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Research Article

Assessing Completeness and Classification Accuracy Errors in Topographic Mapping of Porto Alegre

Avaliação de Erros de Completude e de Acurácia de Classificação no Mapeamento Topográfico de Porto Alegre

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Abstract: Considering the importance of assessing semantic quality in topographic maps, this paper presents a methodology for the identification and quantification of completeness and classification accuracy errors of a select subset of geographical information represented on the topographic maps of the municipality of Porto Alegre. We performed the identification of errors through visual analysis, using orthophotos as reference data and the topographic maps as test data. We analyzed 16 feature classes from the Transportation System and Urban Structure categories, quantified the errors, and created thematic maps to represent their spatial distribution. In total, we identified 1,653,673 features across these categories and found 2,080 errors, 1,845 omission errors, 91 commission errors, and 144 classification accuracy errors. These represent 0.111%, 0.005%, and 0.009% of the total features, respectively, indicating that the topographic mapping demonstrates adequate semantic quality when evaluated based on the analyzed quality parameters and a maximum error threshold of 2.5%.

Keywords: Topographic Mapping; Semantic Quality; Geospatial Data Quality.

Resumo: Considerando a importância de avaliar a qualidade semântica em mapas topográficos, este trabalho apresenta a metodologia utilizada na identificação e na quantificação de erros de completude e de acurácia de classificação das informações geográficas representadas nos mapas topográficos do município de Porto Alegre. A identificação dos erros foi realizada por meio de análise visual, utilizando ortofotos como dados de referência e os mapas topográficos como dados de teste. Foram analisadas 16 classes de feições pertencentes às categorias Sistema de Transporte e Estrutura Urbana, quantificados os erros e elaborados mapas temáticos para representar sua distribuição espacial. No total, foram identificadas 1.653.673 feições e encontrados 2.080 erros, sendo 1.845 erros de omissão, 91 erros de comissão e 144 erros de acurácia de classificação. Esses valores correspondem a 0,111%, 0,005% e 0,009% do total de feições, respectivamente, e indicam que o mapeamento topográfico apresenta qualidade semântica adequada, no que se refere aos parâmetros de qualidade analisados e considerando um erro máximo de 2,5%.

Palavras-chave: Mapeamento Topográfico; Qualidade Semântica; Qualidade de Dados Geoespaciais.

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1. Introduction

Topographic mapping provides the basis for many activities such as urban planning, territorial management, and engineering projects. This highlights the importance of continued research on the methodologies of analysis and determination of quality criteria.

Recent advances in geoinformation science have increased the demand for spatial information. These advances have enabled new forms of visualization and use of cartographic information, such as interactive displays, free software, smartphones for data collection and mapping, and the free availability of spatial data. This has promoted the production of cartographic products and expanded the use of geospatial data. However, users and producers are not always experts. Galo & Camargo (1994) assert that the popularization of spatial information led to the need for standardizing the generated products and assessing the quality of these products.

It is important to assess the quality of spatial data, since positional, temporal, or thematic quality may have been neglected during spatial data analysis or production (Galo & Camargo, 1994; Santos 2010; Lunardi *et al.*, 2012; Hecht *et al.*, 2013). To produce a high-quality cartographic product, it is necessary to follow standards and technical specifications to meet user's needs.

Many countries and institutions have developed standards that encompass the assessment of positional and semantic accuracy of cartographic products. Brazil has established several standards and technical specifications regarding geospatial data quality, such as Decree Nº 89,817, the Technical Specification for the Acquisition of Vector Geospatial Data (ET-ADGV), the Technical Specification for Geospatial Data Quality Control (ET-CQDG), and the Technical Specification for the Structuring of Vector Geospatial Data (ET-EDGV). Large-scale topographic maps (1:1,000, 1:2,000, and 1:10,000) were not covered by the national regulations until 2017 with the ET-EDGV version 3.0.

In 1995, the Commission on Spatial Data Quality of the International Cartographic Association (ICA) published the document Elements of Spatial Data Quality (Guptill & Morrison, 1995), which established criteria and methodology for assessing the quality of geospatial datasets. The quality parameters were lineage, positional accuracy, attribute accuracy (integrity), completeness, logical consistency, semantic accuracy, and temporal accuracy. The International Organization for Standardization (ISO) published ISO 19157:2013 standard, which updated and established parameters for characterizing the positional and semantic quality of geospatial data. This set of parameters includes completeness, logical consistency, positional accuracy, thematic accuracy, temporal accuracy, and metaquality (ISO, 2013). ISO 19157:2013 served as the basis for the development of the ET-CQDG (DSG, 2016) and the Technical Manual for Geospatial Data Quality Assessment (IBGE, 2019). ISO published a new version of this standard, ISO 19157-1:2023 (ISO, 2023), in 2023. However, the changes introduced in this version do not affect the topics addressed in this work.

Given the complexity of data quality assessment, this study evaluated only the completeness and classification accuracy quality elements. Completeness refers to the absence (omission) or excess (commission) of features in the map, according to the map scale (Östman, 1997; ISO, 2013; DSG, 2016; IBGE, 2019; ISO, 2023). Omission occurs when a feature that should be represented is omitted, and commission occurs when a feature that should not be represented is included in the map. Figure 1 illustrates omission errors in the Buildings class, whereas Figure 2 illustrates a commission error in the same class, in which six awnings were mapped and classified as Buildings. According to the product standards and specifications, temporary roofing structures (e.g., canvas, nylon, or mesh coverings) should not be represented (PMPA, 2011). Thematic accuracy evaluates the correctness of the attributes of mapped features. It comprises accuracy of non-quantitative attributes, accuracy of quantitative attributes, and classification accuracy (ISO, 2013; DSG, 2016; IBGE, 2019; ISO, 2023). Classification accuracy errors occur when the class assigned to a feature or its attributes does not correspond to the reference data. Figure 3 shows a classification accuracy error in which docks and piers were classified as Bridges and Viaducts. According to the product specifications, these features should have been classified as Stairs and Ramps.

