number of reference data points.

The comparison between the elevation and slope values of the models was carried out in an area located in the central-eastern region of the state of Paraná (Figure 1H). This region is characterized by heterogeneity and is subdivided into three main geomorphic compartments: i) reverse side of the Devonian Escarpment, composed of Paleozoic sedimentary rocks and high/moderate dissection relief; ii) Piraí Depression, composed of porphyritic granites, quartzites and volcanic-sedimentary rocks, and low dissection relief; iii) Upper Ribeira Valley, composed of metamorphic and igneous rocks, and high dissection relief (Mineropar, 2001; 2006; Oka-

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Fiori et al., 2006; Santos et al.; 2006). The region is also characterized by the presence of linear geological structures in a NW-SE and NE-SW direction, associated with the Ponta Grossa Arch and the Cenozoic Rift System of Southeastern Brazil (Ferreira, 1982; Zalán et al., 1987; Zalán; Oliveira, 2005). As a result of the presence of these structures, there is structural control over part of the drainage network in this region (Firmino, 2015; Oliveira; Pinto, 2015; Barreto; Pinto, 2017; Firmino; Souza Filho, 2017).

The comparison of vertical accuracy between the models was carried out in three different zones. The three zones were chosen because they are located in three different geomorphic compartments and have different land uses: a) zone 1 (≈ 36,000 hectares) has flat (slope <12.5%) to undulating (slope >12.5% and <25%) terrain (Figure 1A) and a predominance of plantations and pastures (Figure 1B); b) zone 2 (≈ 56 thousand hectares) has flat terrain (slope <12.5%), located on the flood plain of the Iapó River (Figure 1C), and predominantly plantations and pastures (Figure 1D); c) zone 3 (≈ 70 thousand hectares) has strongly undulating terrain (slope >25% and <50%) (Figure 1E) and predominantly forest (Figure 1F).

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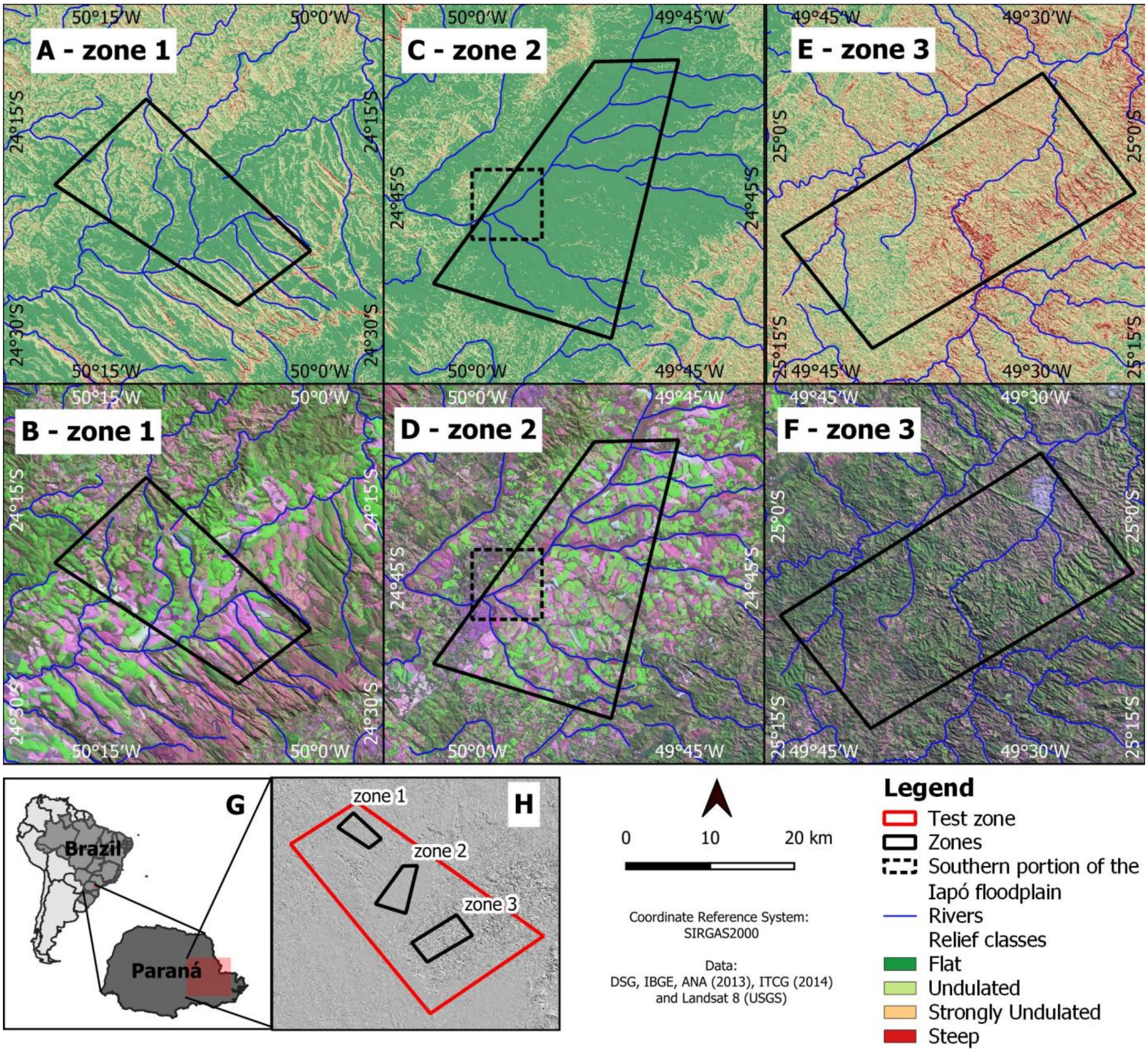

