

# Positional Accuracy of Cave Location Data and Implications for the Management of Brazilian Speleological Heritage: A Case Study from Rio Branco do Sul, Paraná

## Qualidade posicional dos dados de localização das cavernas e as implicações para a gestão do patrimônio espeleológico brasileiro: o caso de Rio Branco do Sul – PR

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### Abstract

The quality of location data for natural caves recorded in the National Registry of Speleological Information (CANIE) is fundamental to the management, monitoring, and control of environmental conditions in Brazilian caves. Since its creation in 2004, CANIE has integrated data from different sources, methods, and historical periods, including records produced prior to the widespread use of GNSS receivers, resulting in significant variations in positional accuracy. The caves registered in the municipality of Rio Branco do Sul (Paraná State) exemplify this heterogeneity. In this context, the objective of this study was to assess the positional quality of the data recorded in CANIE and to update the municipal speleological registry through high-precision GNSS surveys and the establishment of topographic control points in the field. The data obtained met the Cartographic Accuracy Standard for Digital Cartographic Products (PEC-PCD) at a 1:1,000 scale and were structured in accordance with the National Spatial Data Infrastructure (INDE), subsequently being incorporated into the CANIE and the National Cave Registry (CNC) databases. The comparison between the originally registered coordinates and those obtained through field surveys for the caves analyzed in Rio Branco do Sul revealed significant inconsistencies, with positional errors ranging from tens to hundreds of meters, compatible with a 1:250,000 scale (PEC-PCD), thus exposing the fragility of part of the historical records. The results reinforce the need for systematic field validation of speleological information, especially for datasets produced without the use of GNSS technologies, in order to effectively support the management and protection of Brazil's speleological heritage.

### Keywords:

Positional error, High-precision GNSS survey, Speleological database, Cartographic validation.

## Resumo

A qualidade dos dados de localização das cavidades naturais registradas no Cadastro Nacional de Informações Espeleológicas (CANIE) é fundamental para a gestão, o monitoramento e o controle das condições ambientais das cavernas brasileiras. Desde sua criação, em 2004, o CANIE integrou dados de diferentes fontes, métodos e períodos históricos, incluindo registros anteriores à disseminação do uso de receptores GNSS, o que resultou em variações significativas de acurácia posicional. As cavidades cadastradas no município de Rio Branco do Sul (PR) representam essa heterogeneidade. Nesse contexto, o objetivo deste trabalho foi avaliar a qualidade posicional dos dados cadastrados no CANIE e atualizar o cadastro espeleológico municipal por meio de levantamentos GNSS de alta precisão e da implantação de marcos topográficos em campo. Os dados obtidos atenderam ao Padrão de Exatidão Cartográfica para Produtos Cartográficos Digitais (PEC-PCD) na escala 1:1000 e foram estruturados conforme a Infraestrutura Nacional de Dados Espaciais (INDE), sendo posteriormente incorporados às bases do CANIE e do Cadastro Nacional de Cavernas (CNC). A comparação entre as coordenadas originalmente cadastradas e aquelas obtidas em campo para as cavidades analisadas em Rio Branco do Sul (PR) evidenciou inconsistências significativas, com erros posicionais variando de dezenas a centenas de metros, compatíveis com a escala 1:250.000 (PEC-PCD), revelando a fragilidade de parte dos registros históricos. Os resultados reforçam a necessidade de validação sistemática em campo das informações espeleológicas, especialmente para cadastros produzidos sem o emprego de tecnologias GNSS, de modo a subsidiar de forma eficaz a gestão e a proteção do patrimônio espeleológico nacional.

### Palavras-chave:

Erro posicional, Levantamento GNSS de alta precisão, Cadastro espeleológico, Validação cartográfica.

## I. INTRODUCTION

The Paraná Speleological Studies Group (GEEP-Açungui), particularly during the 1980s and 1990s, was responsible for collecting a large portion of the data currently contained in the CANIE for the state of Paraná and, consequently, for the municipality of Rio Branco do Sul, Paraná (Figure 1). These records generally reflect the technical limitations that existed prior to the adoption of GNSS technology. In summary, the lineage of these data included: (1) the use of topographic maps and aerial photographs for cave location; (2) analog recording of geospatial data; (3) digitization and transformation between reference systems (Córrego Alegre, SAD69 – 1st and 2nd realizations, Chuá Astro, and WGS84, currently updated to SIRGAS 2000); (4) digital processing; and (5) integration into the National Cave Registry (CNC) and the National Speleological Information Registry (CANIE).

