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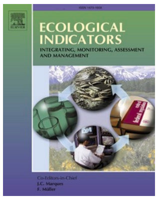

Original Articles

On the quality of the drainage network cartographic representation

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ABSTRACT

One of the most important features of topographic maps is the stream network. Its accurate representation is essential for several applications. This work evaluates the quality of the stream network representation of Brazil and Portugal's official topographic maps. These maps were produced using different scales (1:10,000, 1:25,000, and 1:50,000) and methods (photo interpretation and automatic drainage network extraction). The intention of this analysis is to focus on quality data analysis, optimization and reduction of management costs, and the achievement of better planning. To assess the completeness and positional quality, two actions were taken. The first, concerning the completeness assessment, used the methodology proposed by ISO 19157. The second is related to positional quality analysis using the Buffer Overlay Statistical Method. Results show that completeness and positional errors can appear at different locations, intensities, and scales and may promote changes in the extent and direction of mapped watercourses, drainage density, and consequently the size of the watersheds.

1. Introduction

Topographic maps are the result from both field surveys and observations. They comprise evidence of natural and artificial landscape features such as buildings, roads, and rivers (Medyńska-Gulij and Żuchowski, 2018). They are used for several applications, such as military, planning and management, resources and demographic analysis, etc. (Kent and Hopfstock, 2018). Regarding their complete depiction of the landscape and the wide range of both uses and users, these are highly complex maps with several cartographic structures linked together (Buckley et al., 2005).

It is important to remember that the cartographic base is, as its name implies, the basis for the municipal technical register, and for a municipal Geographic Information System (GIS). Therefore, it is of the utmost importance that it be well specified, standardized, executed, and controlled so that all geoprocessing activities can be built on an accurate and current landscape representation. Generally, the distinctive standing of topographic maps comes from the high level of confidence that users have in them and from their long-term importance (Kent and Vujakovic, 2011; Ory et al., 2015).

Thus, to be effective a cartographic basis must meet two basic premises, being both up-to-date and accurate. It is possible to say that the more accurate and current a cartographic base is, the more accurate and efficient local, municipal and regional plans will be because they are based on the cartographic base.

One of the most important features of topographic maps is stream geometry, as its accurate depiction is essential for several applications linked to river systems, e.g. biogeochemistry (Tiwari et al., 2017) and exchanges with the atmosphere (Natchimuthu et al., 2017). Hence, the river system must be understood as a complex system, i.e., composed of multiple interconnected features. The system should be viewed as a system considering all required features necessary to preserve the water and maintain suitability.

Streams can be categorized as intermittent or perennial by their surface flow perpetuity. Those that are intermittent may stop flowing, a common feature of the regular stream's hydrology (Acuña et al., 2014). This may be due to several factors, e.g., freezing, less transmission, evapotranspiration, groundwater tables moving down, or the decline of hillslope runoff (Larned et al., 2010).

An accurate description of stream length is a key issue for its usefulness. In this matter, one issue is to identify the smallest streams called "Aqua Incognita" (Bishop et al., 2008), a pertinent designation as most of the small streams are usually poorly charted (Kuglerová et al., 2017). Even the finest obtainable property map for Sweden (1:12,500) ruthlessly underestimates the full length of stream networks (Ågren and Lidberg, 2019). While Wallin et al. (2018) emphasized the significance

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of these small streams, they are difficult to map using traditional methods like remote sensing imagery (airborne or space-borne), as a result of low spatial resolution, vegetation covering, or limited field data (Benstead and Leigh, 2012; Persendt and Gomez, 2016). However, stream networks retrieved from very high-resolution Digital Elevation Models (DEM), if properly calibrated, are more inclusive (Benstead and Leigh, 2012; Stein et al., 2014).

Although DEMs are nowadays broadly used in stream extraction, their usage brings some associated errors, DEMs frequently display shallow depressions that can be mitigated through a stream burning algorithm (Chen et al., 2012). This algorithm frequently recognizes streams that are indistinguishable in the DEM, avoiding severe errors in the extraction method.

Nevertheless, particularly in shallow areas, many other topographies (e.g., hardened roads, small dams, artificial rivers) can cause significant depressions and limit the accuracy of the model (Turcotte et al., 2001). Furthermore, the best open-source DEM accessible has a limited spatial accuracy of 12.5 m. Hence, DEM handling can produce unlikely stream networks derived from big depressions and small elevation changes in local-scale areas, with special incidence on river plains (Callow et al., 2007).

This article intends to evaluate the quality of the stream network represented in Brazil and Portugal's proprietary topographic maps. This analysis will lead to both the optimization and reduction of management costs and a better and socially just planning system.

2. Drainage network datasets

The cartographic representation drainage network is used as the basis for research aimed at establishing cause-effect relationships between changes in land use, climate change and surface water availability (Tucker and Slingerland, 2010), the definition and delimitation of territorial management and aquifer units (da Rosa Filho et al., 2011), geologic studies and mapping (Geological Society of London, 2002; Zernitz, 1932), water resources planning, the delimitation of Environmental Protection Areas (EPA) and others.

The representation of the first-order streams (Jaeger et al., 2007) serves as a basis for the understanding of the genesis and structuring of the drainage network in the landscape (Moussa, 2009; Warntz, 1975) and to define morphometric parameters, like the Drainage Density (Dd) (Morisawa, 1957). This is because the first-order streams are sensitive to the interactions and modifications of the drainage network conditions (Pike et al., 2009). However, this segment presents positional and completeness errors, as well as hardly representing correctly the place of origin and the typology of the flow (intermittent or perennial) (Chorley and Dale, 1972; McCoy, 1969). Due to errors, the different drainage patterns that are conditioned by factors such as lithology, relief, and climate (Gardiner and Park, 1978) and should reflect the interaction between them, often are found in topographic maps associated to their boundaries (Fig. 1).

The reduced size, the presence of vegetation cover, and variations in the morphological pattern of relief (Montgomery and Dietrich, 1994), are examples of factors that interfere in the stream mapping process, reducing the accuracy observed in the maps, and in turn difficult to correctly define their tracing and typology (perennial and intermittent).

The same should not be observed in places where the rivers present dimensions compatible with the resolution of orbital and suborbital sensors and is not covered by vegetation (Schuch and Loch, 2011).

From the 1990s the process of mapping drainage networks has included techniques of mathematical morphology and algorithms for the mapping and simulation of the surface flows (Reddy et al., 2018; Shilpi, 2014; Zhang et al., 2017). These algorithms have been adopted for different uses, from automatically deriving drainage and catchment boundaries to mapping stream networks. These have supported improved the representation and assess the quality of existing maps (de Freitas, 2016; Martínez-Casasnovas and Stuiver, 1998; Vogt et al., 2003; Zhang et al., 2017).

Although potentially promising, these methodologies need more in depth studies for application on stream network mapping, because the results obtained often had their quality evaluated by land information from small areas (Passalacqua et al., 2010; Sangireddy et al., 2016), and when used to map large areas, the quality is often assessed by comparison with different algorithms (Reddy et al., 2018; Rueda et al., 2013), satellite images (Jiang et al., 2014) or pre-existing mappings (Chen et al., 2018; de Freitas, 2016; Schneider et al., 2017).

In order for these algorithms to be used to map a real stream network with its channels, headwater sources, perennial and intermittent flows, it is necessary to know how similar the extracted drainage network is to the in the field. In this sense, the comparison of the extracted drainage network with maps may not be adequate, as maps may present different and unquantified errors.