Figure 1 – Zones where comparisons were made between global models. A, C and E: relief classification based on Bielski et al. (2024); B, D and F: RGB composition made from a Landsat 8 image; G: location of the study area in relation to Brazil and the state of Paraná; H: location of the test zone and the three zones used to calculate the RMSE.

DELINEATION AND ANALYSIS OF THE QUALITY OF DRAINAGE NETWORKS FROM DIFFERENT GLOBAL MODELS

Drainage networks for each model were delineated using the simple-flow direction (SFD) and multi-flow direction (MFD) methods available in GRASS GIS 7.8.4 (Grass Development Team, 2017). Minimum flow accumulations of 100 pixels (90,000 m^2) and 500 pixels (450,000 m^2) were tested.

The qualitative analysis of the results was based on the interpretation of altimetric and longitudinal profiles, field observations and the comparison of reference data (DSG/IBGE 1:50000 hydrographic base),

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Landsat 8 imagery and the extracted drainage networks. It is important to note that although the 1:50000 hydrological base is official for the state, however it contains inaccuracies (Sousa; Sampaio, 2015). To this end, we analyzed: the similarity between the drainage networks extracted from the three models using the MFD and SFD methods in relation to the 1:50000 hydrographic base; and whether the FABDEM model, which theoretically does not take into account the elevations of vegetation and buildings, was able to represent only the elevations of the analyzed terrain and thus generate better quality drainage networks compared to the drainage networks extracted from the other models.

The analysis focused on the southern portion of the Iapó River floodplain (Figure 1C and Figure 1D). The choice of this floodplain was due to its spatial representation, as being the largest flat area in the study area. Consequently, the floodplains are the area where the automatic extraction of the drainage network may have greater limitations.

III. Results and discussion

Comparison between models and calculation of vertical accuracy

Of the three inter-model comparisons, the largest mean differences in elevation were obtained when comparing FABDEM and SRTM. This result was to be expected as the two models are derived from different data sources. In addition, the FABDEM data refer only to the land surface, whereas the SRTM data refer to the surface, which also includes forest canopies and buildings. On the other hand, the smallest mean elevation differences were obtained when comparing COPDEM and SRTM, because both DEMs and their data refer to the surface, which includes the elevation of forest canopies and buildings (Table 1).

Table 1 – Comparison of elevation data from the models

Model	Maximum difference (m)	Mean difference (m)	Standard deviation (m)
COPDEM vs SRTM	106.58	3.42	3.60
COPDEM vs FABDEM	69.05	4.00	3.80
FABDEM vs SRTM	107.54	5.39	5.07

Source: The authors.

When comparing slope values, the largest difference was found between COPDEM and SRTM. Meanwhile, the smallest difference was found when comparing COPDEM and FABDEM (Table 2). This is a different scenario from that observed when comparing elevation data.

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Table 2 – Comparison of slope data (in %) from the models

Model	Maximum difference	Mean difference	Standard deviation
COPDEM vs SRTM	107.67	4.50	4.56
COPDEM vs FABDEM	83.41	2.42	2.91
FABDEM vs SRTM	127.27	4.44	4.51

Source: The authors.

Among the three models, FABDEM was the one with the lowest RMSE in all three zones, both for the elevations of the elevation points and for the elevations of the points where the contour lines intersect the hydrography (Table 3). Thus, we can claim that FABDEM is the model analyzed with the best vertical accuracy. The result confirms that the FABDEM model is the more accurate to the reference data, i.e. the more accurate to the land surface data. This is evidence that the removal of forest and building surfaces from the COPDEM model data performed by Hawker et al. (2022) was significantly successful in the area analyzed. In summary, the FABDEM can be considered as the best model for this region, although it does not completely remove the effects of vegetation and buildings.