Oliveira-Galvão (2014) highlights that one of the most significant changes in the consolidation of CANIE was the definition of standardized parameters and methods for speleological data collection, formalized by National Center for Cave Research and Conservation (CECAV, 2009). This standardization established that cave

coordinates should preferably be obtained using GNSS (Global Navigation Satellite System) receivers, in geographic coordinates (decimal degrees) and the WGS84 datum, positioned at the main cave entrance or at the topographic “zero base.” When such data collection is deemed “unfeasible,” the use of a georeferenced anchor point connected to the zero topographic base is recommended (Brazil, 2025).

Currently, according to information published on the official CECAV website, cave locations must be obtained using GPS equipment (more accurately described as GNSS technology), employing geographic coordinates in decimal degrees, the SIRGAS 2000 datum, and signal acquisition from at least four satellites well distributed within the constellation. The maximum allowable positional error is 15 meters (ideally 3 m, preferably up to 10 m), and the point should be collected at the main entrance, where the zero topographic base is located.

Considering that the management of speleological heritage—especially following CONAMA Resolution No. 347, which establishes a 250 m area of influence around caves lacking prior studies—fundamentally depends on the accurate location of caves, the importance of the spatial component becomes evident. However, Ferreira (2019), based on data from the Brazilian Federal Court of Accounts (TCU), found that only 8.7% of the caves registered in CANIE had been field-validated by 2014.

There is also a notable scarcity of studies with a cartographic focus dedicated to cave location methods and positional validation. The literature tends to prioritize speleometric approaches, internal surveying issues, calculations of area, volume, and linear development, geotechnical characterizations, and predictive modeling of cave occurrence.

In this context, the precise definition of cave positions and the *in situ* materialization of topographic reference points for each cave emerge as an effective methodological strategy for the positional validation of CANIE data, particularly for records predating the widespread adoption of GNSS technology (referred to as GPS by CECAV).

Accordingly, the objective of this study is to present the methodological procedures and results of the project “Updating and adjustment of the speleological information registry of the municipality of Rio Branco do Sul – PR,” developed under Public Call Notice No. SBE 01/2023 – Ampliando Rotas. The project reviewed the locations of the 47 caves registered in the municipality according to the National Speleological Information Registry (CANIE, 2022).

The research also addresses issues related to the positional quality of the data and highlights the need to expand field surveys using appropriate techniques to improve the geospatial information of Brazilian caves.