Figure 1. Omission errors in the Buildings class.

Figura 1. Erros de omissão na classe Edificações.

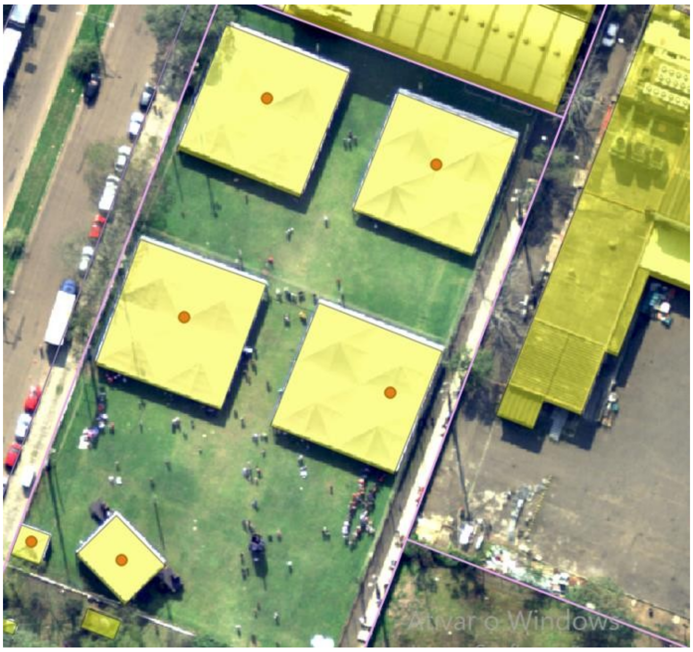

Figure 2. Commission errors in the Buildings class.

Figura 2. Erros de comissão na classe Edificações.

Figure 3. Classification accuracy errors.

Figura 3. Erros de acurácia de classificação.

This paper presents a methodology for identifying and quantifying completeness and classification accuracy errors in a selected subset of geographic information represented on topographic maps of the municipality of Porto Alegre at a scale of 1:1,000. We evaluated the occurrence of these errors using the direct evaluation method (ISO, 2013; ISO, 2023), in which test data are compared with reference data, as commonly applied in remote sensing (Van Oort, 2004) and volunteered geographic information (VGI) (Haklay, 2010; Dorn et al., 2015) studies. We used very high-resolution orthophotos as the reference data. The quality assessment was based on the error rate, considering a maximum error threshold of 2.5%.

2. Materials and Methods

To achieve the objective of this study, we followed a methodological workflow that included data selection, definition of the study area, identification of completeness and classification accuracy errors in topographic maps, and the quantification and mapping of these errors. We used QGIS version 3.8.1 (Zürich) for the analyses. Figure 4 illustrates the methodological workflow.

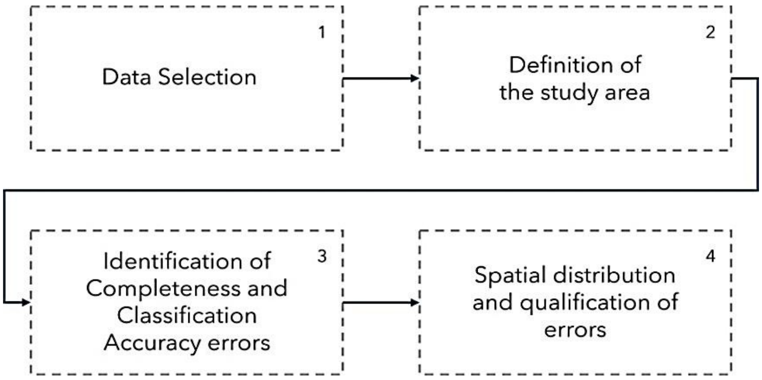

Figure 4. Methodological workflow.

Figura 4. Etapas da metodologia.

2.1 Data Selection

Identifying and quantifying completeness and classification accuracy requires reference and test data that can be compared. We used very high-resolution orthophotos as the reference data and the municipality's topographic mapping as the test data. The orthophotos have a spatial resolution of 12.5 cm, and the topographic maps are at a scale of 1:1,000. These data were provided by the Municipality of Porto Alegre (Portuguese: Prefeitura Municipal de Porto Alegre, PMPA). The orthophotos were derived from the aerial photogrammetric survey carried out in 2010, and the topographic maps were produced through the photogrammetric restitution of the same photographs taken that year.

Consistent with the concept that quality refers to the degree to which a product complies with established specifications and meets user requirements, we adopted the standards and specifications defined in the Planning Report for the Development of the Cartographic Base – Digital Topographic Mapping of Porto Alegre (PMPA, 2011). According to this document, the geospatial information represented on the maps is organized into nine general categories: Transportation System, Energy, Hydrography, Vegetation, Mining, Urban Structure, Elevation, Reference Points, and Boundaries. For the analysis, we chose the categories Transportation System and Urban Structure. This is because they encompass the largest number of features, have the greatest extent of mapped areas, and contain features that are easily identified in the orthophotos. We analyzed all the features of these categories. Table 1 lists the feature classes in the Transportation System and Urban Structure categories.