Table 3 – Root mean square error (RMSE)

Comparison with the elevations of the elevation points			
Model	RMSE (m) (Zone 1)	RMSE (m) (Zone 2)	RSEM (m) (Zone 3)
SRTM	6.11	8.61	8.93
FABDEM	5.82	6.60	7.99
COPDEM	6.44	7.45	8.25

Comparison with the elevations of the points where the contour lines intersect with the hydrography			
Model	RSEM (m) (Zone 1)	RSEM (m) (Zone 2)	RSEM (m) (Zone 3)
SRTM	11.98	15.60	16.55
FABDEM	8.12	12.54	10.21
COPDEM	11.40	14.50	14.54

Zone 1: low/medium dissected relief; Zone 2: low dissected relief, floodplain; Zone 3: high dissected relief and forested. Source: The authors.

This result is consistent with that obtained by Bielski et al. (2024) for areas with flat or undulating terrain. In these areas, FABDEM showed a higher data quality than COPDEM and SRTM using terrain elevation data from LiDAR sensors as a reference data. However, Bielski et al. (op. cit.) ranked COPDEM as having the best quality among the three models for strongly undulating and steep areas, followed by FABDEM and SRTM. The authors found FABDEM to have the highest quality for both forested and non-forested areas, followed by COPDEM and SRTM.

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Meadows, Jones, and Reinke (2024), also using terrain elevations from LiDAR sensors as reference data, found similar results. FABDEM had the best overall vertical accuracy regardless of land use class. In terms of topography, FABDEM was more accurate for flat areas, while COPDEM was more accurate for steep, forested areas (Meadows; Jones; Reinke, *op. cit.*). On the other hand, Gaida et al. (2024), using elevations measured from topographic surveys by Global Navigation Satellite System (GNSS) receivers as reference data, found that FABDEM, SRTM, and Aster GDEM data did not show statistically significant differences in a forested area. However, the fact that the FABDEM altimetry data did not show any overestimation indicates that there is less influence of the forest canopy on the elevations represented by this DTM.

The lowest vertical accuracies for the elevations of the elevation points were calculated in area 3, which is characterized by a strongly undulating relief and is more densely forested. On the other hand, the highest vertical accuracies were calculated in area 1, which is characterized by a flat or undulating relief and a predominance of plantations and pastures. However, the lowest vertical accuracy of the FABDEM for the elevations of the intersection points between the contour lines and the hydrography was calculated in area 2, which is characterized by the flat relief of the Iapó River floodplains. The lowest vertical accuracy for the COPDEM was calculated in area 3, although with a value close to that calculated in area 2 (Table 3).

The scenario described above demonstrates the gain in accuracy of the FABDEM model data, especially at points on the stream channels located in areas of strongly undulating and densely forested terrain. Furthermore, since the vertical accuracy for all models is higher at the elevation point, we can assume that the vertical accuracy is higher in the divide drainage than in the drainage network. The difference in vertical accuracy is almost double for the SRTM and COPDEM models. The difference between the vertical accuracy values for the FABDEM is smaller (less than 1.5) for the areas 1 and 2 (Table 4).

Table 4 – Difference in vertical accuracy between comparisons with elevations of elevation points and between comparisons with elevations of contour points with hydrography

Model	Zone 1	Zone 2	Zone 3
SRTM	1.96	1.81	1.85
FABDEM	1.40	1.90	1.27
COPDEM	1.77	1.95	1.76

Source: The authors.

Work by Falorni et al. (2005), Mukherjee et al. (2013), Hu et al. (2017), and Tran et al. (2023) showed that the vertical accuracy of the models is lower in areas with steeper relief than in areas with flat relief. Similar scenarios were found in the comparison with the elevation data of the elevation points for all models, as well

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as in the comparison with the elevation data of the points of intersection between contour lines and hydrography for the SRTM and COPDEM. However, in the latter case, the lowest vertical accuracy was calculated for the FABDEM in the flattest area (area 2). This shows the difficulty of semi-automatic delineation of drainage networks in floodplains.

DELINEATION AND ANALYSIS OF THE QUALITY OF DRAINAGE NETWORKS FROM DIFFERENT GLOBAL MODELS

Faced with the challenge of extracting the drainage network in floodplain environments, we analyzed the results of the tests carried out with different global models and with different parameters to define the flow directions, focusing on area 2 (Iapó River floodplain). The drainage networks were extracted from a minimum flow accumulation of 100 pixels (90,000 m^2) (Figure 2). This minimum flow accumulation value was chosen due to its greater similarity to the drainage network from the DSG/IBGE 1:50000 hydrographic base.