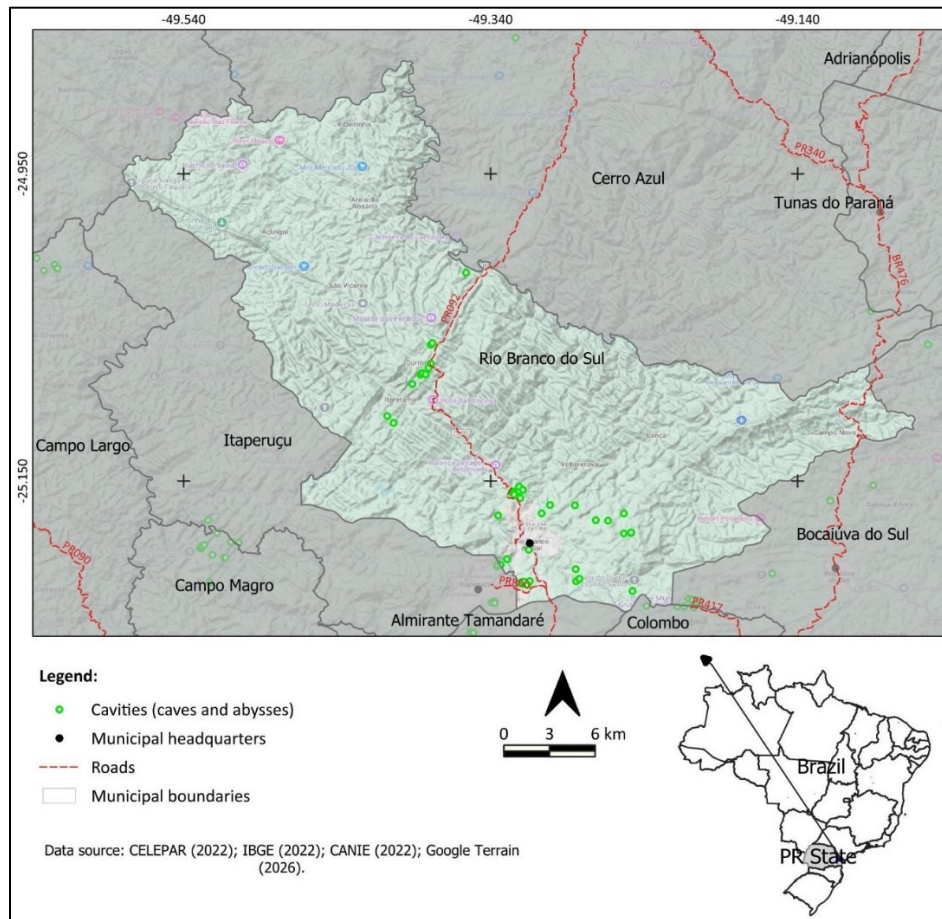


Figure 1 – Location of the municipality of Rio Branco do Sul, Paraná State (highlighted in the figure), and the location of natural caves according to CANIE (2022).

## II. MATERIALS AND METHODS

According to the geomorphological mapping of the State of Paraná (Santos et al., 2006), the municipality of Rio Branco do Sul is located within the Atlantic Orographic Belt, which is subdivided into four morphosculptural units represented by deeply dissected plateaus with a high degree of incision, drained by the Ribeira River basin. Geological evolution, according to Fiori (1994), includes tectonic events that fractured, faulted, and metamorphosed the Neoproterozoic lithotypes of the Açungui Group. These deformations, especially those of a brittle nature, directly influence the regional karst landscape. The metacarbonate units that host the caves occupy 44% of the municipal area and are oriented in a NE–SW direction (Bigarella, 1953).

The prevailing climate is classified as Cfb according to the Köppen system, characterized as temperate, humid, and mesothermal, with mild summers, well-distributed rainfall throughout the year (1,100–2,000 mm),

average temperatures below 22 °C in the warmest month, and the annual occurrence of approximately ten to twenty-five frost days.

The location information of caves within the municipality of Rio Branco do Sul, Paraná State, was obtained from the CANIE database (2022), which comprises data collected at different times and using different acquisition methods. In addition to the CANIE database, data acquired and systematized by the Paraná Speleological Studies Group (GEEP-Açungui) since the 1980s were also considered. Although these data have already been incorporated into CANIE, they were useful for resolving uncertainties related to cave location and correct toponymy, as well as for providing more detailed descriptions to support cave identification in the field.

For field localization of the caves, satellite images available through Google Earth Pro (2024) were analyzed, considering a temporal series from the 1990s to 2020. The combined analysis of satellite imagery and cave location points enabled the identification of optimal access routes and guided field navigation. The integration of spatial data for field surveys (raster and vector data) was carried out using the OruxMaps GP software (smartphone) and a multi-band GNSS receiver (Garmin GPSMAP 65s).

The installation of topographic benchmarks and the materialization of the spatial reference for each cave prioritized proximity to the respective cave entrance (topographic base zero) and considered two main limiting factors: (1) GNSS signal multipath effects caused by interactions with surrounding surfaces, particularly relief and vegetation—mitigated by distancing the receiver from rock outcrops and installing the antenna in areas with less dense vegetation (natural clearings or areas opened for GNSS data tracking); and (2) the presence of suitable soil conditions to allow penetration of the metal rod and fixation of the topographic benchmark (Figure 2), using a hole punch designed for soil perforation.

For the installation of the topographic benchmarks, GNSS constellation signal tracking was conducted and the coordinates corresponding to their field positions were determined. A dual-frequency (L1, L2), multi-band, multi-constellation GNSS receiver (ArduSimple – RTK Calibrated), with centimeter-level accuracy, was used. The receiver antenna was positioned at a height of 2 m (two meters) relative to the central position of the metallic plaque of the topographic benchmark (Figure 2). The only exception occurred at Gruta do Estilo, where the entrance is located on a decommissioned mining bench, lacking sufficient soil thickness for proper benchmark installation and with a height of less than 2 m, which prevented standard antenna positioning.