Without information about where head channels begin, which are

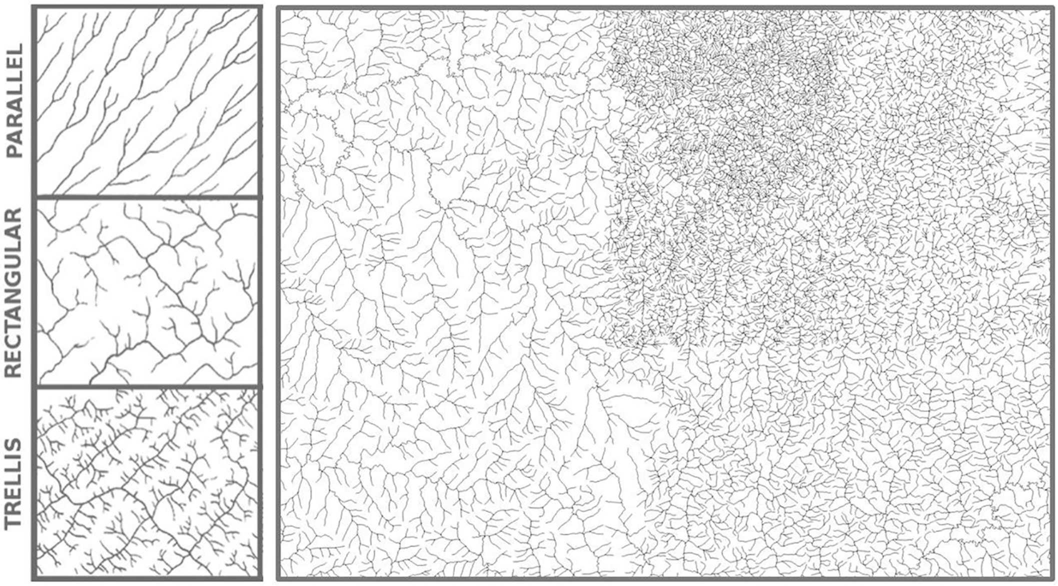

Fig. 1. Theoretic drainage patterns – left - associated geology and geomorphology (Arthur David Howard, 1967) and “real” patterns observed in maps (1:50,000), right.

intermittent and perennial streams in the real world, and the effects of the DEM in the network design, it is not possible to know how appropriate these algorithms are for application on a large-scale process of stream network mapping. Likewise, if it is better than traditional techniques.

The objective of this research is to characterize and quantify positional and completeness errors observed in the hydrographic dataset obtained by different methods and scales (i.e. photogrammetric restitution and automatic extraction from DEM). The completeness analysis only will consider the first-order stream.

This research used datasets from Portugal and Brazil (Paraná State) built using globally methodologies to make topographic maps in large and medium scales and are official data used in planning and research.

3. Material and methods

3.1. Datasets

This research used four hydrographic datasets: two from Paraná (Brazil), scales 1:10,000 and 1:50,000 (PR10K and PR50K); and two from Portugal, scales 1:25,000 and 1:50,000 (PT25K and PT50K).

These datasets are available with full territorial coverage, but the Paraná 1:10,000 dataset has only partial coverage. The booth 1:50,000 hydrographic dataset (PR50K and PT50K) was obtained by photogrammetric restitution and photo interpretation. Hydrographic datasets 1:10,000 and 1:25,000 (PR10K and PT25K) were obtained by automatic extraction from DEM, with final adjustments by photo interpretation.

The PR50K is part of Systematic Mapping of Brazil produced between 1950 and 2005. Due to their relevance, printed maps were compiled and vectorized generating the current official Unified Hydrographic Base of the State – BHU-PR (389 printed maps covering a territorial area approx. 198,000 km^2) (COPEL et al., 2011). The BHU-PR was officially approved by the National Water Agency (ANA) and by the Technical Chamber of Cartography and Geoprocessing of the State of Paraná (CTCG).

In BHU-PR, topology errors were adjusted and a partial update was made by the PARANACITY project in 2007 (https://www.paranacidade.org.br). However, no field surveys were considered to validate the mapped data, which caused completeness and positional errors already existing in the original dataset and resulting from the photo interpretation process to be transposed to the BHU-PR.

According to the Government of the State of Paraná, these data are essential for all "… *state planning processes. It is the basic information for the environment, energy generation, urban planning, registration of rural properties, agriculture, sanitation, geology, water resources management, among others*" (COPEL et al., 2011).

The PR10K base, dating from 2016, covers 2,134.56 km^2 of the Paraná area. This cartography was provided to the private BRADAR Industry SA by the State Department of the Environment and Water Resources of Paraná (SEMA). The DEM used to extract the hydrographic network was obtained by radar interferometry using the P band. According to the company report, the final map presents an RMSE value close to the accuracy limit allowed for this scale of representation. In addition, the dataset was topologically corrected.

The cartographic base of Portugal 1:50,000 is called M7810 and consists of 175 maps. It was produced by the General Directorate of the Territory and is based on Portugal Map at 1:10,000, orthophoto, military map from Portugal at 1:25,000, and geographical information from various entities. This database is made available in a raster format by DGT - General Directorate of the Territory (available at http://ows.dgterritorio.pt/wss/service/scartograficas-wms/guest?). The military map 1:25,000 was produced by the Geographic Institute of the Army (IGeoE), is called M888 and is composed of 633 maps (Continental Portugal). This dataset serves to support the operations of the Armed Forces, civil community, public services, and others, thus expanding its range of applications.

In Fig. 2 it is possible to see the mapping errors associated with the boundaries of the topographic maps. Different cartographic perspectives are clear in both the BHU-PR (1:50,000) and Portugal (1:25,000), resulting in map sheets with different degrees of data representation.

Two methods were used to assess completeness and positional quality. The first, concerning the completeness assessment (applied only to the first-order streams – perennial and intermittent) uses the methodology proposed by ISO 19157. This norm is the same used in cartographic regulation of Brazil and Portugal/EU. The second set of actions uses Buffer Overlay Statistical Method proposed by Tveite and Langaas (1999) to evaluate positional quality.

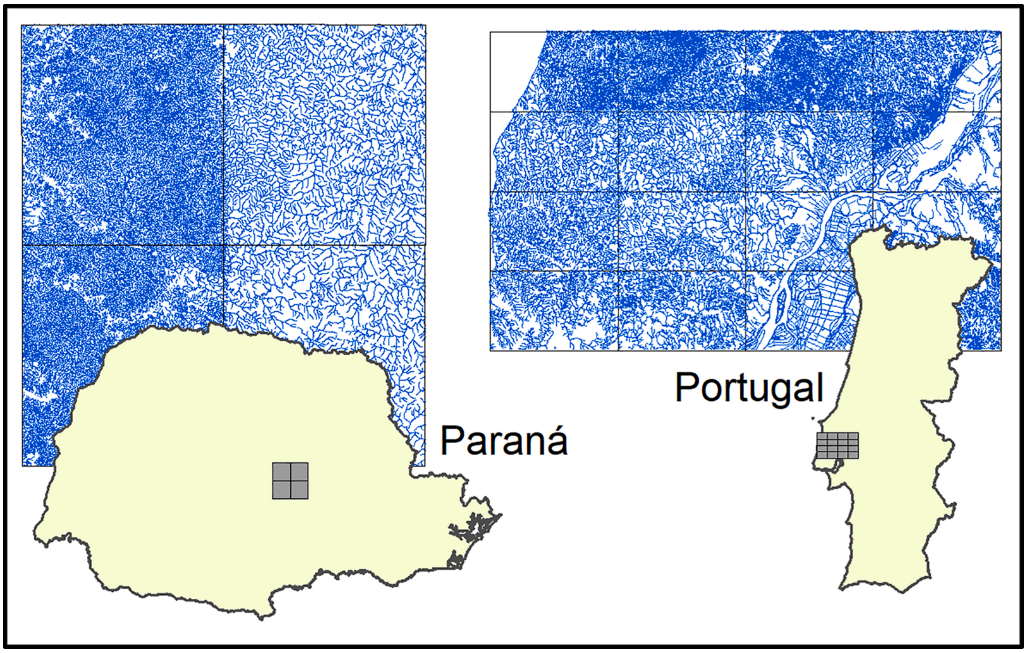

Fig. 2. Unified Hydrographic Base Datasets – PR (PR50K on the left and PT25K on the right). It is possible to observe the different drainage patterns associated with the limits of the Topographic Map Sheets.