Table 1. Feature classes in the Transportation System and Urban Structure categories

Tabela 1. Classes de feições das categorias Sistema de Transporte e Estrutura Urbana

Transportation System	Urban Structure
Streets and Alleys	Buildings
Curbs	Squares and Parks
Median Strips, Roundabouts, and Shoulders	Fences and Walls
Blocks	Urban Lots
Railways	Sports Courts and Soccer Fields
Bridges and Viaducts	Interior Parks
Footbridges	
Stairs and Ramps	
Airport and Approach Cone	
Bus Stops and Bus Terminals	

2.2 Study Area

To verify the feasibility of conducting this study, we initially selected a pilot area comprising two orthophotos. The orthophotos were selected based on the presence of all feature classes in the selected categories, as well as the occurrence of completeness and classification accuracy errors.

Following this preliminary analysis, we extended the study area to encompass the entire municipality (Fig. 5), as the proposed methodology proved to be suitable. According to the 2022 Demographic Census conducted by the Brazilian Institute of Geography and Statistics (IBGE), Porto Alegre covers a total area of 495.98 km² and has a population of 1,332,845 inhabitants (IBGE, 2022).

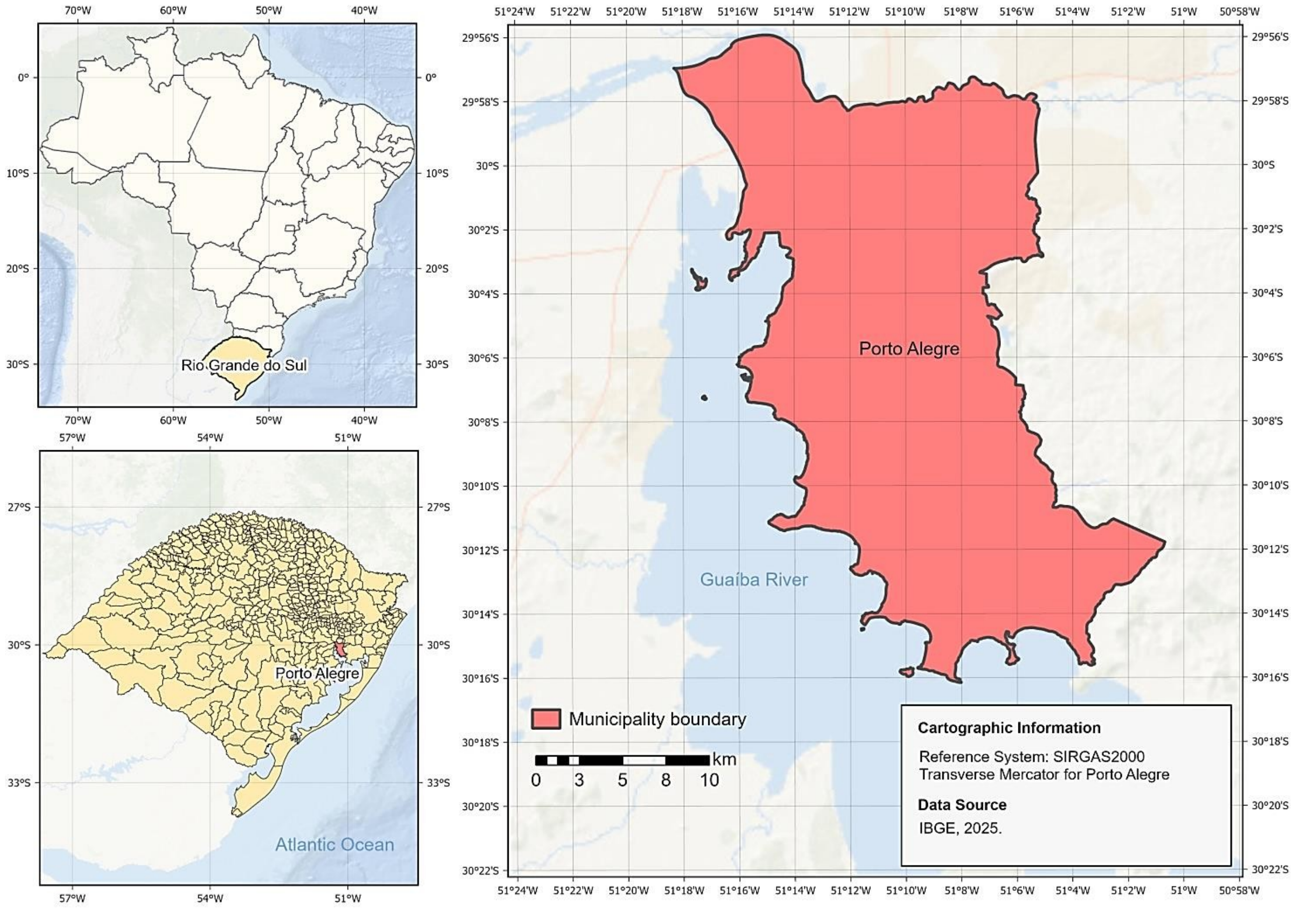

Figure 5. Study area.

Figura 5. Área de estudo.

2.3 Identification of Completeness and Classification Accuracy Errors

We identified completeness and classification accuracy errors through a complete visual inspection of the dataset, using orthophotos as the reference data and the topographic mapping as the test data. First, we created a separate layer for each type of error. We then overlaid the map features, in shapefile format, onto the orthophotos. We also used the IBGE Statistical Grid (IBGE, 2016a) to minimize errors during the visual inspection. The grid consists of 200 × 200 m cells aligned in the east–west and north–south directions. This grid system ensures continuous visual inspection regardless of political-administrative boundaries while promoting spatiotemporal stability, adaptability to spatial divisions, versatility, hierarchy, and flexibility (IBGE, 2016b).

We performed the visual inspection using strips of orthophotos arranged in a north–south direction together with the Statistical Grid. The study area comprises 115 orthophotos distributed across 14 strips. Each orthophoto covers an area of 19.77 × 22.52

km on the ground. We began the inspection at the upper-left corner of the leftmost orthophoto in the first strip, proceeding from west to east and from north to south until all grid cells within the orthophoto had been inspected. We repeated this procedure for each orthophoto in the strip and then continued with the remaining strips until the entire municipality had been analyzed.