In areas with mobile internet coverage, Networked Transport of RTCM via Internet Protocol (NTRIP) was used to perform real-time differential correction between the receiver installed on the benchmark and the

Curitiba-UFPR and/or Pinhais (PRPI) reference stations. Both stations are located within 20 km of the study area and are part of the Brazilian Network for Continuous Monitoring of GNSS Systems (RBMC).

For GNSS data acquisition in areas without mobile data coverage, a tracking duration of 40 minutes and a sampling frequency of 5 Hz were adopted, which was sufficient to record representative positional information. Post-processing for differential correction based on RBMC data was carried out using Emlid Studio 1.7 software.

To optimize fieldwork and reduce GNSS tracking time in areas without mobile data coverage, a satellite internet receiver antenna (Starlink) was occasionally used. This enabled real-time differential corrections and the acquisition of sub-meter accuracy coordinates with tracking times of approximately 5 minutes. For each installed topographic benchmark, a “point monograph” was prepared, providing a detailed description of the benchmark information, particularly its positional attributes.

The geospatial data for each cave were structured in accordance with the Technical Specification for the Acquisition of Vector Geospatial Data (ET-ADGV), version 3.0, using the “Gruta\_Caverna” class within the “Relief” (REL) category. This class is instantiable at all scales and uses a point geometric primitive, as defined in the ET-ADGV object acquisition table. To structure the data in compliance with the Technical Specification for the Structuring of Vector Geospatial Data (ET-EDGV), the DSG Tools plugin installed in QGIS software was used, and both spatial and non-spatial data were stored in a geospatial database managed by PostgreSQL/PostGIS.



Figure 2 – Receiver system installed on a topographic benchmark for GNSS signal tracking (Gruta Taici I) and determination of coordinates (latitude and longitude) and elevation.

### III. RESULTS AND DISCUSSION

Field surveys enabled the identification of 42 caves within the municipality of Rio Branco do Sul, Paraná State, including 29 positional corrections of caves previously registered in CANIE (2022) and 13 newly discovered caves recorded during the field surveys (Tables 1 and 2). It was observed that some caves registered during the 1980s and 1990s were partially or totally destroyed by mining activities, corroborating reports from local residents, speleologists, and data provided by the Municipal Government indicating that several caves were blasted during the 2000s.

The positional data obtained for the 29 spatial corrections revealed substantial differences when compared to the coordinates originally recorded in CANIE (2022) and those obtained in the field for the installation of topographic benchmarks at the cave entrances (Table 3). Positional errors ranged from 13 m to

772 m. The largest discrepancies were observed for Gruta da Piedade, with an error of approximately 670 m, and Gruta da Boa Vista II, with an error of approximately 772 m. In contrast, the smallest positional errors were recorded for Gruta Taici II (~13 m) and Abismo do Deslize (~17 m).

The median positional error was approximately 58 m. The first quartile (Q1) was around 29 m, indicating that 25% of the analyzed caves exhibited positional errors equal to or less than this value, whereas the third quartile (Q3) was approximately 130 m, indicating that 75% of the records showed positional deviations below about 130 m. The interquartile range was approximately 101 m, reflecting the dispersion of the central values of the dataset. Normality tests using Shapiro–Wilk ( $W = 0.6025$ ;  $p < 0.001$ ) and Jarque–Bera ( $JB = 66.79$ ;  $p < 0.001$ ) indicated that the data do not follow a normal distribution. Accordingly, descriptive analysis was conducted using non-parametric statistics. The 90th percentile of the distances was 337 m, summarizing the magnitude of the largest deviations observed in the analyzed dataset (Table 4).

The distribution of positional errors exhibited right skewness, with a concentration of values below 100 m and the presence of records with deviations exceeding 300 m. These extreme values exceed the upper limit defined by the interquartile range criterion, characterizing statistical outliers within the analyzed dataset (Figure 3).

Due to the observed asymmetry and the presence of extreme values, the analysis was conducted using non-parametric statistics, prioritizing measures of central tendency and dispersion. The results of the normality tests are presented in Table 5.

