Navigating Boundary Discrepancies in SAD69-Based Delimitation: A Case Study and Practical Guidelines

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Abstract: The delimitation of the 84,130-hectare Serra do Tabuleiro State Park, a fully legally protected Conservation Unit in Santa Catarina, Brazil, relies on shapefiles provided by the managing institution and based on the SAD69 Coordinate Reference System. However, user-defined parameters when handling these shapefiles may result in up to three slightly different polygon representations, each affecting the perception of boundaries shared with adjacent territories. This study investigates these polygon discrepancies and assesses which representation most accurately reflects the intended delimitation. Although a definitive solution is not reached, the authors provide valuable recommendations for public authorities and GIS users to standardize interpretations and improve boundary accuracy.

1 INTRODUCTION

The last change to the boundaries of a Conservation Unit, a legally protected area henceforth referred to only as a ***PARK*** took place in 2009, by means of a State Law, which re-evaluated and redefined the already existing Park's boundaries (Figure 1). The law's documentation includes the approximate plane coordinates of the points that define the Park's polygons and their associated areas (SANTA CATARINA, 2009). The law also establishes that the shapefile published by the public institution responsible for managing the Park would be the reference for the purposes of interpreting and delimiting the Park's boundaries (SANTA CATARINA, 2010).

> *'Paragraph 3 For the purposes of interpreting and demarcating the defined boundaries... the delimitation in shapefile format prepared by .... is established as the reference.'*

The shapefile made available by the management institution has served its purpose and has become the basis for society's interpretation of the Park's boundaries. The establishment of administrative or criminal procedures in the event of unauthorized intervention in the protected area depends on the correct and precise interpretation of the boundaries, an interpretation that is a routine activity in forensic examinations involving alleged crimes against the environment.

The Environmental Military Police, municipal environmental bodies with powers of protection and inspection, the Scientific Police, technical assistants, lawyers and society in general all rely on the Park's demarcation polygons to argue their case in proceedings and fines involving non-authorized interventions inside that Protection Unit (Park).

Unfortunately, two versions of the shapefile were published, each one using a different Coordinate Reference System (SAD69 and SIRGAS2000). This paper aims to show that the officially available shapefiles of the Park's delimitation can lead to three polygons that are slightly offset from each other (in the order of meters), which has caused doubts and confusion in cases where the areas under discussion are near the Park's borders.

The possible alternatives that may have produced versions with slightly different borders will be

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analyzed, using the official planimetric coordinates provided in the state legislation as a reference source.

Finally, some recommendations will be presented for professionals working in environmental forensics, for public agencies and for Geographic Information Systems' users in general. The study is structured to address a key practical challenge: the accurate specification of boundaries, with a focus on a natural park. The insights and conclusions drawn may prove helpful in addressing similar challenges in other areas of environmental management and geodesy

Figure 1: Location map of a Conservation Unit (a legally Protected Area) named Serra do Tabuleiro State Park, located in the eastern region of the State of Santa Catarina (Brazil). Area 84,130 hectares. The Park was created in 1975 (IMA, 2024).

2 MATERIAL AND METHODS

2.1 Coordinate Reference Systems (CRSs) for Brazil

The Coordinate Reference Systems used in Brazil were (in historical order): Córrego Alegre, Astro Datum Chuá, SAD69, and currently SIRGAS2000. SAD69 stands for South American Datum 69. SIRGAS2000 stands for "Sistema de Referência Geocêntrico para as Américas 2000", or Geocentric Reference System for the Americas 2000.

