

ORIGINAL RESEARCH ARTICLE

Quality analysis of the cadastral map in Costa Rica using geographic information systems (GIS) of public license

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ABSTRACT

This article presents a methodology to perform quality analysis on the cadastral map, based on the tools provided by open (public or free) license geographic information systems (GIS). The errors presented in the cadastral map have a direct impact on the information systems, which can lead to erroneous decisions and to an increase in the costs of maintenance and updating of spatial data. The methodology developed was used and tested by Costa Rica's Cadastre and Registry Regularization Program; as a product of this program, a continuous cadastral map has been created for Costa Rica, on which cadastral and registry transactions will be processed within the National Registry of Costa Rica. The methodology allows detecting, locating and classifying errors in the cadastral map for easily correcting, so that this map correctly represents the reality of the properties that conform it

Keywords: Cadastre; Cadastral Map; Geographic Information System (GIS); Open License

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1. Introduction

Spatial information or geo-information has become a fundamental element for modern human activities. The acquisition, processing and visualization of spatial data is a useful function in all current information systems, including cadastral information systems.

During the implementation of modern Cadastral Information Systems (CIS), Geographic Information Systems (GIS) have become an essential tool, both for the production of graphic data and for the administration of cadastral information. In addition, the existence of multiple GIS with public licenses allows institutions to have these tools at their disposal in an expeditious manner without economic investment.

The quality of the cadastral database is extremely important, since other systems, such as Spatial Data Infrastructures (SDI), land tax collection systems, real estate valuation systems, emergency systems, and so on, are developed and based on it. The quality of the cadastral map has a direct impact on other information systems, so that map errors can lead to erroneous decision making and increased maintenance and updating costs of spatial data.

The process of purging a cadastral map is tedious and has a high economic cost, hence, there is a need to propose solutions such as the one described in this article to automate the detection, locate and classify errors, in order to facilitate their correction. The methodology developed was tested within the framework of the Regularization Program of the Cadastre and Registry of Costa Rica. Under this regularization project, a continuous cadastral map has been created for Costa Rica, on

which cadastral and registry transactions will be processed within the National Registry of Costa Rica.

2. Theoretical and conceptual framework

2.1 The Cadastre

The National Cadastre Law No. 6545^[1] defines the following fundamental concepts of the cadastre:

Article 2. The Cadastre consists of the graphic, numerical, literal and statistical representation and description of all lands included in the national territory. Its operation meets public interest and serves legal, economic, fiscal, administrative purposes and all those determined by the laws and regulations.

Article 3. The fundamental documents of the Cadastre are:

a) Cadastral maps showing the location, identification and boundaries of the parcels.

b) Cadastral records consisting of: cadastral records, parcel indexes by maps and alphabetical indexes.

c) In accordance with the plans of the Cadastre, documents showing the present and potential use of the land, the waters included, the natural resources and any others that serve the specific purposes of the Cadastre may be incorporated.

Article 6. Parcel is the cadastral unit represented by a portion of land, which constitutes a complete physical unit, and which is delimited by a line that, without interruption, returning to its point of origin.

Article 7. Predio is the portion formed by one or several contiguous parcels, which is interdependent among themselves. And they located in a single province, belonging to one or several owners or possessors.

2.2 Geomatics and Geographic Information Systems (GIS)

Geomatics involves a comprehensive and multidisciplinary approach, using specific tools and techniques for acquiring, integrating, managing, analyzing and distributing geo-referenced spatial data in digital format^[2].

As a specific tool, the geographic information

system (GIS) is defined as a powerful set of tools for collecting, storing, querying, transforming and presenting real-world spatial data for specific purposes^[3] within the field of geomatics. It is the GIS that allows storing, managing and analyzing the graphic, numerical, literal and statistical description of the cadastre parcels.

Among the analysis tools in a GIS, spatial analysis tools that consider the location and relationship of geographic objects are of importance for cadastral data. This is because relationships such as overlaps or spaces between objects of interest to the cadastre (parcels or properties) have registry and legal implications. Topology is the science and mathematics of relationships between objects, which is useful for geometric validation in drawing, editing, maintenance, and others^[4].