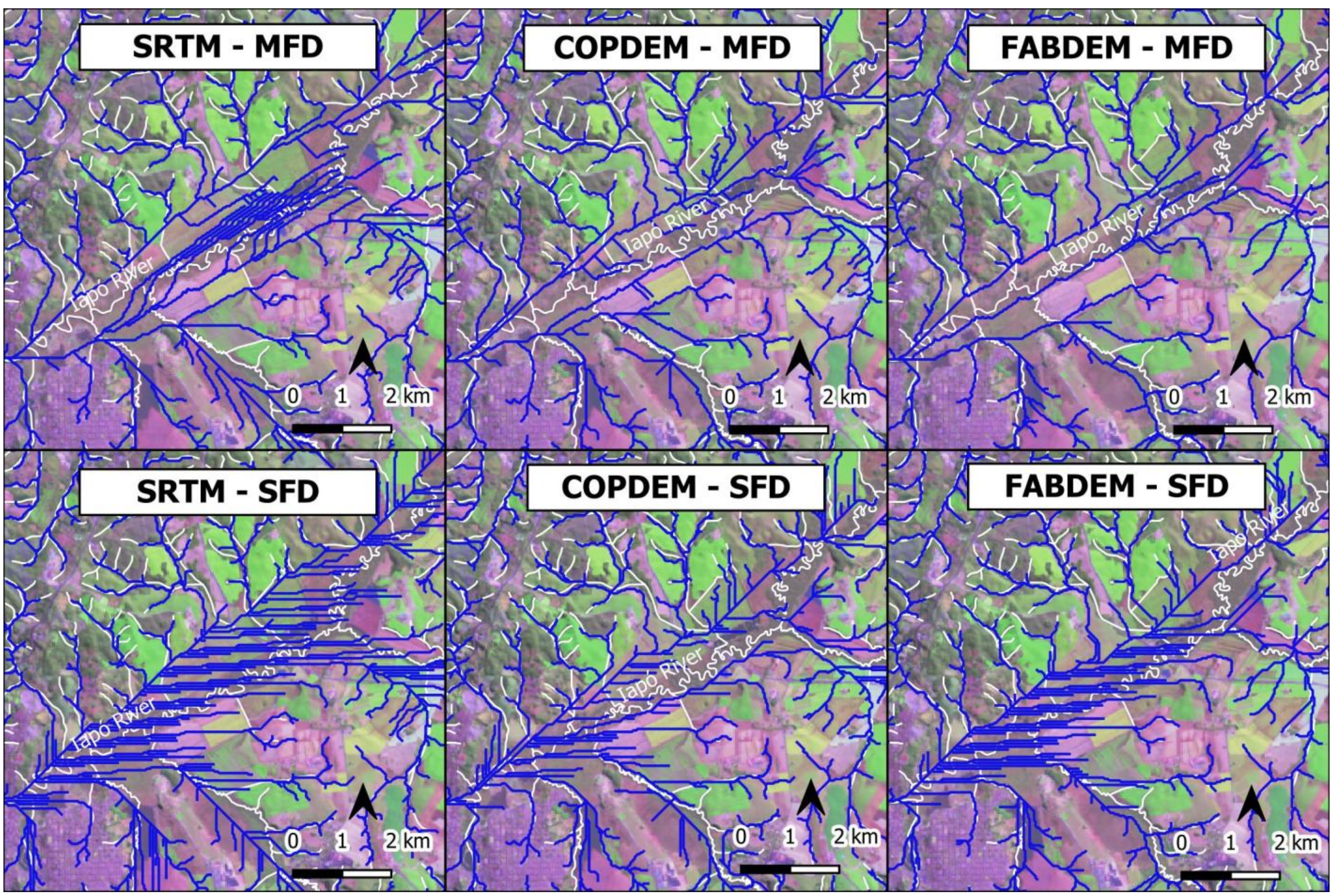

Figure 2 – Drainage networks delineated for each model using the MFD and SFD methods, with a minimum flow accumulation of 100 pixels. The blue lines represent the semi-automatically delineated drainage networks, while the white lines represent the DSG/IBGE hydrographic network at a scale of 1:50000. Background image: Landsat 8.

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The best performance of the multi-flow method (MFD) is evident for the three models when they are analyzed by visual interpretation. The MFD method can delineate a drainage network on the floodplain in a more natural way, where there is a main channel connected to the other tributary channels. Nevertheless, the MFD method delineated more than one main channel, parallel to each other and confluent in the most downstream part of the floodplain. On the other hand, the SFD method resulted in a main channel that was not centralized in relation to the area of the floodplain, as well as several small rectilinear tributaries that covered the entire area of the floodplain.

The analysis of the drainage network derived from FABDEM using the MFD method shows that the most centralized channel has been delimited near the Iapó River, and there is less presence of small straight channels in the middle of the plain. However, the centralized channel is a tributary channel, while the main channel of the network is delineated further north. A similar scenario occurred not only with the drainage network resulting from FABDEM, but also with the drainage networks resulting from SRTM and COPDEM. In turn, the drainage networks delineated by the SRTM model showed the greatest presence of small straight and parallel channels.