Initially, the *Córrego Alegre* coordinate reference system (CRS) was the first horizontal CRS used in Brazil, remaining in use until the early 1970s. It was briefly succeeded by *Astro Datum Chuá*, until the official adoption of SAD69 in 1977. In 1996, an updated version, known as SAD69(96), was introduced to refine the system. Then, in 2005, the IBGE issued a resolution designating SIRGAS2000 as Brazil's official CRS. A transition period of up to ten years was established, during which SIRGAS2000 could be used alongside SAD69. This transition period concluded in 2015

As it is customary within the geoprocessing community, Coordinate Reference Systems (CRSs) are represented by EPSG codes, which are numbers up to five digits that represent and catalogue definitions of different CRSs. The acronym EPSG originated from the now-defunct European Petroleum Survey Group. In practical terms of EPSG nomenclature, the following apply for Brazil, considering only the SAD69 and SIRGAS2000 reference systems, and focusing solely on planimetric coordinates (UTM):

- **A. EPSG 29192** – SAD69 (Classic Network). According to the system description from the EPSG Geodetic Parameter Dataset website (https://epsg.org), it is possible to verify that, in Brazil, this system was replaced by the SAD69(96) system (code 5532, deprecated). Another source (https://epsg.io) identifies EPSG code 5858 as a replacement for code 29192.

- **B. EPSG 5858** – SAD69(96). The obtained description indicates that this system replaces EPSG 29192 and was, in turn, replaced by EPSG code 31982 (SIRGAS2000).

- **C. EPSG 31982** – SIRGAS2000. This is the EPSG code officially used in Brazil for projects and surveys involving geoprocessing.

Brazil presents an additional complexity, as there is another reference system not previously mentioned. In addition to the reference systems with cited EPSG codes (29192, 5858, and 31982), there is also a reference system known as "SAD69/96 Doppler Technique or GPS".

Brazilian Institute for Geography and Statistics (IBGE) provides a platform (an application) for transforming coordinates between different official geodetic reference systems used in the country. The application (available as both a desktop and online version) allows coordinate transformations between the Córrego Alegre, SAD69, and SIRGAS2000 systems. It is a straightforward and objective tool to support the geospatial data user community in the transition to SIRGAS2000. The platform/application is named ProGRID (IBGE, 2009).

In this work, the three transformations in ProGriD that accept SAD69 as the input reference were used. Thus, in addition to the systems with EPSG codes cited in the previous section (EPSGs 29192, 5858, and 31982), the “SAD69/96 Doppler Technique or GPS” reference system is also a possible input reference for data.

2.2 Shapefile Sources for the Park

The polygon that represents the Park's boundaries is available for download on a platform maintained by the management body, which we'll call the Map Library (ML polygon). The information is georeferenced and presented in vector, raster and WMS formats, all designed for use in the UTM SIRGAS 2000 coordinate reference system (EPSG:31982).

The Map Library is widely used by government bodies and society in general. One can download the existing files from the Map Library, from which the layer corresponding to the Park's boundaries was extracted, using the SIRGAS2000 Coordinate Reference System (IMA, 2023).

However, the Park's boundaries are also available on the Management Body's website, catering for those users who don't want to or don't know how to navigate the Map Library, preferring to go directly to the desired shapefile. But we point out that this shapefile unfortunately uses the SAD69 Reference System, although it should represent the same official polygon.

Despite the availability and practicality, unfortunately a practical problem was risen, since there are two official sources (from the Management Body) that provide the Park's delimitation polygons: the Map Library and the website, each with a different Coordinate Reference System (SIRGAS2000 and SAD69).

2.3 ML and CB Polygons

The first source (Map Library) shows these features using the Coordinate Reference System cataloged as EPSG:31982, which correctly represents the Planimetric Coordinate System recommended for Brazil: UTM 22J SIRGAS 2000. The delimitation obtained will henceforth be referred to simply as the ML Polygon or simply ML.

The second source, which shows the ‘Current Boundaries’ of the Park, henceforth referred to simply as CB Polygon or CB for short, shows the features using the Coordinate Reference System cataloged as EPSG:29192, which represents the UTM zone 22S SAD69 Planimetric Coordinate System.

At first, it would be indifferent to use either file, as they should produce the same result. However, when importing the two files (ML and CB) into geoprocessing software, a small difference in positioning was observed between the polygons, which are displaced by distances of around one meters(average difference of 1.2 meters).It should be noted as a very important feature, that the importing of the file with EPSG:29192 can be automatically subjected to an on-the-fly transformation by the geoprocessing software, depending on the settings stipulated by the user.