2.3 Open Source of GIS (OSGIS)

The development of software applications based on the philosophy of collaboration among developers and researchers distributed around the world has been well received by the global community. This type of applications provides the opportunity to implement new methods, algorithms and tools, allowing the refinement and improvement of existing code^[5]. For end users this development model provides high-interoperability and sophisticated tools at no cost. In the field of Geographic Information Systems, these free of cost and open-source applications have also become widespread.

There are multiple options of GIS programs with public license (known as open source), from simple viewers of cartographic layers and their attached data, to applications with a great variety of tools for advanced spatial analysis. Some recognized examples of OSGIS are:

- GvSig, available from <http://www.gvsig.org/web>
- Kosmo, available from <http://www.opengis.es/>
- QGIS, available from <http://qgis.osgeo.org/es/site/>
- JUMP, available from <http://www.openjump.org/>

There are several types of public use licenses, but the most common is the GNU/GPL license type (details available at the Internet address <http://www.gnu.org/licenses/>). This type of license allows access to the original program code for modification and also free redistribution, as long as the reference to the original author is maintained.

2.4 Program of Regularizing Cadastre and Registration (PRCR)

The Program of Regularizing Cadastre and Registration (PRCR) was approved by the Legislative Assembly of the Republic of Costa Rica in 2001, through Law No. 8154^[6]. The funding came from a loan agreement with the Inter-American Development Bank (IDB) and also from the Government's own contributions.

The primary objective of the program is to form the Cadastre of all existing properties in the country with duly geo-referenced, integrated and to make compatible with the Real Estate Property Registry. The graphic and literal description of the properties resulting from this process forms the digital cadastral map, on which all real estate transactions will be carried out in the National Registry of Costa Rica.

To manage these transactions, the PRCR is implementing a computer system called the Real Estate Registry Information System (RERIS). Additionally, this cadastral map will become part of the fundamental data of the National Territorial Information System (NTIS) of Costa Rica^[7], so that it will be used by different state institutions such as municipalities, the National Geographic Institute, the Municipal Development and Advisory Institute (MDAI), the Technical Standardization Organization (TSO), the Ministry of Environment and Energy (MINE), the Institute of Urban Development (IUD) and etc.

For the creation of the cadastral map of the country, several private companies were contracted and the National Cadastre is in charge of the quality assurance of the map; for this process, a series of requirements that the cadastral map must comply with were defined. Non-compliance with these requirements would be treated as map errors. A

methodology was established to detect errors, their type and location, in order to facilitate their correction^[8].

2.5 The creation of cadastral maps

Photogrammetric techniques are usually the main source for the generation of the cadastral map. Photogrammetric flights are planned and executed at relevant scales according to the area to be mapped, whether in rural or urban^[9].

In the PRCR of Costa Rica, flights were made at a scale of 1:6,000 for urban areas and 1:25,000 for rural areas, which made it possible to generate basic cartography both at a scale of 1:1,000 and 1:5,000 respectively^[10]. Based on the aerial photographs, the basic cartography is created by the restitution or photogrammetric rectification method and on this base cartography the properties that make up the cadastral map are delineated.

In the case of Costa Rica, the cadastral plans registered in the National Registry were used as an input for the edition of the properties in the map drawing stage. The quality of this cadastral map depends a lot on the experience and knowledge of the area of the technical personnel who carry out the basic cartography and the conformation of the cadastral map. These cadastral maps have, in Costa Rica, a very high relative accuracy, but a poor external accuracy, that is to say that the maps reflect very well the reality of the boundaries that delimit the properties (relative accuracy) but the geographic location (absolute accuracy) of the property is very poor. This fact implies that some of the properties may overlap with each other, or leave gaps between them.

In addition to this, in the process of drawing the properties, residual errors can be generated that violate the National Cadastre regulations, such as properties with smaller areas than those allowed areas, boundaries that intersect each other, very short distances between consecutive points that define a boundary, and etc. All these errors in the Cadastral Map must be detected and eliminated in order to generate a quality product that represents the geometric reality of the properties.

The PRCR contracted several private compa-

nies to carry out the photogrammetric work, for cartographic restitution, and creating the cadastral map. Subsequently, a quality control was performed on the cadastral map, so that the detected, located and classified errors were then corrected.

2.6 Quality analysis of the cadastral map

In the quality analysis of a cadastral map, considering the definition provided by Law 6545, which includes the graphic (geographic) and alphanumeric components, two types of fundamental validations can be performed:

- Registry: validation whether the property's registry information reflects the legal reality.
- Graphics: the graphic quality of the cadastral-predial map is validated, it must comply with the established standards.