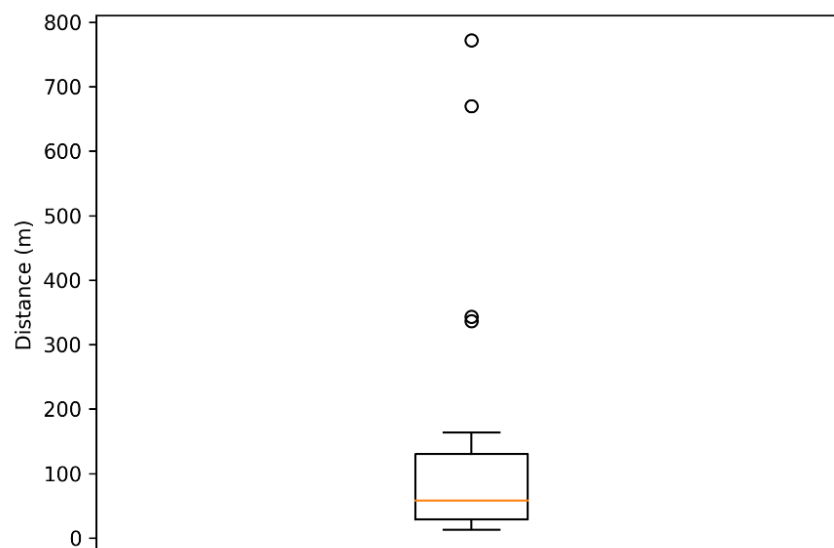


Figure 3 – Boxplot of distances between the positional data registered in CANIE (2022) and the coordinates obtained in the field ( $n = 29$ ). The box represents the interquartile range, the central line represents the median, and the points indicate extreme values.

Table 1 – Caves discovered and recorded during the course of the study.

| Cavity (caves and shafts) | State | Municipality      | Locality      | Cavity status (2024)         |
|---------------------------|-------|-------------------|---------------|------------------------------|
| Gruta da Dúvida           | PR    | Rio Branco do Sul | Bacaetava     | Topographic marker installed |
| Gruta do Batismo          | PR    | Rio Branco do Sul | Bacaetava     | Topographic marker installed |
| Fenda do Cristoph         | PR    | Rio Branco do Sul | Bacaetava     | Topographic marker installed |
| Gruta Norte               | PR    | Rio Branco do Sul | Bacaetava     | Topographic marker installed |
| Gruta dos Causos          | PR    | Rio Branco do Sul | Bacaetava     | Topographic marker installed |
| Boa Vista III             | PR    | Rio Branco do Sul | Boa Vista     | Topographic marker installed |
| Abismo sem Nome           | PR    | Rio Branco do Sul | Bromado       | Topographic marker installed |
| Gruta do Pinheiro         | PR    | Rio Branco do Sul | Cachimba      | Topographic marker installed |
| Toca do Ferrão            | PR    | Rio Branco do Sul | Cachimba      | Topographic marker installed |
| Gruta de Campestrinho IV  | PR    | Rio Branco do Sul | Campestre     | Topographic marker installed |
| Gruta TA 03               | PR    | Rio Branco do Sul | Itaretama     | Topographic marker installed |
| Gruta TA 15               | PR    | Rio Branco do Sul | Olaria        | Topographic marker installed |
| Gruta do Treze            | PR    | Rio Branco do Sul | Paio de Baixo | Topographic marker installed |

Source: CANIE (2022) and Authors.

Figure 4 shows the locations of the 29 topographic benchmarks installed at caves identified in the field and their corresponding positions as recorded in CANIE (2022). It should be noted that differences between municipal boundaries as defined in the Paraná State Government mapping (2014) and those established by the Brazilian Institute of Geography and Statistics (IBGE) in 2022 led to the inclusion of several caves previously registered in the municipality of Bocaiúva do Sul, Paraná State, in the registry of caves belonging to the municipality of Rio Branco do Sul, Paraná State. These caves include Gruta do Batismo, Fenda do Cristoph, and Gruta da Dúvida. In addition, two newly registered caves—Gruta Norte and Gruta dos Causos—are also presented (Table 1).

The caves identified with the information “Topographic Benchmark Installed” had their positional data either corrected (Table 1) or newly inserted (Table 2) into the CANIE–CECAV and CNC–SBE databases.