3.2. The completeness analysis

The completeness analysis was divided into definition and selection of the sample, field inventory, and quantification and characterization of mapping errors. The selection of samples prioritized areas with an intersection of drainage with vicinal roads, preferably close to its bifurcation with the second-order stream (Fig. 3). This procedure minimizes errors related to positional accuracy, presents the possibility to identify omission error, and allows sampling of perennial and intermittent streams, because some of the perennial streams mapped are commission errors.

Samples were not collected in urban areas to avoid errors due to possible recent changes in land use, as well as on the banks of paved and high-traffic roads, to avoid the acquisition of samples in areas with significant changes in the local topography (landfill/cut), and data collection in areas of intense vehicular traffic due to safety.

The field inventory (stage 2) referenced field inventory methodologies proposed by National Resources Inventory (Resources, 2009) and IBGE (IBGE, 2013). The inventory consisted of the collection of georeferenced points with GNSS (Global Navigation Satellite System) equipment capable of tracking the GPS and GLONASS constellations. The points were collected with the support of the ORUXMAP© software, which stores the coordinates, date, and time and allows the acquisition of additional information such as routes, texts, and photos.

Field inventory was conducted only after a drought period of at least 15 days, with the objective of avoiding the mapping of ephemeral drainage channels resulting from recent pluviometric events.

4. Four kinds of points were observed in the field:

1. There is a first-order basin with an intermittent stream in the real world (code 0), the drainage basin has a similar form and area to the others with first-order perennial streams, and in the hydrography dataset there was a correct representation of it (dashed line or continuous blue line with kind of flow = intermittent, stored in the attribute table - code 0); or there is an intermittent first-order stream in the real world (code 0), the drainage basin has similar form and area to the others with first-order perennial streams, but in the hydrography dataset the stream was not represented (code 0) = right (code 00).
2. There is an intermittent first-order stream in the real world (code 0), the drainage basin has a similar form and area to the others with first-order perennial streams, but in the hydrography dataset the stream was represented like a first-order perennial stream (the continuous blue line (code 1)) and there isn't information about kind of flow = wrong (commission error - code 01).
3. There is a perennial first-order stream in the real world (code 1), the drainage basin has a similar form and area to the others with perennial first-order streams and in the hydrography dataset the stream was not represented (code 0) = wrong (omission error – code 10).
4. There is a perennial first-order stream in the real world (code 1), in the hydrography dataset the stream had been correctly represented (code 1) = right (code 11).

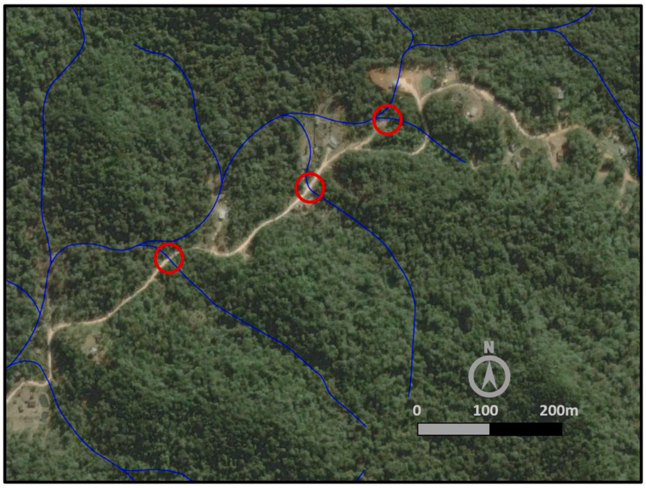

Fig. 3. Example of points chosen to field verification.

Fig. 4 depicts several kinds of stream representations. Types 1 and 2 were considered correctly mapped to this research (code 00), as observed in different datasets.

To reduce errors, streams with incipient water flow were discarded. The notion of incipient was obtained by comparing observed flows in different places and, whenever possible, by information collected from residents about the condition of the streams (intermittent or perennial).

The measurement of completeness (stage 3) was made using the proposal presented by ISO 19157 (ISO, 2013), which separates the analysis according to the type of error observed. In this sense, it evaluates independently the errors of commission (excess) and those of omission (absence). Commission errors are measured from the "percentage of excess items" analysis, which should not have been mapped on the scale of the map. Omission error is the percentage of "objects absent in the evaluated set, about the number of objects that should be present". In this case, the omission errors are calculated by observing the reference sample and the number of omitted objects.

The general analysis of completeness was conducted following methods proposed by de Souza and Sampaio (2018) to evaluate drainage representation quality at first-order streams, using the Total Concordance Index – TCI (Hellden and Stern, 1980). The TCI is calculated from the division of the total hits on the total number of samples.

4.1. The relative positional accuracy

The relative accuracy assessment measures the positional quality of two data sets. For that, by statistical process, the distance below which 90 % of the data is set apart from each other is calculated.

For the analysis of the relative positional accuracy, the Buffer Overlay Statistic Method (Tveite and Langaas, 1999) was used by calculating the distance that sets apart the points that make up the lines present in the referred cartographic bases (homologous lines). This methodology has advantages over other positional quality analysis methods for linear files (dos Santos et al., 2016) and allows the comparison of products at different scales and levels of generalization. In particular, this methodology relativizes positional errors derived from the process of data acquisition, digitization, and displacements related to the altimetric model used in the aerophotogrammetric restitution or automatic extraction process.

According to Tveite and Langaas (1999), to apply this method all lines must be represented in both datasets. In this sense, five steps were applied:

1. Identification of homologous lines (since they are two different scales, the comparison must be made only between lines mapped in the two databases);
2. Vector adjustment and topological problems correction (Fig. 5);
3. Definition of both width and number of buffers;
4. Application of overlay operations, iterative processes, calculations, and result normalization;
5. Identification of functions describing the relationship between mean displacement and relative quality.

The vector and topological adjustments are necessary to make it possible to apply the methodology. Vectorial and topological

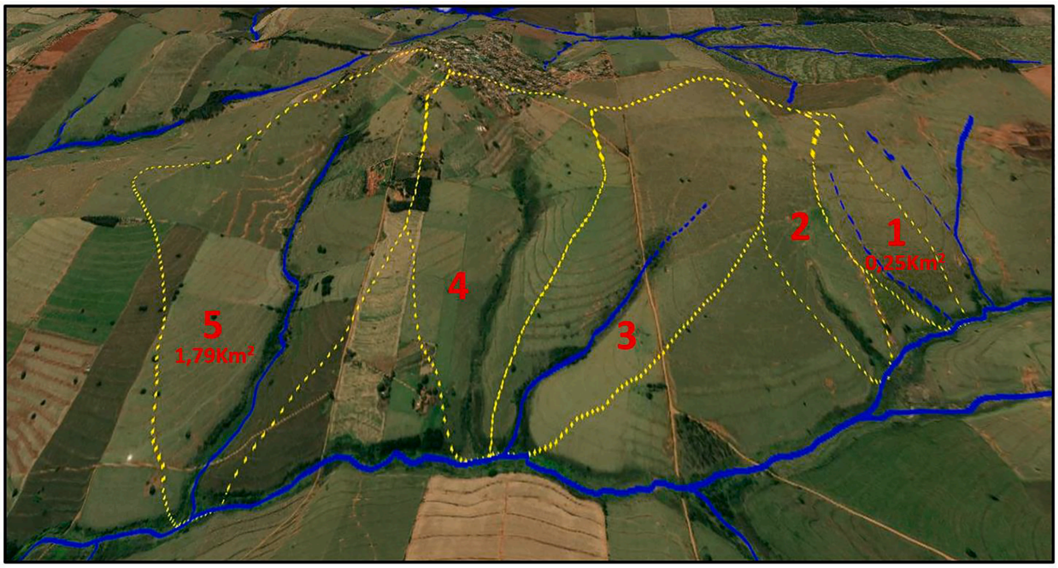

Fig. 4. Example of first-order basin and streams available to completeness (PR50K).