Naturally, this just-a-few-meters-difference is not acceptable for forensic purposes, and therefore the user will decide to ‘reproject’ the website file (CB polygon, EPSG:29192) to EPSG:31928, which is the CRS recommended for official use in Brazil. Routinely, reprojection is recommended so that the file can be correctly used in geoprocessing software to obtain measurements such as distances and areas. Normally, reprojection does not produce any adverse results.

However, when reprojecting the shapefile obtained from the site file (CB polygon) into EPSG:31928, the processing software QGIS Geographic Information System offers TWO options for data transformation (QGIS, 2023).

Using transformation 1, the same polygon produced by the on-the-fly transformation is obtained (with the same difference of around one meter from the Map Library file ML). The polygon resulting from this transformation will henceforth be called CB1 (Figure 2).

If the user chooses transformation 2, it will be obtained a polygon that is displaced by more than three meters in relation to the Map Library polygon (average difference of 3.6 meters). The polygon resulting from this transformation will henceforth be called CB2 (Figure 2).

In fact, to make an informed choice, users should be aware that there are three distinct "materializations" of SAD69: (1) SAD69 Classic, (2) SAD69/96, and (3) SAD69 based on Doppler Technique or GPS. The user must identify which network the maps and databases belong to, and how they were determined, since these 3 networks (SAD69 Classic Network, SAD69/96 and SAD69 Doppler Technique or GPS) have different distortion patterns. Improper use leads to erroneous results (IBGE, 2009).

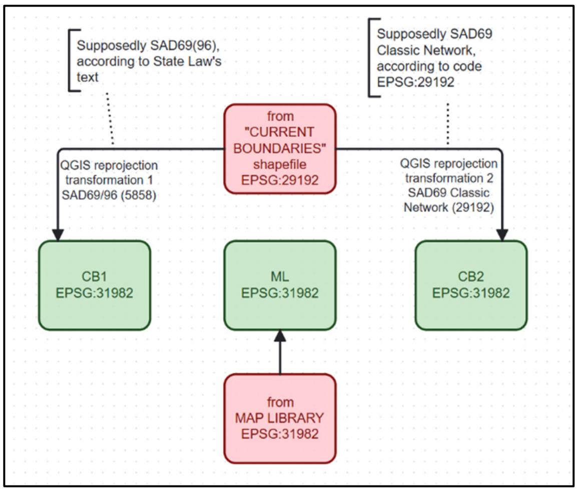

Figure 2: Three polygons obtained for the Park's boundary, depending on the decisions made by the user. The 3 polygons are slightly displaced geographically, in the order of meters.

Two methods were used by our group in our quest to find the correct polygon among the 3 possible polygons (ML, CB1 and CB2). The first method was based on reconstructing the polygon from the planimetric coordinates of the Park's borders, presented in the State Law. The second method was based on a comparison between the polygons obtained (ML, CB1 and CB2) and some physical remnants of the Park's boundaries, in the form of some existing fragments of a "Park fence", physically existing in a few remaining regions.

3 RESULTS

3.1 Reconstruction of the Park's Boundary Polygon from the Coordinates of the Points Reported in the State Law

The Park's polygon was reconstructed based on the planimetric coordinates of the existing points in the State Law (706 points for the polygon). Our group faced some basic problems in the definitions of the points. The first divergence is that point 229 was duplicated and showed different coordinates.

The second divergence is that point 299 was not on the list. It was probably the duplicated point 229 that was typed in wrong. It was then assumed that the entry for the second point 229 was actually point 299.

The third divergence is a series of mistakes. From point 327 to point 340 (14 points in total), each record was duplicated. Fortunately, the coordinates were also duplicated, except for point 335, where the coordinates of the duplicated points were different (differences of approximately 38.7mE and 52.3mN). In this case, it was assumed that the correct coordinates would be from the first entry of duplicate point 335.

The fourth divergence was point 687, which was left unattributed and therefore assumed not to be part of the polygon.

The fifth problem was that the coordinate reference system for which the coordinates are defined is not fully explained in the State Law text, which only mentions the SA69 system (but as we have already seen, there are three possible SAD69 "flavors").