Table 2 – Caves registered in CANIE (2022) considered in this study (colors are used to distinguish caves with different status conditions).

| Cavity (caves and shafts) | State | Municipality      | Locality   | Cavity status (2024)                                   |
|---------------------------|-------|-------------------|------------|--|
| Gruta do Bento            | PR    | Rio Branco do Sul | Areias     | Topographic marker installed                           |
| Gruta dos Ossos           | PR    | Rio Branco do Sul | Areias     | Private property - not accessed (reported destruction) |
| Gruta Rio Branco I        | PR    | Rio Branco do Sul | Areias     | Topographic marker installed                           |
| Gruta Rio Branco II       | PR    | Rio Branco do Sul | Areias     | Not located (report of destruction)                    |
| Gruta Boa Vista I         | PR    | Rio Branco do Sul | Boa Vista  | Destroyed by mining activities                         |
| Gruta Boa Vista II        | PR    | Rio Branco do Sul | Boa Vista  | Destroyed by mining activities                         |
| Gruta de Bom Jardim I     | PR    | Rio Branco do Sul | Bom Jardim | Not located (report of destruction)                    |

|  |    |                   |                    |  |
|--|----|-------------------|--------------------|--|
| Gruta de Bom Jardim II                       | PR | Rio Branco do Sul | Bom Jardim         | Not located (report of destruction)                    |
| Gruta Queimada I                             | PR | Rio Branco do Sul | Bom Jardim         | Topographic marker installed                           |
| Gruta Queimada II                            | PR | Rio Branco do Sul | Bom Jardim         | Private property - not accessed (reported destruction) |
| Gruta Último Suspiro                         | PR | Rio Branco do Sul | Bom Jardim         | Private property - not accessed (reported destruction) |
| Abismo de Bromado                            | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Abismo do Deslize                            | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Abismo do Erro                               | PR | Rio Branco do Sul | Bromado            | Private property - not accessed (reported destruction) |
| Abismo Itaretama                             | PR | Rio Branco do Sul | Bromado            | Private area not accessible                            |
| Gruta da Caveira                             | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta de Bromado I                           | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta de Bromado II                          | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta de Taici I                             | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta de Taici II                            | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta do Abelheiro                           | PR | Rio Branco do Sul | Bromado            | Topographic marker installed                           |
| Gruta da Cachimba                            | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta do Chocolate                           | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta do Cotovelo                            | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta do Edifício                            | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta do Pilãozinho                          | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta do Sapato                              | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Gruta Primeiro de Abril                      | PR | Rio Branco do Sul | Cachimba           | Topographic marker installed                           |
| Caverna Campestrinho I (Gruta de Itacolombo) | PR | Rio Branco do Sul | Campestre          | Topographic marker installed                           |
| Gruta de Campestrinho II                     | PR | Rio Branco do Sul | Campestre          | Not located (report of destruction)                    |
| Gruta de Campestrinho III                    | PR | Rio Branco do Sul | Campestre          | Not located (report of destruction)                    |
| Gruta Campina dos Pintos                     | PR | Rio Branco do Sul | Campina dos Pintos | Not located in the field survey                        |
| Gruta Curriola                               | PR | Rio Branco do Sul | Itaretama          | Not located in the field survey                        |
| Gruta Itaretama                              | PR | Rio Branco do Sul | Itaretama          | Not located in the field survey                        |
| Gruta da Lancinha                            | PR | Rio Branco do Sul | Lancinha           | Topographic marker installed                           |
| Gruta de Paiol do Fundo                      | PR | Rio Branco do Sul | Paiol do Fundo     | Topographic marker installed                           |
| Gruta do Estilo                              | PR | Rio Branco do Sul | Paiol do Fundo     | Topographic marker installed                           |
| Gruta de Pessegueiro                         | PR | Rio Branco do Sul | Pessegueiro        | Topographic marker installed                           |
| Gruta da Piedade                             | PR | Rio Branco do Sul | Piedade            | Topographic marker installed                           |
| Abismo Saivá                                 | PR | Rio Branco do Sul | Saivá              | Not located (report of destruction)                    |
| Buraco da Araucária                          | PR | Rio Branco do Sul | Saivá              | It should not be cataloged as a cave                   |
| Buraco das Andorinhas                        | PR | Rio Branco do Sul | Saivá              | It should not be cataloged as a cave                   |
| Gruta do Garrafão                            | PR | Rio Branco do Sul | Saivá              | It should not be cataloged as a cave                   |
| Gruta Ninho do Urubu                         | PR | Rio Branco do Sul | Saivá              | Topographic marker installed                           |

|                    |    |                   |             |                              |
|--------------------|----|-------------------|-------------|------------------------------|
| Gruta de Toquinhas | PR | Rio Branco do Sul | Toquinhas   | Topographic marker installed |
| Gruta da Casa      | PR | Rio Branco do Sul | Zona Urbana | Topographic marker installed |
| Gruta da Toca      | PR | Rio Branco do Sul | Zona Urbana | Topographic marker installed |