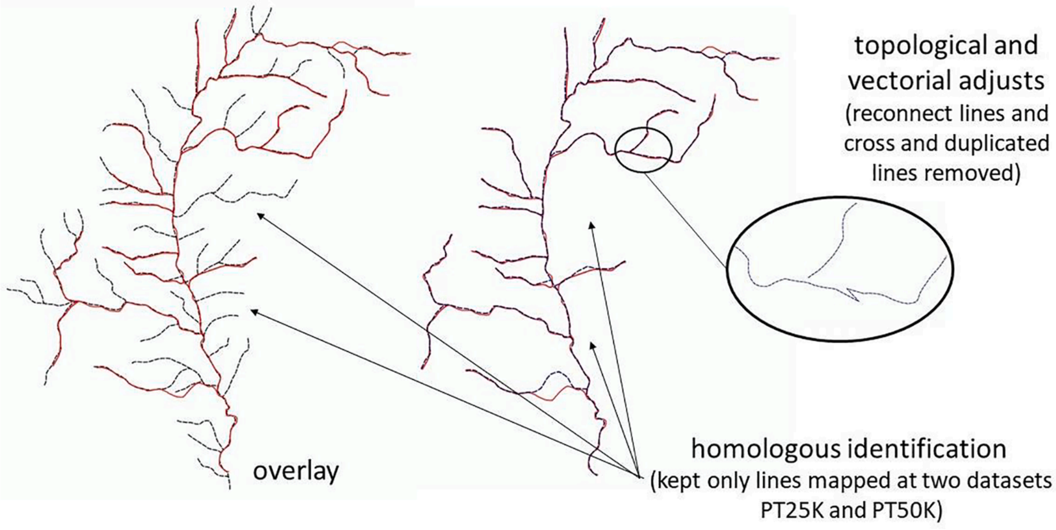

Fig. 5. Steps employed in positional quality assessment (example taken from PT25K and PT50K). Correction of topological and line tracing problems.

adjustments clean cross lines, disconnect lines, and remove duplicates. Like all proceedings, this affects the results too, but by minimizing errors.

The topological adjustment procedures were only applied to Portuguese cartography since the Paraná datasets were already corrected. For the pre-tests, four buffers of 10 m, 20 m, 50 m, and 100 m were defined. The normalization of the results followed the procedure proposed by Tveite and Langaas (1999) as:

$$DE_i = \frac{\pi}{2}\frac{2bs_i Area(XB_{-i} \cap QB_i)}{Area(XB_i)} = \pi bs_i \frac{Area(XB_{-i} \cap QB_i)}{Area(XB_i)} \quad (1)$$

The average discrepancy between the data sets was estimated for 90 % of the data, which is obtained from the relationship between the buffer width and the relative coverage of the data layers.

5. Results

5.1. Completeness analysis

According to ISO 19157 (ISO, 2013), the definition of the sample size for completeness checking should be made considering the size of the original data (batch sampling). For each database, it was estimated that there were more than 500,000 first-order streams, which resulted in a sample of 1250 points (first-order) for field verification.

In Portugal's fieldwork, 529 points were collected in September 2019, covering 23 and 16 map sheets of the 1:25,000 and 1:50,000 official topographic maps, respectively. These points allowed determination the drainage typology (perennial or intermittent) of 9283 mapped first-order streams. This is because it was observed in the field that many of the intersected drainage channels, although not previously selected because they did not correspond to first-order streams, had intermittent drainage.

In these cases, the ratio between the number of field visit points and data confirmed in the cartographic base (about first-order drainage) was higher than the 1:1 ratio, i.e., one field validation point for each cartographic base validation point (Fig. 6).

6. Completeness analysis: Portugal datasets

As mentioned earlier, the cartographic representations of

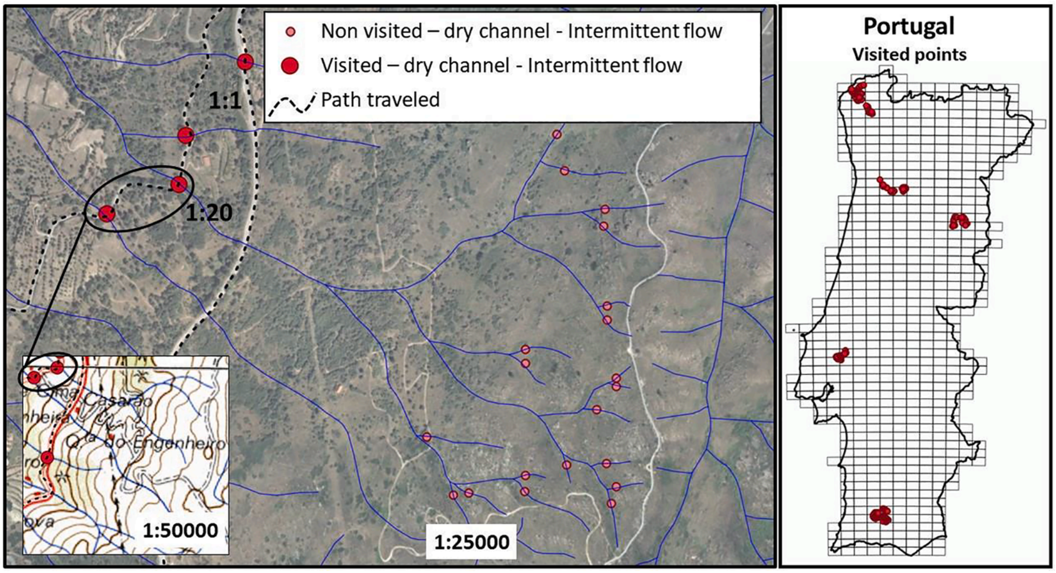

Fig. 6. Example of 1:1 and 1:20 relationship between field and database validated points. All points were checked against the two cartographic bases PT25K and PT50K.

hydrography in the Portuguese databases are built upon different methodologies, namely aerophotogrammetric restitution (PT50K) and automatic extraction (PT25K). In the automatic extraction process, the most important parameter used is the area size or threshold area (Hancock and Evans, 2006; Rokni et al., 2015), which defines the position from which the drainage channel must be represented (blue line).

In the production of the PT25K dataset, navigable and floating watercourses are 30 m wide, and non-navigable and floating watercourses, namely gullies and discontinuous flow streams, are 10 m wide (Law 54/2005, art. 11.°; Law 58/2005, art. 4.° point gg). The streams can be of first-order (>6 km length), second-order (1–6 km length), or third-order (<500 m). The threshold area value was defined to allow the cartographic representation of water lines in all identifiable drainage channels in the DEM, regardless of the existence of perennial water flow.

The adoption of a reduced threshold area value resulted in a large number of first-order stream representations and affected the results of the completeness analysis. By this, in the PT25K dataset omission errors were virtually eliminated (omission errors = 0.01 %), and 9,254 first-order streams mapped as perennial don't exist in the real world (commission error = 99.7 %). Only one unmapped perennial first-order was found in fieldwork.