Graphical validations include the comparison and review of the information in the databases to verify its timeliness and veracity; the focus of this article is the graphical component of the cadastral map.

2.7 Topology in GIS

The adjacency and connectivity relationships of spatial objects in Geographic Information Systems are explicitly defined by topology. Based on the coordinates of the vertices of spatial objects, it is possible to establish the relationships of neighborhood, overlapping, intersection or closeness between objects^[11]. Topology is used to determine the relationships of objects in space, for example to determine which objects are adjacent to a specific object, which applies to lines, points, or areas^[12].

Modern GIS platforms offer tools that allow defining sets of topological rules and through them, to define constraints for editing and creating spatial elements.

2.8 Methodological framework

The following sections present a summary of the steps defined for the application of topological tools in the quality analysis of the cadastral map. Considering the quality guidelines provided by the official regulations in force, the topological rules to be used, a set of test data, tool configuration and

control tests are defined to validate the applied methodology.

The methodological proposal deals with the analysis of the technical and legal norms that govern the National Cadastre in order to define from them a set of geometric rules that allow the development of cadastral maps that correctly represent the physical reality of the properties that comprise them. The solution proposed here allows the quantification and qualification of the errors presented in the cadastral map, so that they can be located and corrected.

2.9 Definition of the quality analysis model

Based on Law 6545 of the National Cadastre and its regulations for the qualification of survey plans, the set of geometric conditions on which the quality model of the cadastral map would be based was defined. This model is expressed in the GIS platform by means of the topological rules described in the following section.

2.10 Definition of topological rules

The topological rules defined for the quality analysis of the cadastral map are the following:

- No overlaps allowed: Properties must not overlap with neighboring properties.
- No gaps allowed: Between neighboring properties there shall be no empty spaces.
- Rings are not allowed: There shall be no holes (donut effect) within the property.
- Self-intersection of boundaries is not allowed: Boundaries on the property shall not intersect each other.
- Minimum areas: Properties with areas below the specifications of the National Cadastre are treated as errors.
- Duplicity of points is not allowed: The points defining the boundaries of the properties may not be repeated.
- Minimum length of boundaries: The boundaries that define the properties must not be less than the standards established by the National Cadastre.
- Multi-polygons are not allowed: The property must not consist of multiple spa-

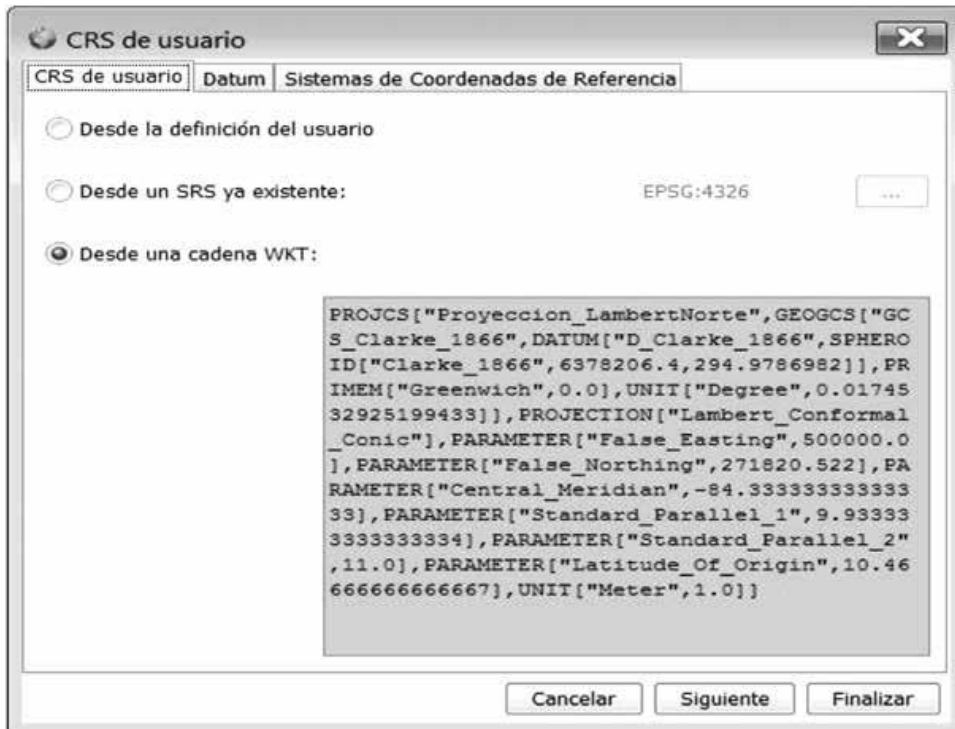


Figure 1. Coordinate definition window.