The drainage networks were delineated based on the minimum flow accumulation of 500 pixels (Figure 3). The use of the highest flow accumulation criterion made it possible to remove the small rectilinear and parallel channels, leaving only the largest channels in the drainage network. This highlights the fact that the SFD method presents more rectilinear channels, as well as a single main channel that is displaced with respect to the Iapó River mapped by DSG/IBGE. However, there are still small rectilinear channels in the floodplain for the drainage network of SRTM and FABDEM. Therefore, the use of an even higher flow accumulation value, leading to a higher generalization of the results was necessary. On the other hand, in the COPDEM drainage network, the delineation of two main channels was accentuated, one partially coinciding with the Iapó River and the other displaced, both converging at the most downstream point of the floodplain.

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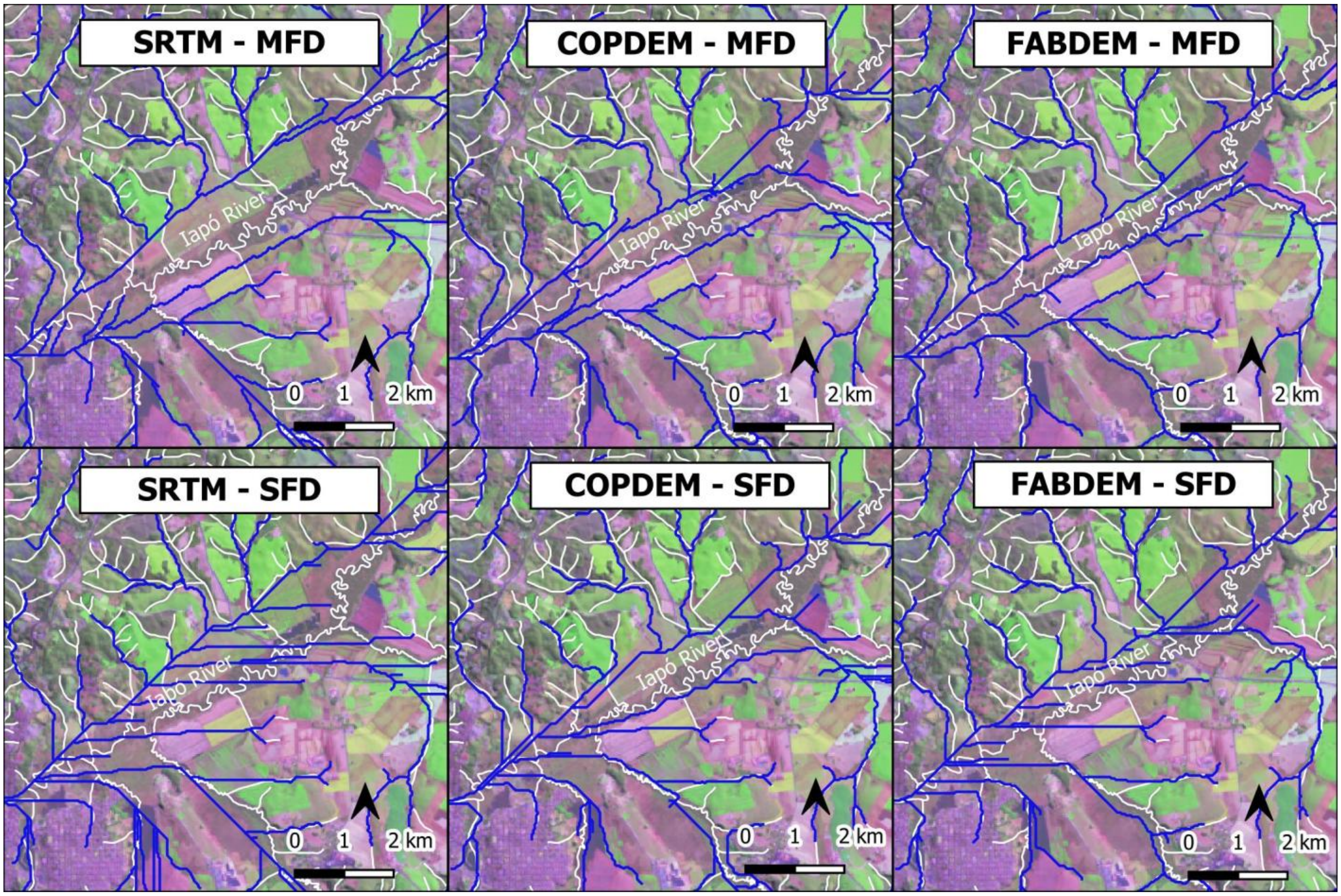

Figure 3 – Drainage networks delineated for each model using the MFD and SFD methods, with a minimum flow accumulation of 500 pixels. The blue lines represent the semi-automatically delineated drainage networks, while the white lines represent the DSG/IBGE hydrographic base at a scale of 1:50000. Background image: Landsat 8.