These omission and commission error values are directly related to the automatic extraction methodology and the threshold area value used. This problem had already been pointed out by Martz and Garbrecht (1995), who stated that automatic extraction with the adoption of a single value to represent the drainage network in large areas generates an excess of perennial first-order streams (misrepresentation of the drainage networks). This is because, according to the authors, different geomorphic areas need different values.

Regarding the PT50K dataset, the fieldwork indicated the omission of 8 and the commission of 701 perennial first-order streams (omission error = 0.1 % and commission error = 7.6 %). In this case, although the

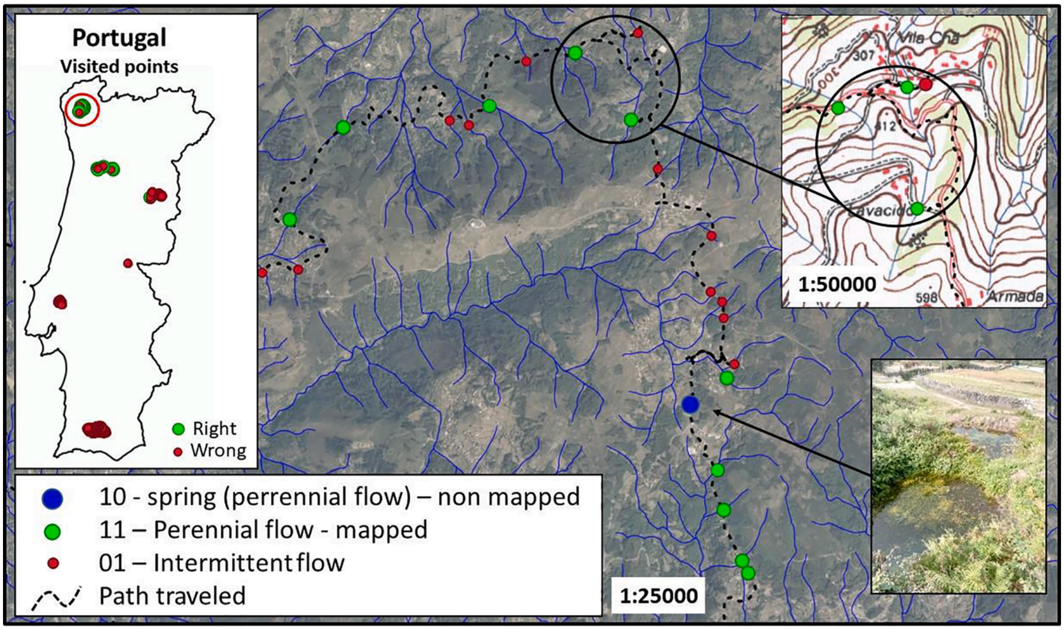

Fig. 7. Spring with unmapped perennial drainage at 1: 25,000 scale (coord. λ = −8.47957°, φ = 41.73030°, EPSG 4326) – map sheet 42 (PR25K)/5B (PR50K).

PT50K mapping employs lower spatial resolution and higher generalized images and stereo models, the photogrammetric restitution resulted in a more accurate representation for the first-order streams.

Spatial distribution of commission errors in the PT25K and PT50K datasets, one can observe the presence of differentiated patterns. In the northern and central-northern regions of Portugal, there is a greater proportionality between correct validations and commission errors, with only one omission error detected. In the central, central-western, and southern regions, there is a predominance of commission errors (Fig. 7 and Fig. 8).

As a reminder of the codes: first number code is the field reality (0 intermittent – 1 perennial), second number code is the map information (0 non-represented – 1 represented). So, 01 is commission error, 10 is omission error, and 11 is right representation.

In the southern most sampled map sheets of Portugal, sheets number 570, 571, 578 (Fig. 9), and 579 of base PR25K, which correspond to sheet 49B of the PT50K map, showed 100 % of commission errors.

In calculating the total completeness according to TCI, i.e., considering perennial and intermittent first-order stream hits about the total points sampled, we observed that the 1:50,000 (PT50K) cartographic maps represent the best type of observed flow in the Portuguese river network (TCI = 92.4 %), while the PT25K dataset has a TCI of 0.3 % (Table 1).

7. Completeness analysis: Paraná dataset (PR50K)

In Paraná, more than 1500 field points were visited (from 2016 to 2018), located in 54 map sheets 1:50,000 (13.8 %). Of these, 985 points were considered viable for completeness analysis. This reduction in the sample was due to the uncertainties in determining the locally observed flow conditions. For this reason, it was not possible to quantify the completeness errors of the 1:10,000 base (PR10K). However, it was clear that it also has completeness errors.

The most recurring completeness error observed in the PR50K database was the commission error, with 40.1 % of the mapped perennial first-order stream not matching the one observed in the real world (Table 2). Errors also have distinct spatial patterns; while in the south-central region of the State there is a predominance of omission errors (Fig. 10), in the north, commission errors are recurrent (Fig. 11).

In the northern region of Paraná is the area corresponding to the topographic map MI-2726–4 (Fig. 12) that presented the lowest TCI value for the first-order streams (TCI = 5.88 % - omission error = 0.00 % and commission error = 94.12 %). The highest TCI value for the first-order streams was observed in chart MI-2832–2, which is located in the south-central region (TCI = 89.09 % - omission error = 10.91 % and commission error = 0.00 %).

Considering only the six map sheets with the largest sample size (over 40), it was observed that there is a predominance of commission errors in the PR50K dataset and that, on average, the TCI value is 52 %.

When comparing the completeness values for the 1:50,000 datasets from Portugal and Paraná (Table 3), some differences in commission errors (PT50K = 7.6 % and PR50K = 40.1 %) and TCI (PT50K = 92.4 % and PR50K = 52.8 %) stand out. This fact may be associated with local environmental characteristics, the mapping process, and mainly, the completeness assessment methodology applied to the first-order stream analysis. This is because field verification considered both intermittent and perennial flows and because of the fieldwork, we obtained a larger number of samples on intermittent first-order streams in Portugal. This favoured the TCI result observed in the PT50K dataset.

7.1. Relative positional accuracy analysis

To assess the relative positional quality, 77.26 km of the Portuguese river network (PT25K and PT50K) and 106.61 km of Paraná (PR10K and PR50K) were analysed. The drainage sections were randomly selected from the point release on the databases. As a result, it was observed that in Portugal the estimated average displacement (AD) for 90 % of the lines was 93.78 m, and in Paraná, 582.85 m.

These values are much higher than the expected positional error values for these scales. According to FGDC (1998), in the 1:10,000, 1:25,000, and 1:50,000 scales, the expected RMSE limit values are, respectively, 2.5 m, 7.5 m, and 15 m, and of 2.8 m, 4.25 m, and 14 m, considering the cartographic precision values used in Brazil (DSG - Diretoria de Serviço Geográfico, 2016).

In Portugal, a mean squared error (MSE) of the altimetry of the contour lines and other three-dimensional linear elements is not permissible above 1.70 m. The representative sample of points of the linear elements, when confronted with values obtained by photogrammetric observations of high precision, cannot differ by more than 2.75 m in 90 % of these points. It is considered correct that the streamline, when driven to its true position, has a horizontal displacement less than or equal to the greater of the values of 0.5 mm or 1/10 of the horizontal distance between curves, maintaining the referred vertical tolerance.