Within each grid cell, we simultaneously inspected all 16 feature classes belonging to the Transportation System and Urban Structure categories (Hoffart, 2023). Whenever an error was identified, we classified it as an omission, commission, or classification accuracy error (Fig. 6).

Figure 6. Error analysis sequence.

Figura 6. Sequência da análise de erros.

2.4 Spatial Distribution and Quantification of Errors

By analyzing the attribute tables of the omission, commission, and classification accuracy layers, we quantified the errors and determined the location, classification, and description of each one. Based on these data, we prepared tables summarizing the occurrence of omission, commission, and classification accuracy errors for all orthophotos. The data quality measure used to evaluate completeness and classification accuracy was the error rate, expressed as a percentage. This rate was calculated by dividing the total number of errors by the total number of features and multiplying the result by 100. During error quantification, we examined the overlapping areas between adjacent orthophotos to ensure that any error appearing in two orthophotos was counted only once, always assigning it to the left orthophoto.

Using these results, we produced graphs showing the occurrence of omission, commission, and classification accuracy errors by feature class. We also generated thematic maps depicting the spatial distribution of these errors. These maps enabled us to visually analyze the spatial distribution of errors, identify their occurrence by neighborhood, and investigate possible spatial patterns.

3. Results and Discussion

During the verification of the topographic mapping of Porto Alegre, we counted 1,653,673 features in the Transportation System and Urban Structure categories. We identified 1,936 completeness errors, including 1,845 omission errors and 91 commission errors, as well as 144 classification accuracy errors, for a total of 2,080 errors. These correspond to error rates of 0.111%, 0.005%, and 0.009%, respectively, relative to the total number of features. The low error rates indicate that quality control performed throughout the mapping process was effective, as shown in Tables 2, 3, and 4. These results indicate that the topographic mapping has adequate semantic quality based on the analyzed quality parameters and a maximum error threshold of 2.5%.

Table 2. Transportation System category errors.

Tabela 2. Erros na categoria de Sistema de Transporte.

Class	Features	Omission Error	Commission Error	Classification Accuracy Error
Streets and Alleys	18,732	9	0	0
Curbs	8,995	5	2	0
Median Strips, Roundabouts, and Shoulders	3,509	16	0	0
Blocks	7,570	0	0	0
Railways	134	4	0	0
Bridges and Viaducts	1,224	76	0	96
Footbridges	85	3	0	0
Stairs and Ramps	614	228	0	0
Airport and Approach Cone	36,591	0	0	0
Bus Stops and Bus Terminals	2,623	2	1	1
Total	**80,077**	**343**	**3**	**97**

Table 3. Urban Structure category errors.

Tabela 3. Erros na categoria Estrutura Urbana.

Class	Features	Omission Error	Commission Error	Classification Accuracy Error
Fences and Walls	764,879	1,267	7	0
Urban Lots	266,247	0	0	0
Sports Courts and Soccer Fields	2,373	56	0	2
Buildings	538,528	159	64	27
Squares and Parks	873	20	17	18
Interior Parks	696	0	0	0
Total	**1,573,596**	**1,502**	**88**	**47**

Table 4. Total number and percentage of errors by category.

Tabela 4. Total e percentual de erros por categoria.

Category	Features	Omission Error	Commission Error	Classification Accuracy Error
Transportation System	80,077	343	3	97
Urban Structure	1,573,596	1,502	88	47
Total	**1,653,673**	**1,845**	**91**	**144**
Percentage	**100%**	**0.111%**	**0.005%**	**0.009%**

The Urban Structure category contains the largest number of features. However, the Transportation System category exhibits the highest error rate relative to the total number of features. We found that 95.157% of the analyzed features belong to the Urban Structure category, whereas only 4.843% belong to the Transportation System category. However, the error rate (omission + commission + classification accuracy) is 0.553% for the Transportation System category, compared with 0.104% for the Urban Structure category.

Within the Transportation System category, we identified 614 features and 228 omission errors in the Stairs and Ramps feature class, representing the highest error rate among all feature classes. In the Urban Structure category, we found the highest incidence of errors in the Fences and Walls feature class.

3.1 Completeness: Omission

We found omission errors in both categories and in almost all feature classes, except for the Blocks and Airport and Approach Cone feature classes in the Transportation System category and the Urban Lots and Interior Parks feature classes in the Urban Structure category. Figure 7 shows the percentage distribution of omission errors by feature class.

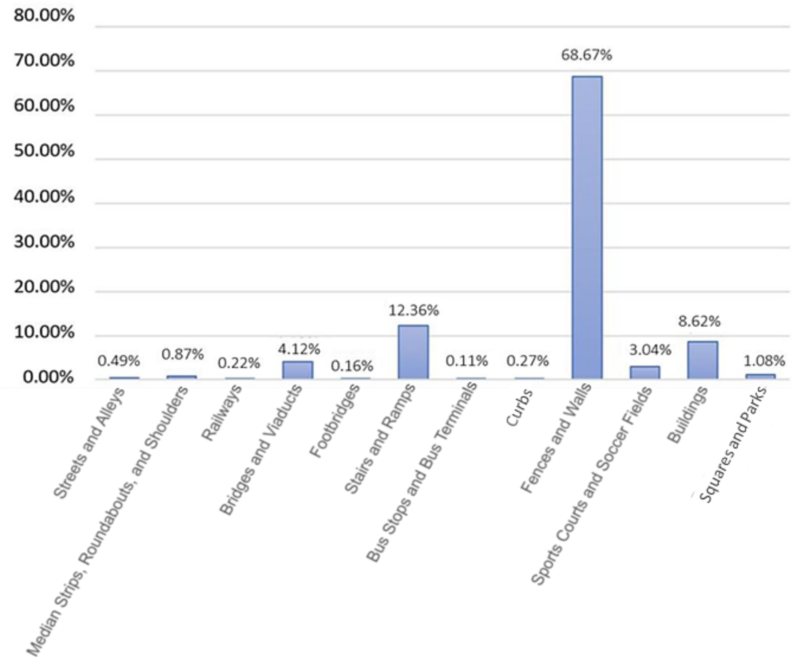

Figure 7. Omission errors by feature class.