Figure 4 shows the drainage networks delineated by the MFD method with a minimum flow accumulation of 1000 pixels and also show the field observations. The examples below show that the drainage network derived from SRTM are more rectilinear (Figure 4A and Figure 4B), even in areas where the Iapó River is highly sinuous (Figure 4A). Also evident is the limitation of all three models in generating a realistic drainage network in areas where the floodplain vegetation is denser and occupies a larger area around the river (Figure 4C). This last case contrasts with areas where the surrounding vegetation is less dense and occupies a smaller area around the river, where the drainage extraction give more consistent results, especially the drainage extraction from COPDEM and FABDEM data (Figure 4B). Finally, there are sections of first order rivers mapped by DSG/IBGE and also extracted by the models that are not found in the field (Figure 4B), highlighting the limitations of both official topographic bases and automated drainage network extraction methods.

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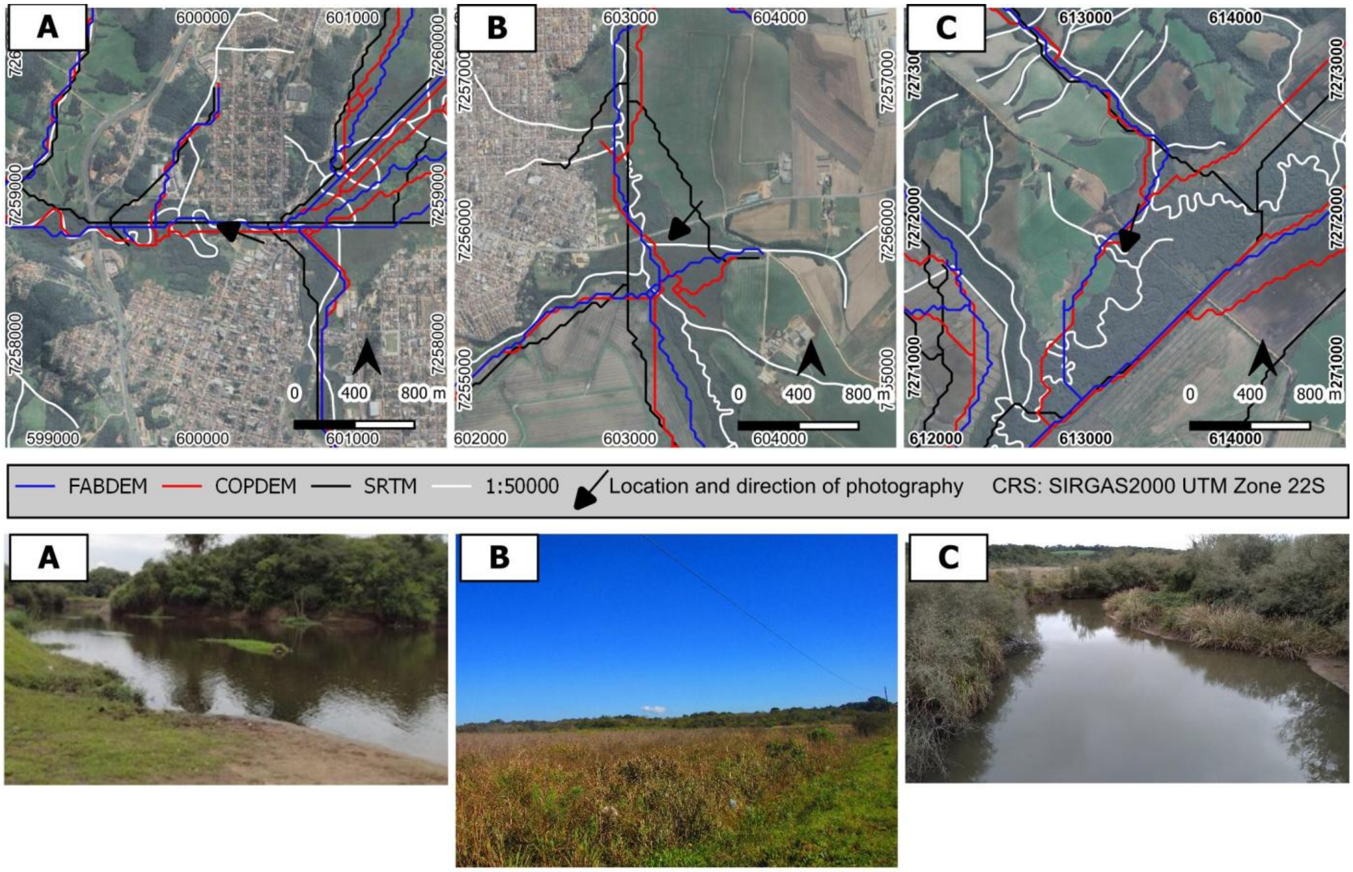

Figure 4 – A: The Iapó River and a river island in the *Prainha* Municipal Natural Park, in Castro - PR; B: The floodplain of the Maracanã River, a tributary of the Iapó River, on the road between the municipality of Castro and the district of Castrolânda. In the background, the riparian forest of the Maracanã River; C: Iapó River. Photograph taken over the bridge of the PR-090 highway. The drainage networks were delineated using the MFD method, considering a minimum flow accumulation of 1000 pixels, and the background images are from Google Earth.