The purified set of coordinates was then used as input for reprojection using QGIS software and for reprojection using the ProGriD platform. For each reprojection platform, the three possible alternatives for the input coordinate reference system were considered.

3.1.1 Reprojection via QGIS

Considering some of the information in the State Law's text, the user could interpret that this is post-1996 SAD69 data, which would lead to the conclusion that the coordinates would be from the SAD69/96 network (EPSG:5858). By reprojecting the file with this choice of EPSG:5858, a polygon is obtained that coincides with polygon CB1 (Current Boundaries with transformation 1, which is the SAD69(96) transformation).

If the user interprets that the coordinates refer to SAD69 Classic Network points (EPSG:29192), the reprojection may result in the CB1 polygon or the CB2 polygon, depending on the transformation option chosen during the reprojection. The possibilities and results were summarized and schematized in Figure 3.

3.1.2 Reprojection via ProGriD

To ensure the transformation with the correct parameters, the planimetric coordinates presented in the State Law were also processed using ProGriD. The platform requires an email address to return the results to, when the input file is very large. Examples of input files on the platform's website are useful for properly formatting the input data (IBGE, 2009). Using ProGriD processing on the same input as before, dully formatted, the following results were obtained (see a summary and illustrative diagram in Figure 3):

a. Assuming SAD 69 Classic Network as the correct input reference, points coinciding with the CB2 polygon are obtained.
b. Assuming SAD 69/96 as the correct input reference, points coinciding with the ML polygon are obtained.
c. Assuming SAD 69/96 Doppler Technique or GPS as the correct input reference, points coinciding with the CB1 polygon are obtained.

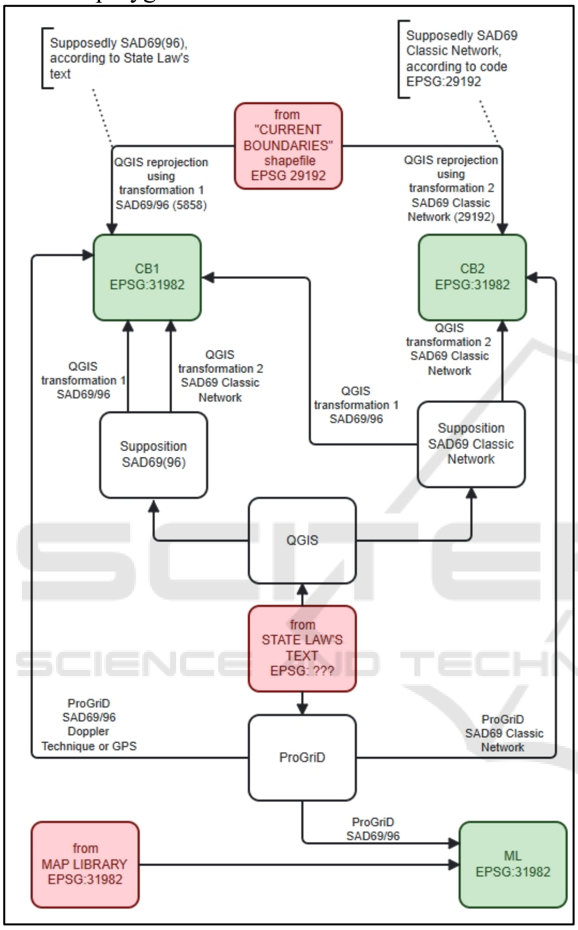

Figure 3: Representative diagram that summaries all the alternatives considered and discussed in this work. The quest to reconstruct the Park's polygon by importing and reprojecting the coordinates provided, using QGIS software, leads to the CB1 and CB2 polygons described in the text. By using the transformations available in ProGriD, our group obtained the CB1, CB2 and ML polygons described in the text.

3.2 Comparison Between the "Park Fence" and the Park Polygons

A second method that was used to try to define the most suitable polygon was based on the existence of some fragments of a fence that would delimit portions of the Park. These fragments of the "Park fence" are well known in the surrounding communities and are generally respected as being the local boundaries of the Park, both by the local community and by institutional representatives (Environmental Military Police, Scientific Police and municipal environmental management bodies).