Topographic cartography considers two levels of detail – level 1

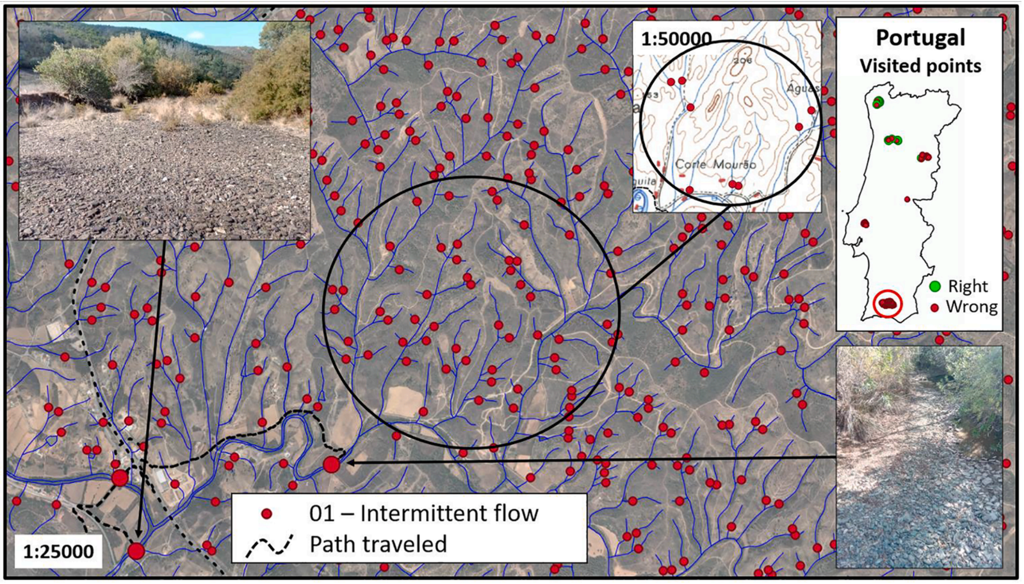

Fig. 8. The predominance of commission errors in southern Portugal. Errors observed in PT25K and PT50K bases - map sheet 578 (PT25K) / 49B (PT50K).

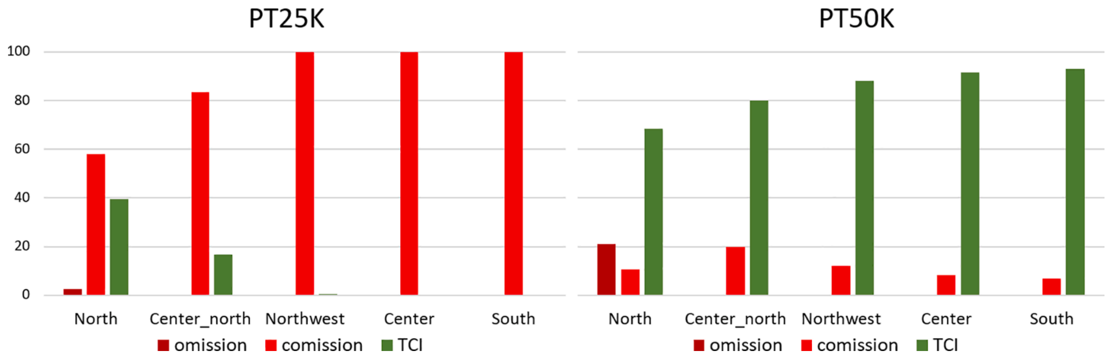

Fig. 9. Spatial patterns of completeness errors in Portuguese bases (PR25K and PR50K).

Table 1
Completeness analysis for Portugal datasets.

Scale	Portugal: completeness		
	Omission	Commission	TCI
1:25,000	0.01	99.7	0.3
1:50,000	0.1	7.6	92.4

Table 2
Completeness analysis for Paraná dataset.

Scale	Paraná: completeness		
	Omission	Commission	TCI
1:50,000	0.071	0.401	0.528

(NdD1), for detailed cartographic representations of circumscribed areas, and level of detail 2 (NdD2), provided for the full representation of the national territory. Points of vector information are randomly selected. Those coordinates are measured on the ground using satellite positioning systems and the SERVIR network (Virtual GNSS Reference Station System). These coordinates are compared with the coordinates obtained from the geographic information acquired by stereo-photogrammetric methods and the corresponding MSE is calculated. To be accepted, the information must have an MSE lower than 5 m both in planimetry and altimetry.

Considering that the maximum expected distance for both the datasets is computed from the displacement of the lines in opposite directions, i.e., is equal to the sum of the RMSE values defined for the analysed scales, it was observed that in Portugal (PT25K and PT50K) the registered MD was 4.1x higher than expected, and in Paraná (PR10K and PR50K) 33.3x higher.

In particular, the AD value detected in the analysis of Paraná bases (AD = 582.85 m) is mainly associated with the difference between the methodologies used for data acquisition. This is because, besides being distinct, the DEM used for automatic drainage extraction (PR10K) was obtained by RADAR interferometry in the P band, which allows the acquisition of data directly on the ground (Hoja et al., 2006; Lavalle et al., 2009). In this sense, it should be considered that in Paraná the area related to the PR10K dataset is in a rugged relief area with practically 100 % of the area covered by dense Atlantic Forest vegetation. Pereira et al. (2019) observed that the presence of dense vegetation cover affects the position and completeness of automatically extracted drainage networks, as well as the choice of DSM/DEM especially affects the extension of first-order streams.

The same was not observed in Portugal, since the models are based on the aerophotogrammetric restitution process, and the DEM used by the PR25K base is derived from the stereo model's level curves. However, although smaller, the displacement observed in Portugal is also higher than expected for the analysed scales.

In Fig. 13 it is possible to observe that the differences in the data

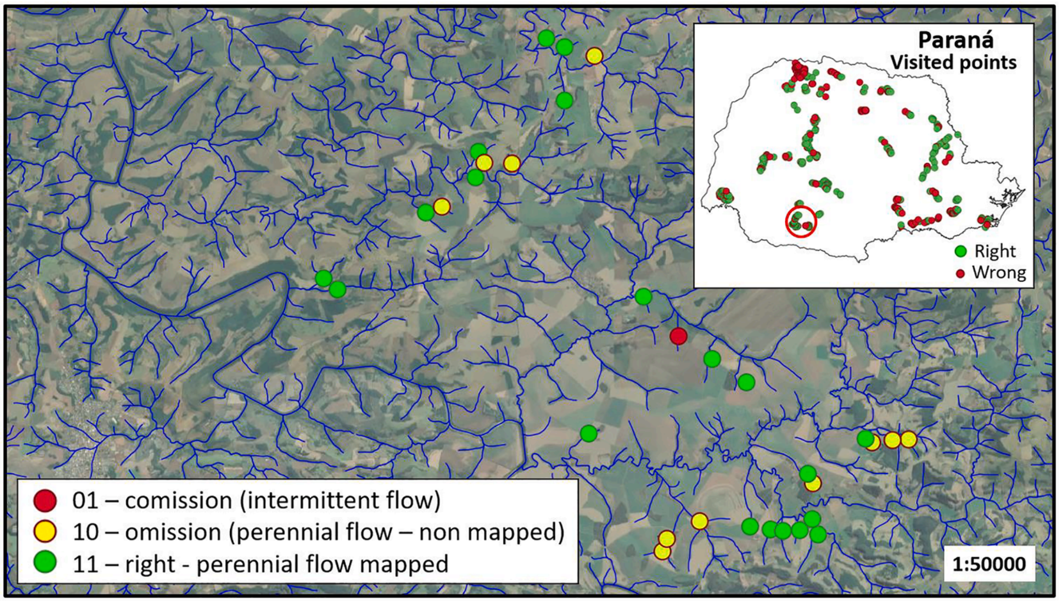

Fig. 10. Commission and omission errors in southern Paraná (PR50K).