Figura 7. Erros de omissão por classe de feição.

The Fences and Walls feature class had the highest number of omission errors, accounting for 68.67% of all omission errors, followed by the Stairs and Ramps feature class, which accounted for 12.36%. Figure 8 presents a map showing the spatial distribution of these errors.

Omission errors were the most frequent type of error identified in the topographic mapping, occurring in almost all neighborhoods of the municipality. We identified the highest number of omission errors in the Lami neighborhood (221 occurrences), followed by the Arquipélago neighborhood (198 occurrences). These neighborhoods are located at the southern and northwestern boundaries of the municipality, respectively. Most omission errors resulted from the lack of representation of Fences and Walls.

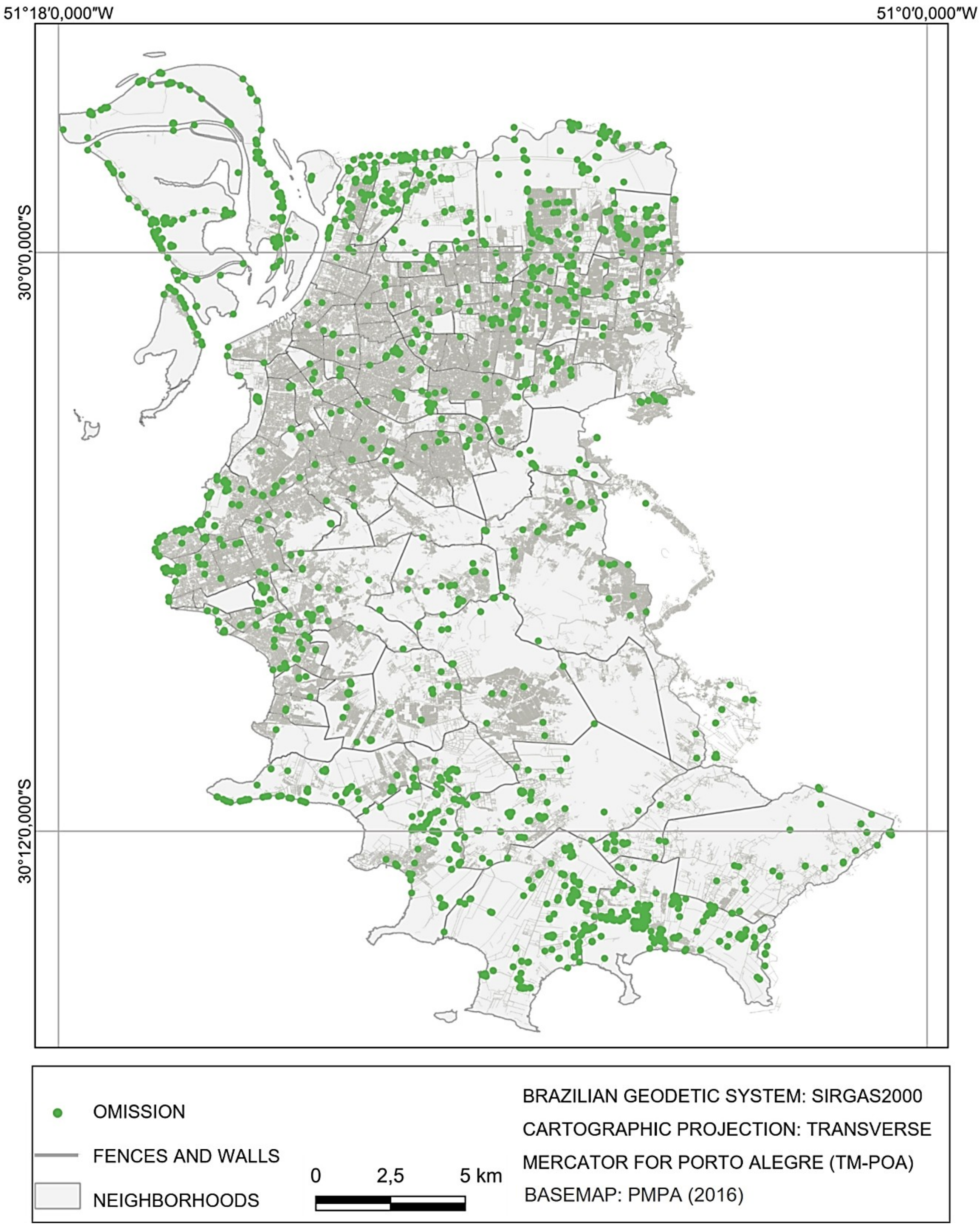

Figure 8. Map of omission errors.

Figura 8. Mapa dos erros de Omissão.

3.2 Completeness: Commission

We identified commission errors in five feature classes: Curbs and Bus Stops and Bus Terminals from the Transportation System category, and Fences and Walls, Buildings, and Squares and Parks from the Urban Structure category. The Urban Structure category concentrated most of these errors, with 88 occurrences, whereas the Transportation

System category presented only 3. Figure 9 shows the percentage distribution of commission errors by feature class.