In summary, when comparing the different models, FABDEM showed the best results when used in conjunction with the MFD method. This result is in line with Gaida et al. (2024), who found that in a forested area, the drainage network derived from FABDEM showed greater spatial correspondence with the existing drainage when compared to the drainage networks derived from SRTM and Aster GDEM.

Figure 5A and Figure 5B show the profiles used to analyze the influence of the forest canopy on the elevation data. These profiles compare the elevations of the three models around Iapó River floodplain. The surface represented by SRTM is systematically higher and flatter, resulting in the main channels of the floodplain delineated by the MFD method being located exactly at the edges of the flat areas. Meanwhile, the surfaces represented by COPDEM and FABDEM overlap in areas without vegetation, and the COPDEM surface is higher in vegetated areas. Thus, the elevation peaks of the COPDEM data observed over the floodplain area refer to portions where vegetation is present. Excluding the floodplain vegetation allowed the MFD method to delineate

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the main channel closer to its actual location without preventing the delineation of two other parallel main channels near the edge of the floodplain.

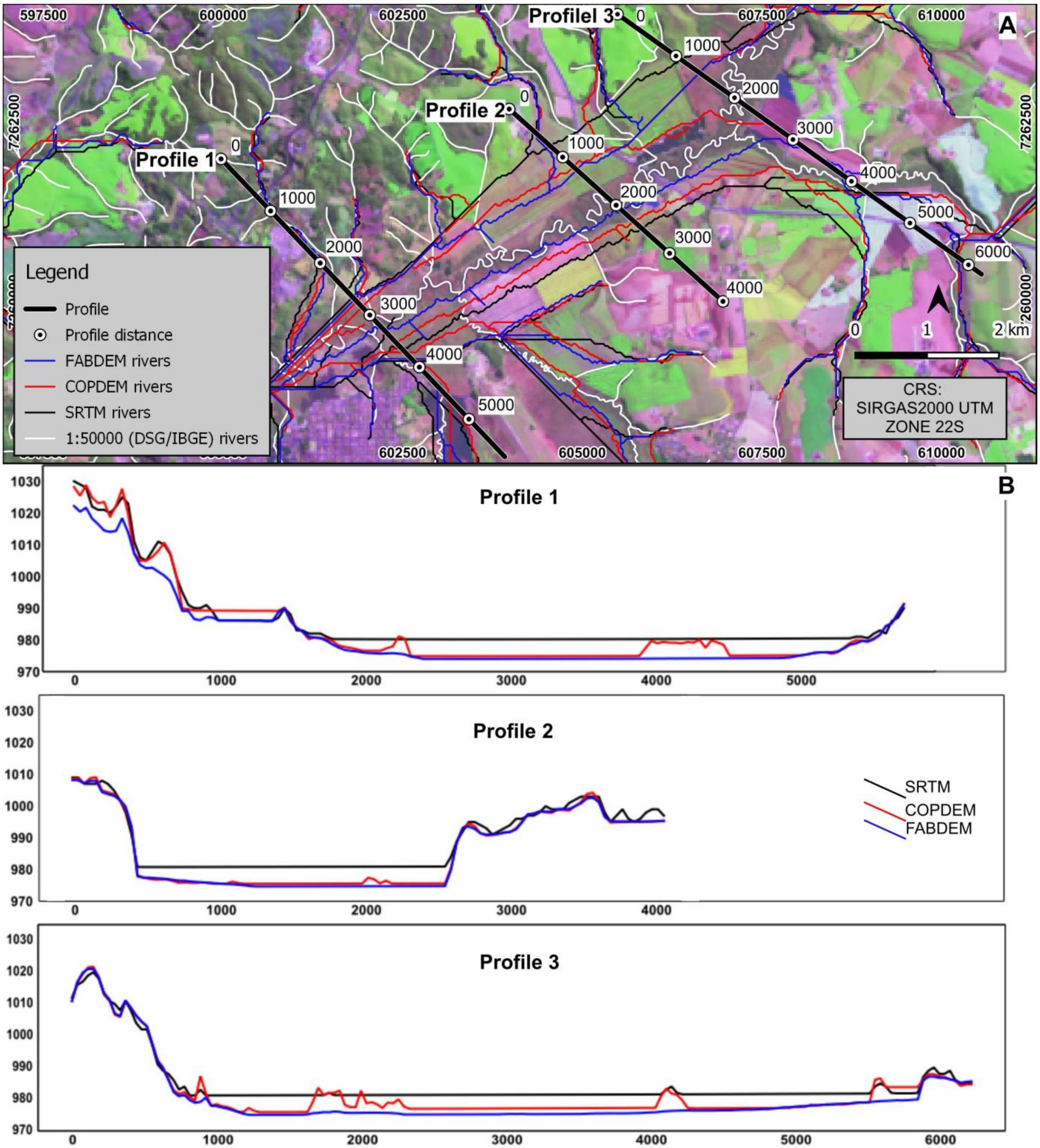

Figure 5 – A: location of the elevation profiles perpendicular to the southern portion of the Iapó River plain. The rivers shown were delineated using the MFD method and a minimum flow accumulation of 1000 pixels; B: elevation profiles based on data from the SRTM, COPDEM and FABDEM. In both figures, elevations and distances are given in meters.