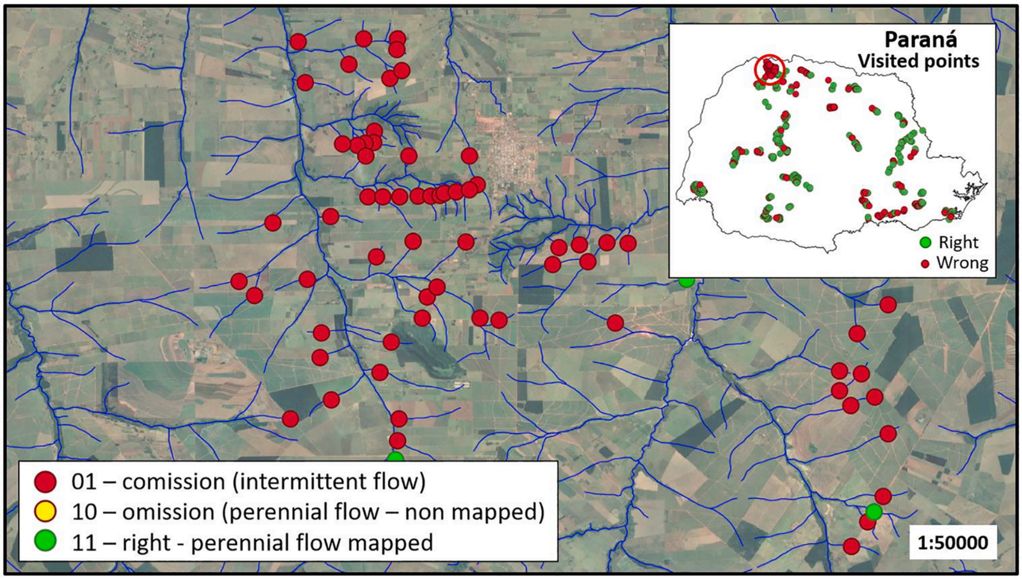

Fig. 11. Topographic Map MI – 27,264 – Northern Paraná – Completeness errors (commission and omission).

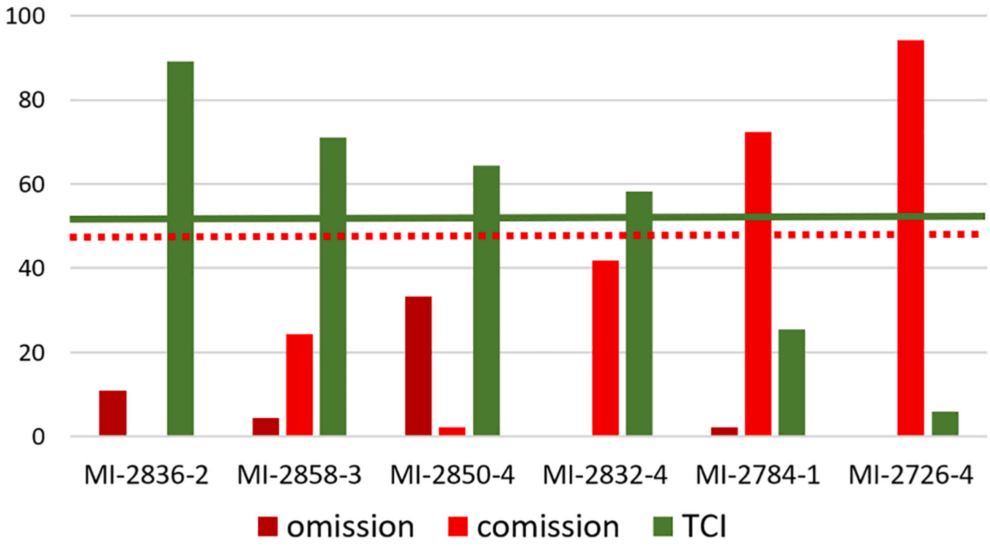

Fig. 12. Types of completeness and TCI errors observed in PR50K. Green line: TCI average, Red line (dashed): commission error average. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Completeness analysis for Portugal and Paraná datasets.

Completeness	Portugal (PT50K)	Paraná (PR50K)
Omission	0.001	0.071
Commission	0.076	0.401
TCI	0.924	0.528

collection processes affected the extension and position, mainly of the first-order stream, and contrary to what is expected, the 1:10,000 hydrographic base shows a higher level of generalization than the 1:50,000 one.

Also, analysing Fig. 13 A and A' points, it's obvious that the representations of the hydrographic network display different flow directions locally and consequently correspond to watersheds with distinct contours and coverage areas.

In B it's possible to detect places that correspond to water dividers (interfluvial) in one dataset and at the same time to valley bottoms in another one. Also, in C it's possible to observe places where the drainage channels are coincident in both bases (PR10K and PR50K).

Comparing the PT25K and PT50K bases, the same positional accuracy problems as the PR10K and PR50K are observed, but to a lesser extent. Fig. 14 shows examples of divergences in defining the extent and origin of the first-order stream (Fig. 14 – A and B) as well as in the direction of flow (Fig. 14 - B and C).

Another factor regarding positional accuracy to consider is the size of the first-order stream. Based on PR10K, the minimum mapping length of 100 m (BRADAR Industria S.A., 2016) was adopted as a criterion for the mapping, despite the current standard in Brazil ET-AGDV (DSG – Diretoria do Serviço Geográfico, 2016) to define the value of 200 m for this scale. In the PT25K dataset, the criterion adopted was the representation of all water lines and, in the PR50K and PT50K, no selective omission criteria were defined (fact related to the date and process of preparation of the datasets). Thus, the smaller scale databases (1:25,000 and 1:50,000) are those with smaller first-order streams (<100 m). This shows that on the researched basis the extension of the first-order stream

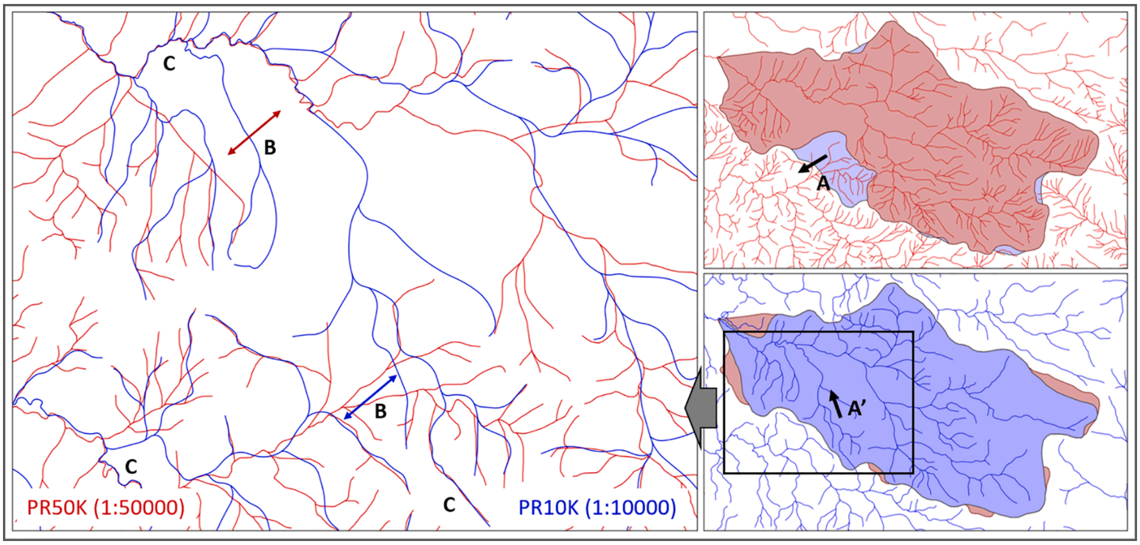

Fig. 13. Divergences between representations of the hydrographic network in the Paraná databases (PR10K and PR50K). The lines and polygons in red correspond to the PR50K base hydrograph and watershed and in blue to the PR10K base. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