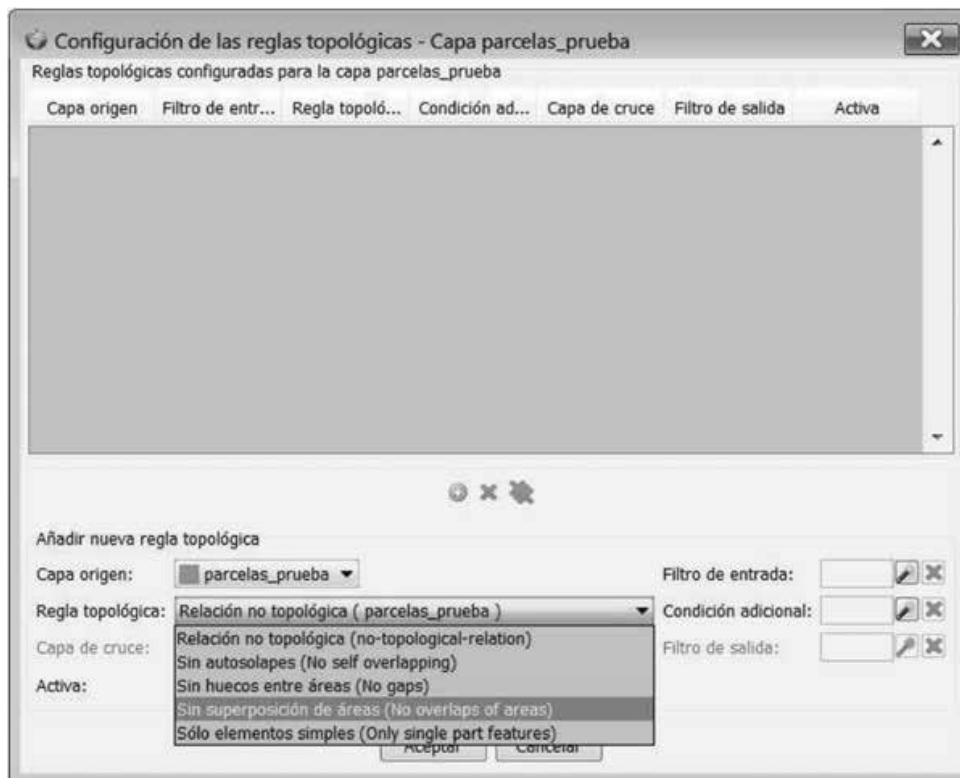


Figure 2. Selection of topological rules to be applied.