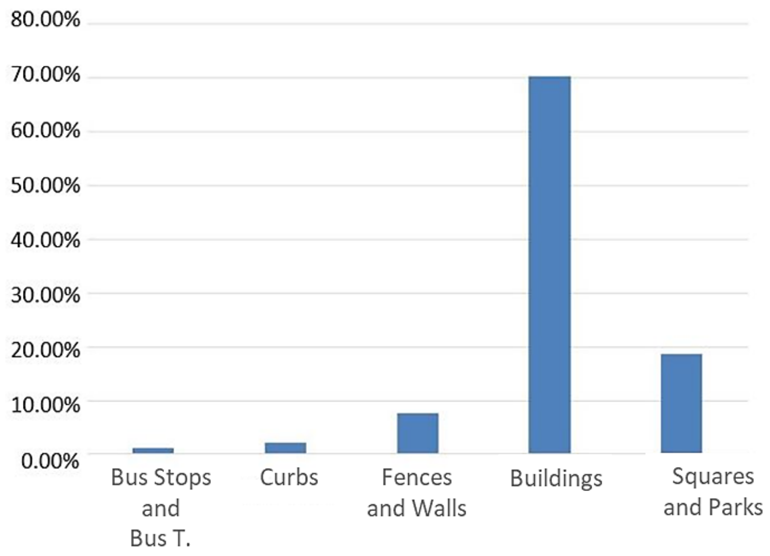

Figure 9. Commission errors by feature class.

Figura 9. Erros de comissão por classe de feição.

We found that commission errors were most frequent in the Buildings feature class, which accounted for 70.33% of the 91 identified errors, followed by the Squares and Parks feature class, which accounted for 18.68%. We observed that the high proportion of commission errors in the Buildings feature class was related to the fact that this class contains the second-highest number of represented features (538,528). The representation of temporary roof structures (e.g., canvas, nylon, and similar coverings) as buildings also contributed to commission errors in this feature class. According to the product specifications (PMPA, 2011), these features should not be represented on the maps.

Although the Squares and Parks feature class is represented by only 873 features in the topographic mapping and has 17 errors, we found that it has the highest proportion of commission errors among the analyzed feature classes. Figure 10 presents a map showing the spatial distribution of commission errors.

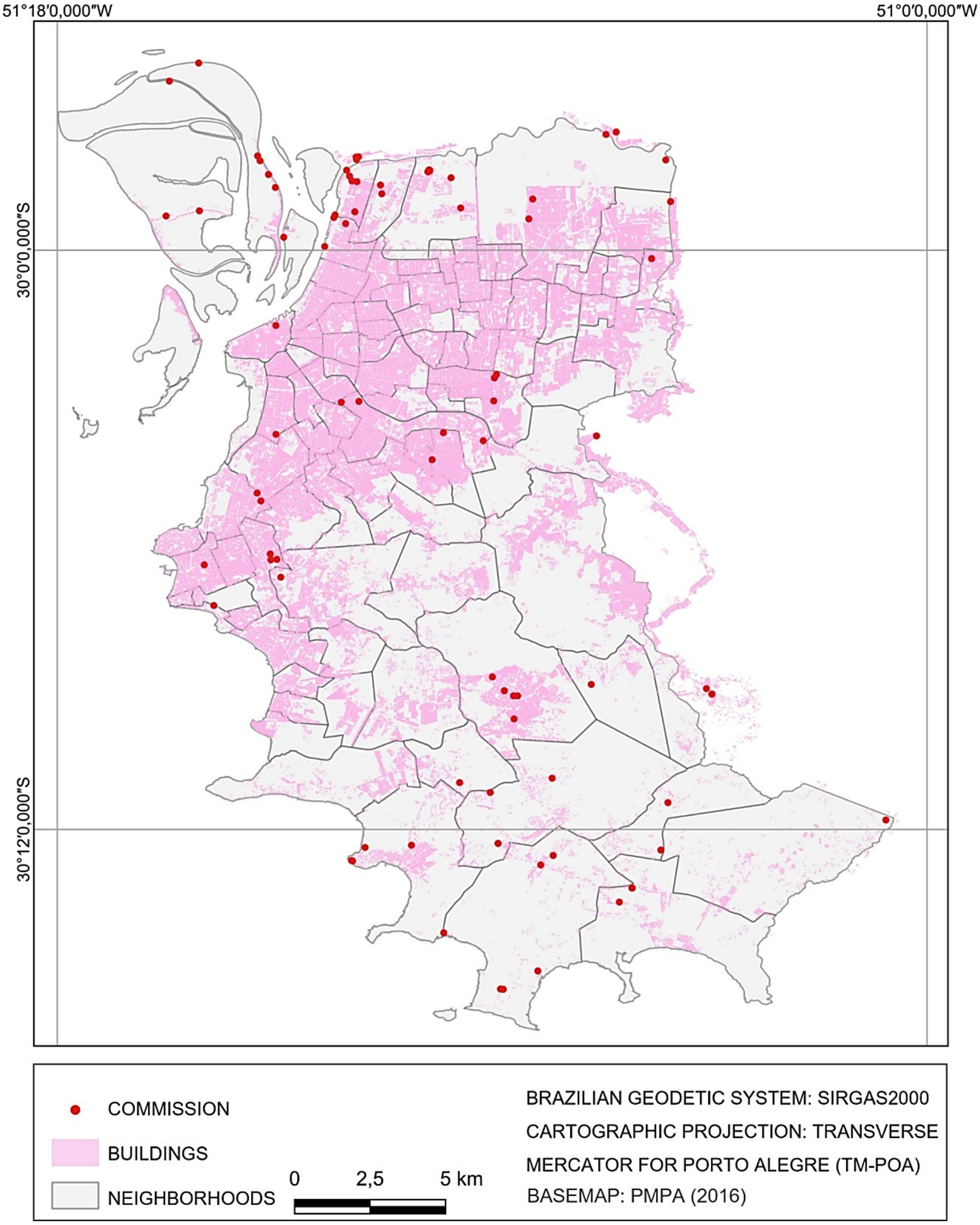

Figure 10. Map of commission errors.