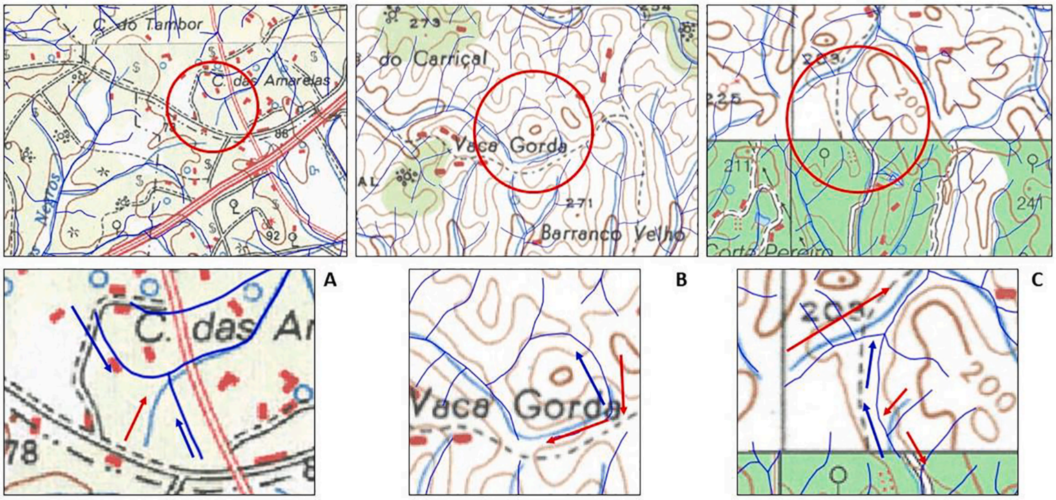

Fig. 14. Portugal datasets and similar errors observed in Paraná datasets. PT50K (here used in raster format and red arrows) and PT25K (overlay in vectorial format and blue arrows), and divergence on position, extend and flow directions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

is not associated with the field reality or the scale of elaboration of the cartographic products.

It should also be noted that the PR10K base has, in some places, the first-order stream starting points at distances of <20 m of each other. Due to the observed distance, it is possible to state that this fact is not associated with the threshold area value used in the automatic extraction, but with the final editing process applied to the database (Fig. 15).

The distance separating the starting points of the first-order stream does not correspond to the threshold area values observed in other works such as Chen et al. (2018), Reddy et al. (2018), and Schneider et al. (2017), which employ larger contribution areas for drainage network extraction and, consequently, would work at greater distances.

8. Summary and conclusion

In the PT25K, PT50K and PR50K databases, commission errors predominate for first-order streams, but with distinct spatial patterns, possibly associated with relief morphology and precipitation. In Portugal, the evaluated bases indicate that the photo interpretation mapping process resulted in a better representation of the typology of water flows observed in the first-order stream.

Depending on the map, scale, and methodology, the completeness errors for the first-order streams can reach over 99 % and the average displacement (AD) of the lines may present a positional error 4x higher than expected for the analysed scales. In other words, the quality parameters associated with scale (such as positional quality and completeness) do not apply to the cartographic representation of first-order rivers.

Research has shown that completeness and positional errors may be present at different mapping locations and scales and may promote changes in the extent and direction of mapped watercourses, drainage density and, consequently, the size of the watersheds. These errors indicate that the cartographic bases should be used with caution to evaluate the effectiveness of the algorithms employed in automatic extraction processes and to validate the extracted drainage networks.

The problems observed in the research indicate that the definition

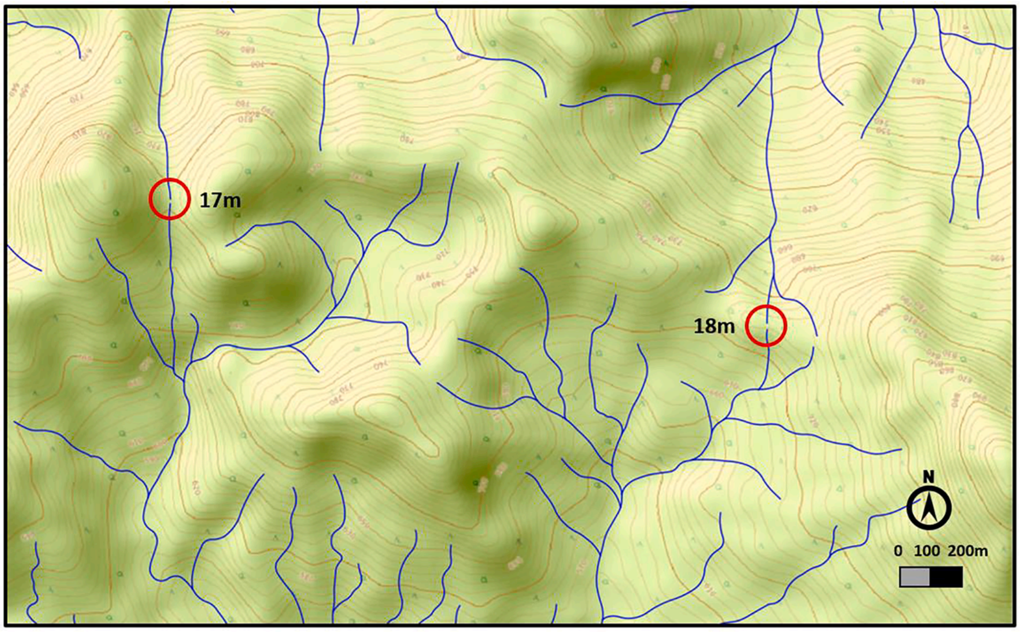

Fig. 15. Proximity to first-order stream origin points.

and delimitation of PPA around springs and watercourses through cartographic bases may result in the creation of protected areas where the presence of springs with perennial watercourses is not confirmed. Moreover, even when observing perennial flow in the real world, the PPA delimited in the database may present positional errors higher than the allowed for the scale in use and, consequently, not correspond to the area to be protected.

It is also possible to state that the observed errors will affect the digital elevation models that incorporate the representation of the drainage network in its elaboration. As well, the cartographic representation of the drainage network is strongly conditioned by the elevation model employed in its construction, either via restitution from stereo models or from automatic extraction.

The research also showed that the adoption of a single threshold area value for automatic extraction of the drainage network on digital elevation models should be avoided, as it results in omission, commission and positional errors.

Both photo interpretation and automatic extraction demand methodological improvement with emphasis on the representation of the first-order drainage network. The incorporation of environmental variables, such as precipitation and morphology, for automatic extraction and the adoption of local keys/standards for mapping based on photo interpretation can contribute to reducing errors. Finally, it was observed that other parameters involved in the mapping process, such as final editing, also affect the density and extent of the hydrographic network more than expected errors to these scales.

This shows that after applying all the final editing procedures (such as generalization) there is a need to check the final quality of the cartographic product, especially concerning the representation of first-order drainage.

Because they are official cartography products, especially products developed directly in digital media (PT25K and PR10K), they should give information about the typology of flows, positional quality, and completeness, allowing the correct representation and use of data. However, this information is not present in the bases studied.

As a future stage of the research, the data obtained in the field will be used to model the influence of morphology and climate on the dimension of first-order drainage basins with perennial rivers.

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CRediT authorship contribution statement

Tony Vinicius Moreira Sampaio: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Project administration, Funding acquisition. **Jorge Rocha:** Methodology, Validation, Resources, Supervision, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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