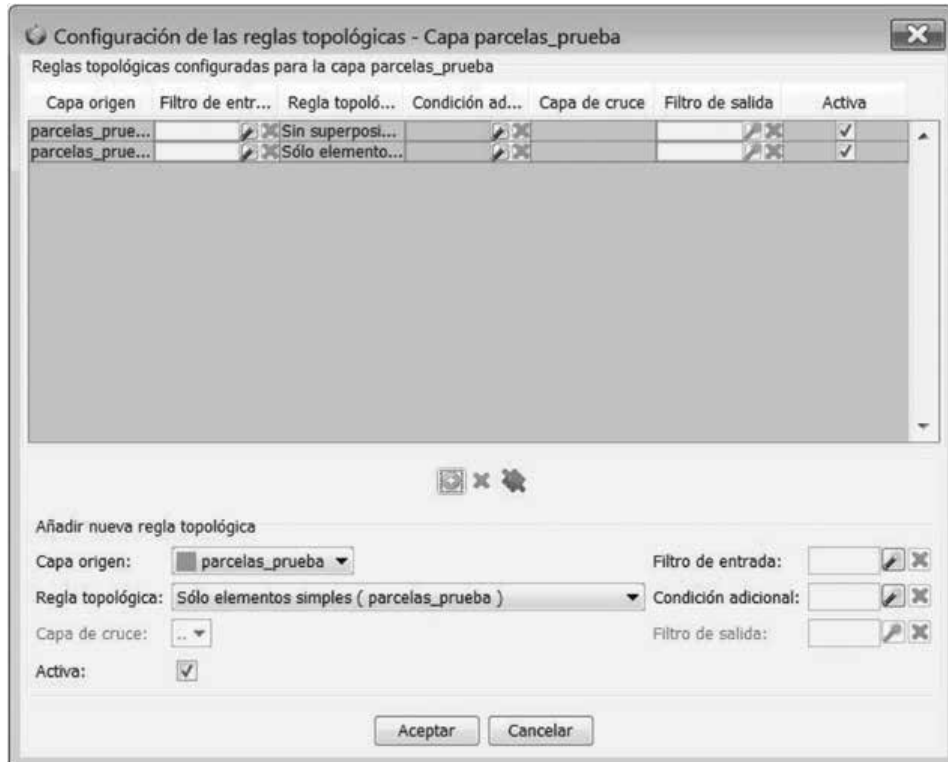


Figure 3. List of topological rules defined for the layer to be analyzed.

- tially separated parts (polygons).
- Correctly georeferenced properties: The properties must be located in the position denoted on the original cadastral map, by means of their geographic location and distances to the corner.

2.11 Configuration of topological tools

The validation methodology included the use of the GIS platform called KOSMO, which is obtained as publicly licensed software. In the configuration stage of the work project, the correct definition of the coordinate system in accordance with the drawing coordinates of the layer to be analyzed is recognized as fundamental; for the layer used it is the projected system Lambert Costa Rica North, with unit in meters.

It was decided to use a layer in this projected coordinate system considering that most of the spatial analysis tools work optimally with coordinates in a linear system, but not in a spherical or episodic coordinate system. **Figure 1** shows the coordinate system definition window in which the standard WKT (Well-known text) option was used.

In the tool configuration stage in the GIS plat-

form, the topology rules configuration window and the geometric validation of layers window are used. **Figures 2** and **3** show the options used for the creation of two topology rules:

- No overlap: Allows you to search for objects with overlapping or overlapping objects on the same layer
- Single items only: Allows you to search for objects that have multiple parts.

3. Control tests

Two data sets were used for the control tests. In the first one, the test data handled consisted of a total of 36 polygons that graphically represent the properties of a geographic area, stored in a shapefile (shp) file. In this set of polygons, arbitrarily and artificially created by errors was foreseen by the quality analysis model derived from the official regulations in force in the country. The proposed methodology was applied on this data set and it was possible to locate and identify each and every one of the errors presented in the map, thus validated the methodology.

The second test dataset consisted of real data from the district of Mansion, canton of Nicoya,

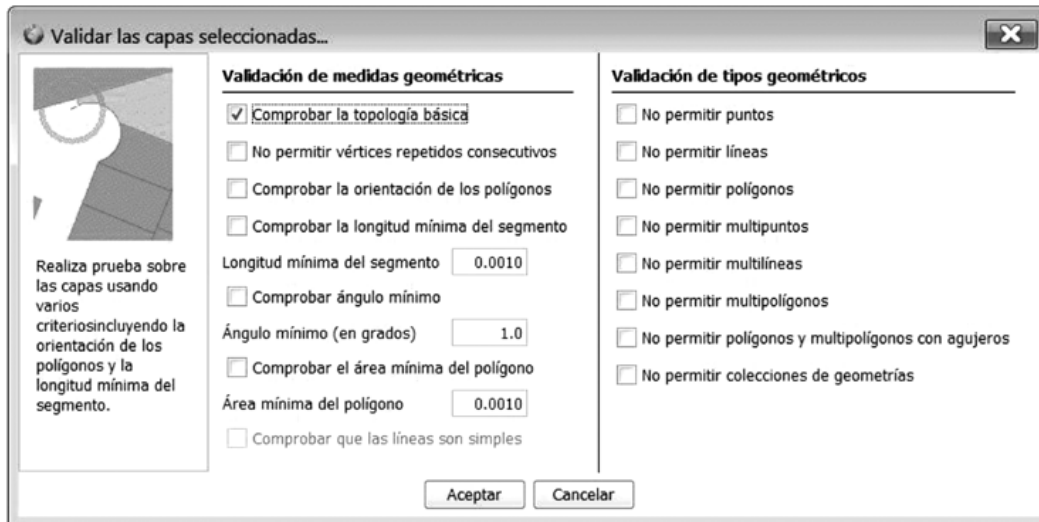


Figure 4. Geometric validation window.