Figura 10. Mapa dos erros de comissão.

3.3 Thematic Accuracy: Classification Accuracy

We identified classification accuracy errors in the Bridges and Viaducts and Bus Stops and Bus Terminals feature classes (Transportation System category), and in the Sports Courts and Soccer Fields, Buildings, and Squares and Parks feature classes (Urban Structure category). Figure 11 shows the number of classification accuracy errors identified in each feature class. The Bridges and Viaducts feature class had the highest number of classification accuracy errors, with 96 occurrences (66.67%), followed by the Buildings feature class, with 27 errors (18.75%).

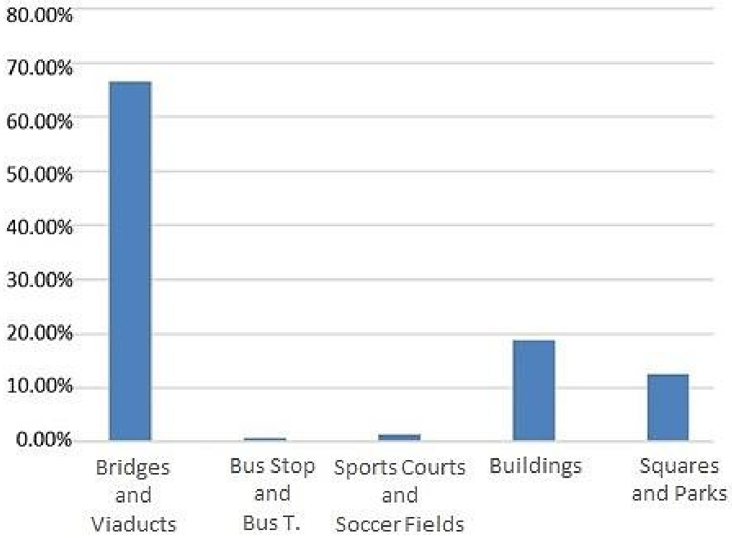

Figure 11. Classification accuracy errors.

Figura 11. Erros de acurácia de classificação.

Figure 12 illustrates the spatial distribution of classification accuracy errors. We found that these errors were concentrated in the Arquipélago neighborhood, which accounted for 93 of the 144 errors identified in the municipality. This concentration was mainly due to the misclassification of docks and piers as Bridges and Viaducts. According to the product specifications (PMPA, 2011), these features should have been classified as Stairs and Ramps.

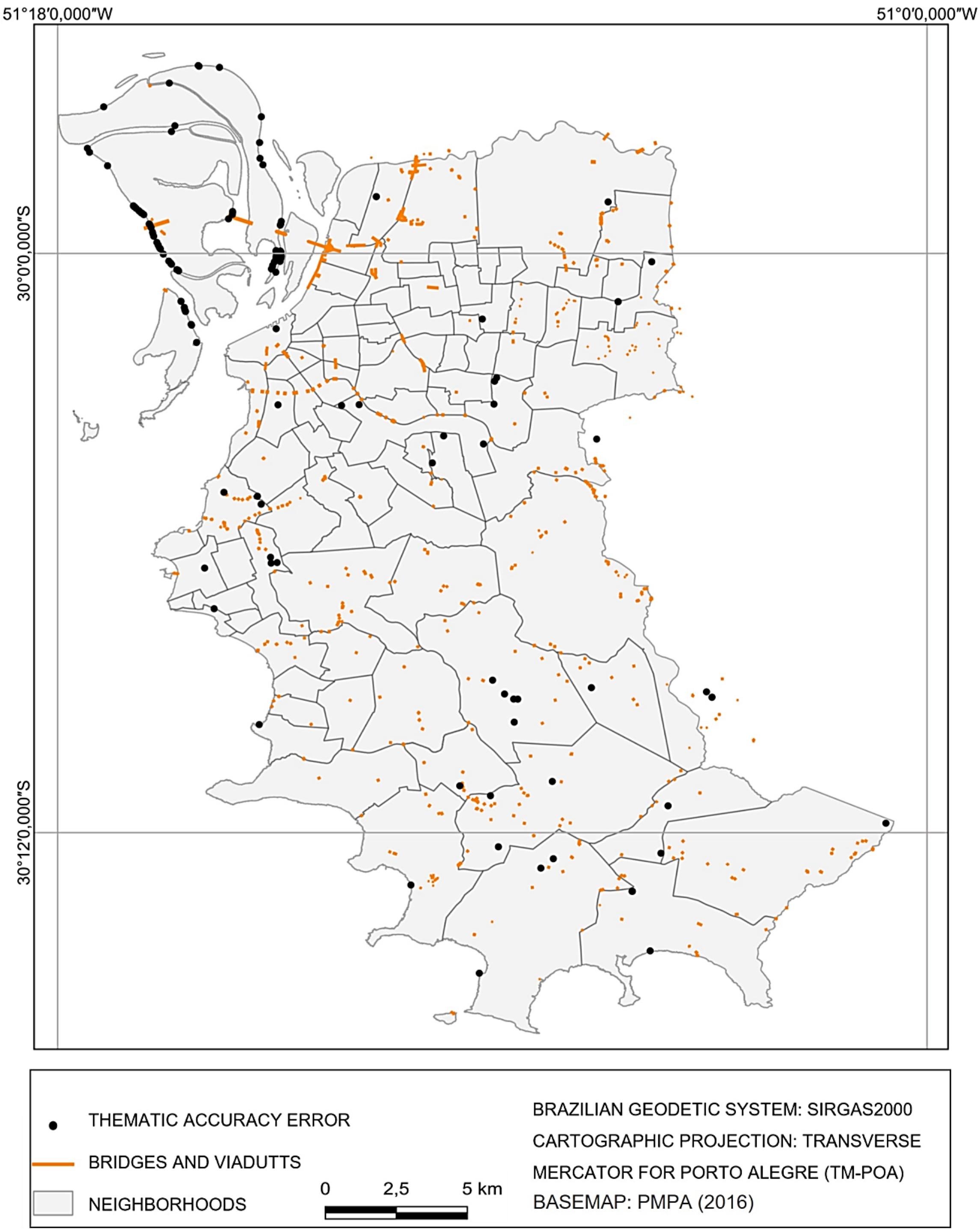

Figure 12. Map of Classification Accuracy errors.