Source: CANIE (2022) and Authors.

Table 3 – Distance data between the positions obtained directly in the field (GNSS) and the positions recorded in CANIE (2022).

| Cavity (caves and shafts) | Distance (m) |
|---------------------------|--------------|
| Taici II                  | 13           |
| Abismo de Bromado         | 17           |
| Abismo do Deslize         | 20           |
| Dúvida                    | 22           |
| Primeiro de Abril         | 23           |
| Casa                      | 25           |
| Abelheiro                 | 26           |
| Ninho do Urubu            | 29           |
| Christoph                 | 32           |
| Paiol do Fundo            | 37           |
| Edifício                  | 37           |
| Sapato                    | 39           |
| Bento                     | 48           |
| Pilãozinho                | 53           |
| Campestrinho I            | 58           |
| Taici I                   | 58           |
| Rio Branco I              | 68           |
| Estilo                    | 85           |
| Pessegueiro               | 86           |
| Chocolate                 | 93           |
| Cotovelo                  | 111          |
| Toquinhas                 | 130          |
| Bromado I                 | 136          |
| Cachimba                  | 142          |
| Bromado II                | 163          |
| <b>Caveira</b>            | <b>336</b>   |
| <b>Lancinha</b>           | <b>343</b>   |
| <b>Piedade</b>            | <b>670</b>   |
| <b>Boa Vista II</b>       | <b>772</b>   |

Source: Elaborated by authors.

Four caves (highlighted in bold in Table 1), representing 14% of the 29 caves whose positions were corrected, exhibit positional errors exceeding the 250 m influence zone established for protection under CONAMA Resolution No. 347.

Table 4 – Descriptive statistics of positional errors observed in relation to the CANIE (2022) registry.

| Statistics                   | Values   |
|------------------------------|----------|
| Sample size                  | 29 caves |
| Minimum distance             | 13 m     |
| 1st quartile (Q1)            | 29 m     |
| Median                       | 58 m     |
| 3 <sup>o</sup> quartile (Q3) | 130 m    |
| Maximum distance             | 772 m    |
| Interquartile range(IQR)     | 101 m    |
| Range                        | 759 m    |

Source: Elaborated by authors.

Table 5 – Normality tests of positional errors observed in relation to CANIE (2022).

| Tests                     | Statistics | p-value |
|---------------------------|------------|---------|
| Shapiro–Wilk              | W = 0.6025 | < 0.001 |
| Jarque–Bera               | JB = 66.79 | < 0.001 |
| Jarque–Bera (Monte Carlo) | -          | 0.0001  |

Source: Elaborated by authors.