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The presence of floodplain vegetation is well shown by the COPDEM surface data at the 2000-meter position of Profile 3. We can also observe a small bulge in the terrain at the same position in the FABDEM data. Thus, we believe that the floodplain vegetation has not been completely removed in the FABDEM model. As a result, the presence of these elevations associated with the vegetation in the COPDEM and FABDEM data caused errors in the delineation of the Iapó River. In the FABDEM drainage network, this elevation did not allow the delineation algorithm to connect the Iapó River to its corresponding upstream section. Consequently, the parallel channel located near the right edge of the floodplain was connected to the upstream section of the Iapó River.

The longitudinal profiles (Figure 6) of the section of the Iapó River shown in Figure 5A also show that the SRTM elevations are systematically higher than the elevations of the other models. Meanwhile, the COPDEM elevations are systematically higher than the FABDEM elevations. The COPDEM data are noisier than the other models. The lower elevations and reduced noise indicate that the processing that produced the FABDEM was able to filter out a significant influence of vegetation on its elevation data. On the other hand, the noise identified in the FABDEM data in the downstream and upstream sections shows that in areas where the floodplain vegetation appears to be denser and occupies a larger area around the river, the filtering process was not able to completely reduce the influence of the forest canopy on the elevation data.

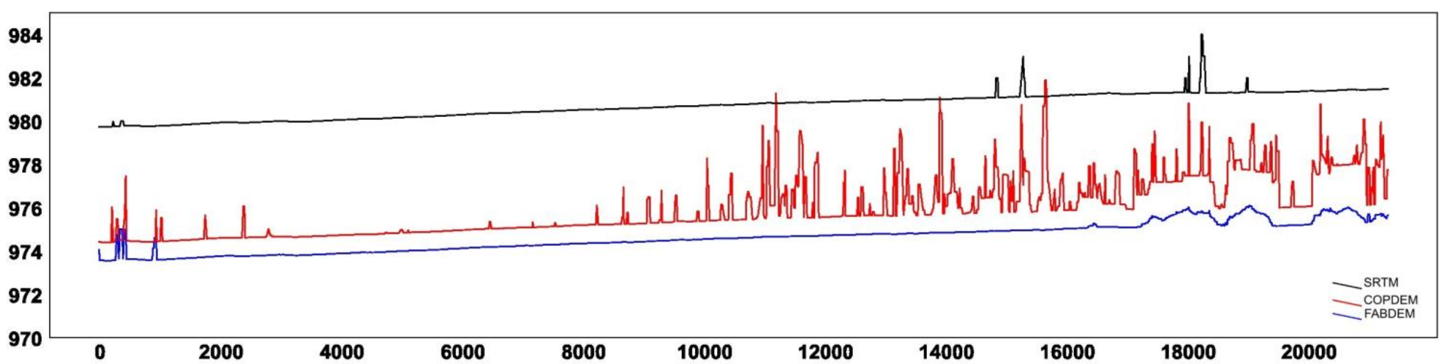

Figure 6 – Longitudinal profiles of the section of the Iapó River (1:50000) shown in Figure 5A, based on the SRTM, COPDEM, and FABDEM models.

IV. Conclusion

When comparing the SRTM, COPDEM and FABDEM global models, the latter showed the highest vertical accuracy with respect to the terrain surface. The quantitative results of the comparison between the three models obtained in this study are consistent with those obtained in other studies that have compared the new FABDEM global model with other global models.

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The use of elevation points and points of intersection between contour and hydrography from topographic maps allowed the calculation of vertical accuracy and quantitative comparison between different DEMs/DTMs. Despite its limitations, this methodology is a viable option for comparing models in areas where LiDAR data are not available.

A qualitative comparison showed that the quality of the drainage network generated by FABDEM in a floodplain area was better, especially when used in conjunction with the multi-flow direction (MFD) method.

The partial removal of floodplain vegetation by FABDEM allowed a more reliable delineation of the main river. Therefore, the FABDEM drainage network shows a more natural delineation when compared to the drainage networks derived from the SRTM and COPDEM.

Finally, although the FABDEM was the global elevation database with the best results, important limitations in its use were identified. This scenario demonstrated the challenge of semi-automated extraction of drainage networks in flat areas.

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