Figura 12. Mapa dos erros de Acurácia de Classificação.

Figure 13 presents the simultaneous representation of omission, commission, and classification accuracy errors. We identified omission errors as the most frequent type of error in the topographic mapping, as they occurred in nearly all neighborhoods of the municipality.

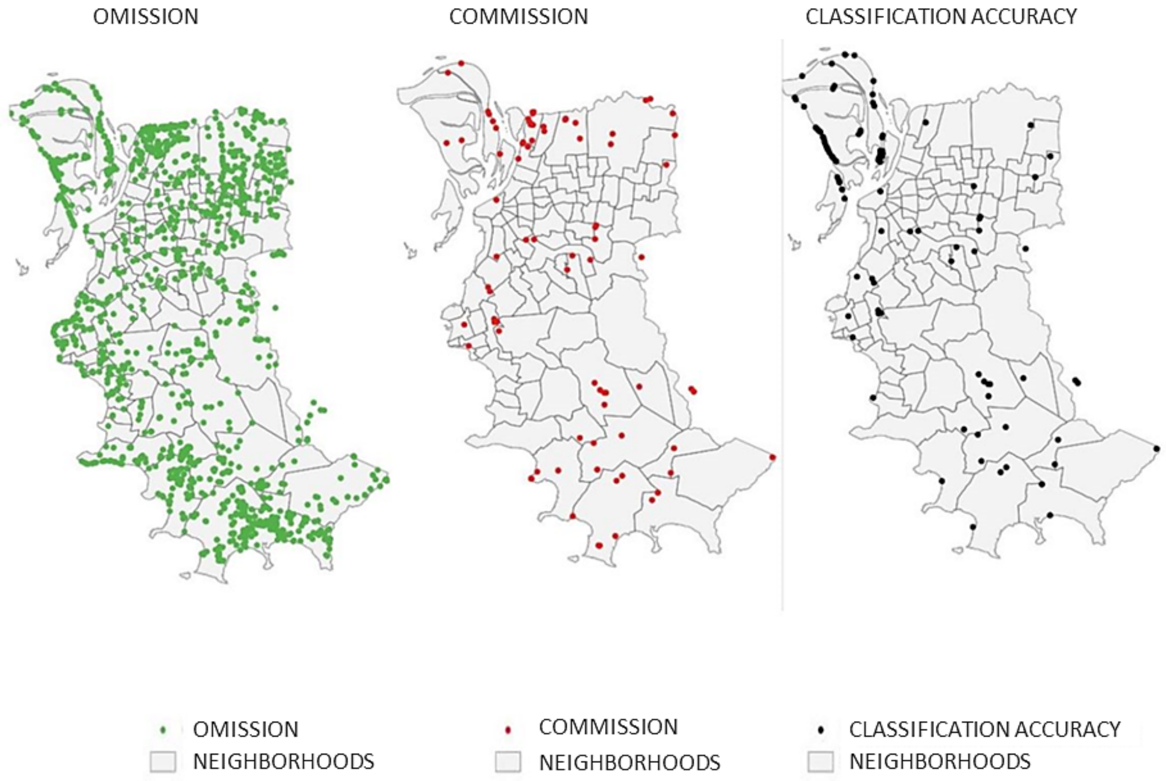

Figure 13. Omission, commission, and classification accuracy errors.

Figura 13. Erros de omissão, de comissão e de acurácia de classificação.

4. Conclusions and Future Work

In this study, we presented a methodology for assessing the semantic quality of large-scale topographic maps. We identified and quantified errors related to the completeness and classification accuracy parameters within the Transportation System and Urban Structure categories.

We adopted the standards and criteria established in the Planning Report for the Development of the Cartographic Base – Digital Topographic Mapping of Porto Alegre (PMPA, 2011), using orthophotos as the reference data and the topographic mapping as the test data. Supported by the Statistical Grid, which enabled a systematic and continuous visual analysis, we demonstrated that the proposed methodology was effective for conducting this assessment.

The reported error rates are descriptive indicators derived from a complete inspection of the dataset. Omission, commission, and classification accuracy errors accounted for 0.111%, 0.005%, and 0.009%, respectively, of the total number of analyzed features. These values indicate that the evaluated topographic mapping exhibits satisfactory semantic quality based on the analyzed quality parameters and a maximum error threshold of 2.5%.

We identified omission errors in nearly all neighborhoods, primarily due to the absence of features from the Fences and Walls class. Commission errors were concentrated in the northern sector of the study area and were mainly associated with the representation of buildings that were not present in the orthophotos. Classification accuracy errors occurred predominantly in the Islands region and were mainly related to the misclassification of features from the Bridges and Viaducts feature class.

As future work, we intend to automate the process of identifying completeness errors, as the current methodology requires significant manual effort. This development may improve the efficiency of semantic quality assessments for large-scale topographic mapping. We also recommend revising Brazilian standards based on the new ISO standard to support the quality assessment of geospatial data.

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