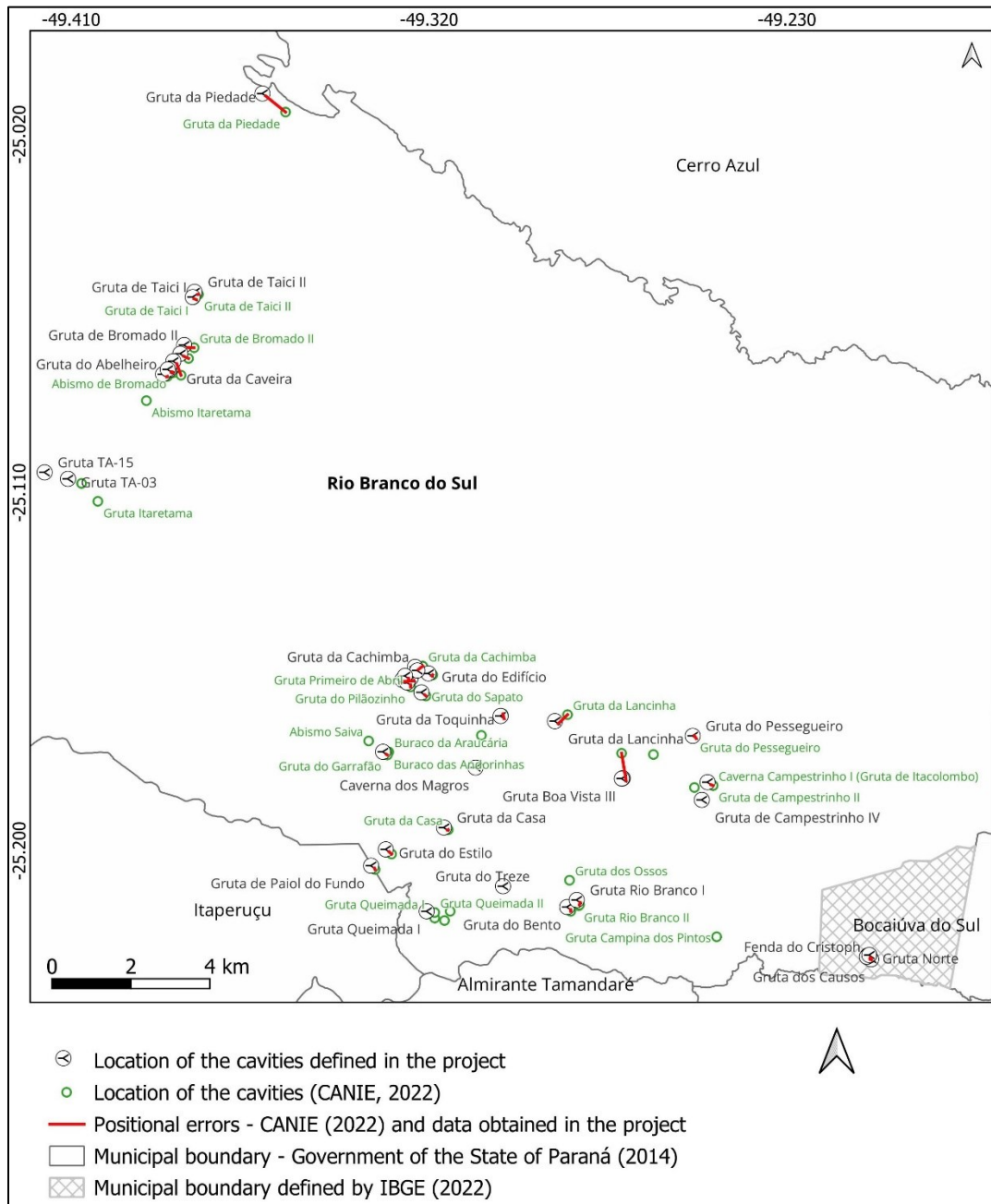


Figure 4 — Caves located in Rio Branco do Sul, Paraná State.

#### IV. CONCLUSIONS

The acquisition of sub-meter positioning and the establishment of permanent reference points for natural caves in the municipality of Rio Branco do Sul, Paraná State—both for newly recorded caves and for those previously registered and positionally corrected in the CANIE and CNC databases—enabled the updating

and qualification of municipal speleological information. The procedures adopted allowed the unequivocal geolocation of more than 40 caves, reducing uncertainties associated with historical records.

The methods employed, particularly the installation of topographic benchmarks near cave entrances, establish a consistent and durable cartographic reference that can be used by public authorities, researchers, and other stakeholders involved in the management of regional speleological and karst heritage. Although official databases currently adopt coordinate precision compatible with a 1:1,000 scale, the acquisition of sub-meter data in the field expands the potential use of this information, especially as a reliable reference for tying and controlling topographic surveys conducted within natural caves.

The results demonstrate that the lack of systematic positional validation can significantly compromise the management of speleological heritage, particularly in contexts of intense anthropogenic pressure. Therefore, the adoption of standardized high-precision GNSS survey procedures and the materialization of topographic reference points in the field constitute a replicable methodological strategy capable of supporting the revision and qualification of historical speleological registries in other municipalities and regions of the country. This approach contributes to greater effectiveness of public conservation policies and to the strengthening of legal certainty associated with these territories, in line with the objectives of the National Program for the Conservation of Speleological Heritage.

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