province of Guanacaste. This dataset had a total of 3,000 properties, geometrically represented as polygons in shapefile format. By applying the quality control methodology, it was also possible to detect, locate and classify the errors present in the map. A total of 1,357 errors were detected, 951 overlaps, 223 boundaries that intersected on themselves, 78 properties with areas less than the allowed, 89 properties with boundary length less than the allowed and 94 properties with duplicated vertices.

The selected topology rules allowed the search and identification of problems from registry, cadastral and legal aspects, such as the overlapping of parcels or properties. The review to locate other types of topological problems was performed with the tools of the geometric validation window of

layers shown in **Figure 4**:

- Check the minimum length of a segment.
- Check the minimum area of a polygon.
- Do not allow multi-polygons or polygons with holes.

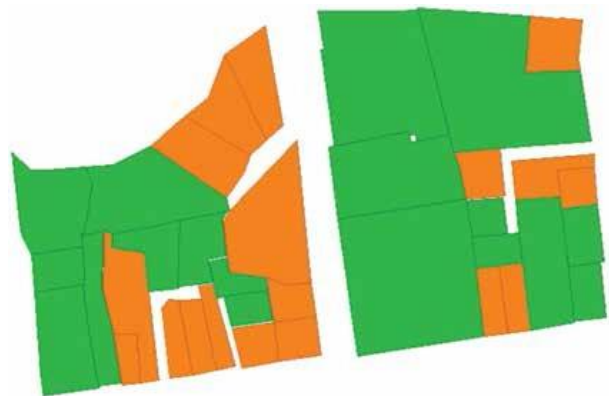


Figure 5. Graphical result of the application of topological rules.

Ver atributos : Errores de topología parcelas_prueba

Errores de topología parcelas_prueba (18 elementos - 0 seleccionados)

| GID | ID_FEATURE | SOURCE | OPERATION | TARGET | REASON |
|-----|------------|-----------------|--|--------|---------------------|
| 0 | 5 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 1 | 6 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 2 | 7 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 3 | 8 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 4 | 10 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 5 | 12 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 6 | 14 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 7 | 15 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 8 | 16 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 9 | 18 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 10 | 20 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 11 | 22 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 12 | 24 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 13 | 28 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 14 | 29 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 15 | 30 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 16 | 33 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |
| 17 | 34 | parcelas_prueba | Sin superposición de áreas (parcelas_prueba) | NULL | No cumple topología |

Figure 6. Tabular result of the application of topological rules.

4. Results

The results obtained from the application of topological rules on the test areas are shown in **Figures 5 and 6**. **Figure 5** shows in green color the properties without overlapping problems and in orange color the polygons involved in overlaps. **Figure 6** presents the related tabular result, where the identification information of the polygons with overlapping can be seen.

Based on the results of the quality analysis, each of the errors detected were reviewed and corrected, so that the resulting digital cadastral map is correct from a geometric point of view, i.e. It represents the reality of the country's properties for the purposes of the National Registry of Costa Rica. All real estate transactions will be based on this cadastral map, including registrations, segregations, reunions of properties, as well as the generation of property certifications

5. Conclusions

The use of publicly licensed GIS tools such as KOSMO allows performing quality analysis processes on digital cadastral maps at a low cost. This allows ensuring the quality of the map, so that it can be used as a basic input in cadastral and registry information systems or support systems for decision making such as emergency systems, spatial data infrastructures (SDI), municipal tax collection systems, among others.

Open Source of GIS (OSGIS) that have a variety of tools for topological analysis, such as KOSMO, allowing the application of topological rules in the analysis of the cadastral map. Additionally, they represent a free option for institutions such as municipalities to analyze and exploit the cadastral map.

The methodology developed to perform the quality analysis processed on a cadastral map al-

lows automating the detection, location and classification of errors, thus facilitating the editing and correction stage, resulting in a map that correctly represents the physical reality of the properties.

Conflict of interest

The authors declare no conflict of interest.

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