On 13/Dec/2023, several points of the fence were visited and the planimetric coordinates of the base of the fence-posts were taken. In this study, precise planimetric coordinates were obtained using the Real-Time Positioning (RTK) network technique (Figure 4).

Figure 4: In December 2023, several remaining fragments of the Park's fence were visited. The precise planimetric coordinates of various points representing the geometry of the fence were recorded.

This technique uses reference stations to generate and transmit corrections to the mobile receiver via the NTRIP protocol. For this survey, the Brazilian Network for Continuous Monitoring of GNSS systems in real time (RBMC-IP), the official IBGE network, was used. The reference station used was located in the campus of the Federal Institute of Santa Catarina (IFSC), in the city of Florianópolis, because it was the closest base. Transmitting the corrections in real time to the mobile receiver in the field allows for a significant reduction in positioning errors, ensuring that coordinates are obtained with high precision, to the nearest centimeter.

The limiting factor for using the networked RTK system is related to the transmission range of the radio waves. In our case, the distance between the base station (IFSC) and the mobile station was no more than 25 kilometers in a straight line, a fully acceptable distance for this positioning method and the topography of the area to be surveyed.

The 20 points sampled (excluding outliers) were imported into QGIS and compared with the polygons mentioned above (ML, CB1 and CB2 polygons). The points obtained do not coincide exactly with any of the 3 polygons (Figure 5). However, the samples of the fence coordinates show a greater proximity to polygon CB1 (distance μ=0.19 meters σ=0.14 meters). The points fall at greater distances from the ML polygon (distance μ=0.62 meters σ=0.21 meters) and the CB2 polygon (distance μ=2.85 meters σ=1.26 meters).

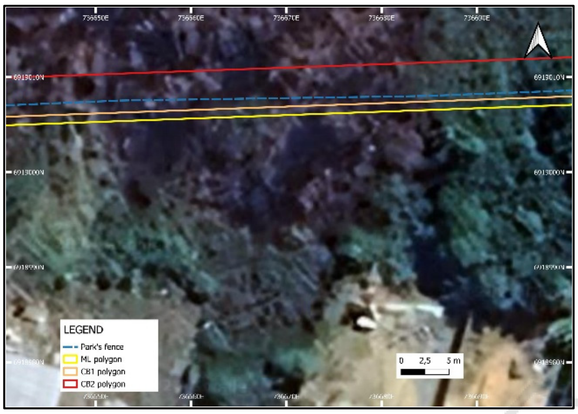

Figure 5: The fragments of the "Park fence" are not exactly aligned with the polygons analyzed, but they are closer to the CB1 polygon. Map produced by the authors, using QGIS 3.30.1-'s-Hertogenbosch. Coordinates are stated in UTM22J SIRGAS2000 (EPSG:31982).

4 DISCUSSION

IBGE Resolution No. 1/2005 established SIRGAS2000 as the new CRS for the Brazilian Geodetic System. A transition period of ten years was granted (expired in 2015), allowing SIRGAS2000 to be used concurrently with SAD69The Map Library file ML provides a polygon referenced using the EPSG:31982 UTM SIRGAS 2000 system (which is currently the official coordinate reference system in Brazil).

The 'Current Boundaries' file shows the shapefile referenced using SAD69 Classic Network (EPSG:29192), in non-compliance with IBGE Resolution 1/2005

The "Current Boundaries" file can provide two polygons, depending on the user's interpretation: (1) polygon CB1, assuming that the data is referenced to the SAD69/96 system (as suggested by the dates in the description in the State Law’s text); (2) polygon CB2, assuming that the data is referenced to the SAD69 Classic Network system (as suggested by the EPSG:29192 code used in the available shapefile).

When using ProGriD platform to transform the Park's boundaries coordinates (informed in the State Law), the same three polygons are obtained, depending on the choice between three possible transformations: SAD 69 Classic Network (provides CB2); SAD 69/96 (provides ML); and SAD 69/96 Doppler Technique or GPS (provides CB1).

The polygon in the map library (ML) and the two polygons from the 'Current Boundaries' file (CB1 and CB2) do not coincide, which could lead to problems in the characterization of the Park's border.

Furthermore, the points obtained as a sample for the "Park fence" do not coincide with any of the three polygons, although they are closer to the CB1 polygon.

Although the field GPS data suggest an advantage in using the CB1 coordinate reference system, the challenges in coordinate transformations prevented a clear conclusion regarding the most suitable system for defining the park's boundaries. The discrepancies between the various transformation methods—such as SAD69 Classic Network, SAD69/96, and the Doppler Technique—resulted in inconsistent outcomes. This lack of alignment between the transformations, combined with uncertainties in the input data, complicated the decision-making process. Despite the GPS data favoring CB1, the differences between the transformed polygons and the park's boundary points highlight the difficulty in selecting a definitive coordinate reference system. These issues, along with the lack of consensus in transformation systems, are discussed in greater detail in the alternatives analyzed below.

Alternative A. Assuming the data were from SAD69 Classic Network, the CB2 polygon would be obtained using both the QGIS reproject and ProGrid transformation. It is reasonable to assume that the input data is in the SAD69 Classic Network system, since this is stated in the EPSG of the shapefile (EPSG 29192), but the text of the State Law suggests otherwise. Furthermore, the CB2 polygon obtained is the one furthest away from the "Park fence".

Alternative B. If the data were from the SAD69/96 system, then the CB1 polygon would be obtained (using the QGIS reproject), but the ML polygon would be obtained (with the ProGriD transformation). It is reasonable to assume that the data is from this reference system, due to the dates declared in he State Law’s text. However, this produces two different polygons, with the ML polygon being favored because it was produced by ProGriD, which is the official transformation platform. However, the points collected from the "Park fence" are closer to the CB1 polygon and not the ML polygon.

Alternative C. Assuming that the data were originated from the SAD69/96 Doppler Technique or GPS system, then the CB1 polygon would be obtained (with the appropriate ProGriD transformation). It's reasonable to assume that the data is from this system, because in this case you get the polygon that is closest to the points collected from the "park fence" fragments.

By disregarding alternative A, two viable polygons remain: CB1 and ML. If CB1 were to be established as the legitimate polygon, there would be a number of implications that would make this option costly and not defensible..The first consequence would be the need to reconstruct the Park's polygon to replace the existing one in the Map Library.

When considering the ML polygon as correct, it can be seen that the only way to obtain this polygon from the points in the State Law's text, would be to use ProGriD with the transformation that considers the origin of the data in the SAD69/96 system. If this is the correct polygon, it is important to note that the points collected near the fragments of the Park's fence do not coincide with this polygon, but are a certain distance apart (μ=0.62 meters σ=0.21 meters).

5 CONCLUSION

Under the light of the discussions in this study, our group has produced the following recommendations as a contribution to public authorities and Santa Catarina society.

Recommendation 1 – Recommendation to the State Government that the Managing Body expressly and unequivocally define which shapefiles (UTM 22S SIRGAS 2000 EPSG:31982) correctly define the Park's polygons.

Recommendation 2 - Recommendation that users always use shapefiles reprojected to EPSG:31982, refraining from using on-the-fly transformations. Whichever network is selected for importing the points (SAD69 Classic Network or SAD69/96), the user must take appropriate care when "reprojecting" the points to the UTM 22 SIRGAS 2000 reference system (EPSG:31982), as choosing the wrong transformation can lead to positional errors of the order of a few meters.

Recommendation 3 - Recommendation that users always obtain information or confirmation of the origin of the data when using SAD69 coordinates, so as not to confuse SAD69 Classic Network data, SAD69/96 data and SAD69/96 Doppler Technique or GPS data. When importing into QGIS, pay attention to the deprecated codes. The EPSGs 29192 (SAD69 Classic Network), 5858 (SAD69(96)) and 31982 (SIRGAS 2000) should be used.

Recommendation 4 – The park's fence does not coincide with the Map Library's original polygon. However, the fence has been respected by the communities and has been used as a marker by the Environmental Military Police and the Scientific Police. The government should clarify the role played by this so-called park fence in the regions where this structure remains.

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