Analysis of OpenStreetMap to support an official hybrid database

Rogério L. R. Borba*, Julia C. M. Strauch, Jano M. Souza*, David J. Coleman*****

* Federal University of Rio de Janeiro (UFRJ). Institute Alberto Luis Coimbra of Postgraduate Studies and Research in Engineering. Systems Engineering and Computing Program (PESC)
** Brazilian Institute of Geography and Statistics (IBGE) – Rio de Janeiro, RJ – Brazil
*** University of New Brunswick (UNB). Geodesy and Geomatics Engineering (GGE)

Abstract. This paper performs an exploratory analysis in the Brazilian OpenStreetMap database identifying the layers and areas with the most concentration of information. To accomplish this, the databases were reconciled and spatial analysis operations were implemented. The analyses encompass three levels: the country, the state of Rio de Janeiro and the city of Rio de Janeiro - a big urban area. Findings point out the need to develop methodologies to analyze the accuracy and geometry of the data at the local level so that the open data can be incorporated into local official base forming a hybrid database.

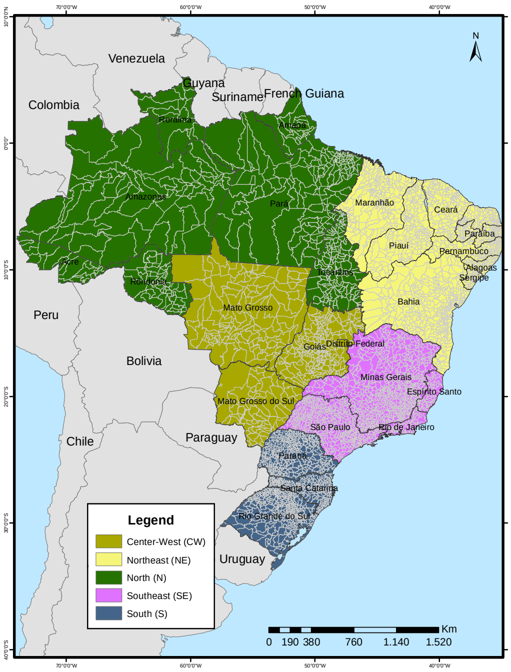
Keywords: Hybrid database, Open data, Exploratory analyses

1. Introduction

Brazil is an emerging country of continental size and disparate conditions. With 5,570 municipalities and 27 federal units, as illustrated in *Figure* 1, the mapping and updating cartographic processing is time consuming, expensive and requires a great deal of effort. Within the Government, there are organizations that produce geographic information, such as the Geography and Statistics Brazilian Institute (IBGE) and the Board of Geographical Service of the Brazilian Army (DSG). However, the lack of technical, financial and human resources is a critical factor that undermines the mapping processes conducted by these institutions. The consequence of this scenario is stagnation of official cartographic production. These organizations are failing to carry out their activities in the face of increasing public demands.

On the other hand, the use of geographic information produced by initiatives of crowdsourcing in geographical information for public and private institutions around the world is now underway or under study (Coleman, 2013). Indeed, the term Volunteered Geographic Information (VGI) coined by Goodchild (2007) is now a growing area of research and has gained attention in academia.

Numerous research projects have been and are being conducted in this area. Some research showed that in certain regions, this type of information has a significant variability in relation to their community, production and quality and some implicit and explicit factors influence this variability. For example, Neis *et al.* (2013) conducted a survey in 12 urban areas in different parts of the world. They found similarities and differences in relation to the database and the user community. Furthermore, their analyses show urban areas provide significantly different data concentrations in OpenStreetMap (OSM) database, but the number of volunteers does not necessarily correlate with the general population density of these areas and socio-economic and income factors may have an impact on the number of active contributors and the data provided in the these areas.



States	Region	Mun.	Hab/Km^2	HDI2010
Roraima (RR)	N	15	2,0	0.690
Amazonas (AM)	N	62	2,2	0.674
Mato Grosso (MT)	CW	141	3,4	0.725
Acre (AC)	N	22	4,5	0.663
Amapá (AP)	N	16	4,7	0.708
Tocantins (TO)	N	139	5,0	0.699
Pará (PA)	N	144	6,1	0.646
Rondônia (RO)	N	52	6,6	0.690
Mato Grosso do Sul (MS)	CW	79	6,7	0.729
Piauí (PI)	NE	224	12,4	0.646
Goiás	CW	246	17,7	0.735
Maranhão (MA)	NE	217	19,8	0.639
Bahia (BA)	NE	417	24,8	0.660
Minas Gerais (MG)	SE	853	33,4	0.731
Rio Grande do Sul (RS)	S	497	37,9	0.746
Paraná (PR)	S	399	52,4	0.749
Ceará (CE)	NE	184	56,8	0.682
Rio Grande do Norte (RN)	NE	167	60,0	0.684
Santa Catarina (SC)	S	295	65,3	0.774
Paraíba (PB)	NE	223	66,7	0.658
Espírito Santo (ES)	SE	78	76,3	0.740
Pernambuco (PE)	NE	185	89,62	0.673
Sergipe (SE)	NE	75	94,4	0.665
Alagoas (AL)	NE	102	112,3	0.631
São Paulo (SP)	SE	645	166,2	0.783
Rio de Janeiro (RJ)	SE	92	365,2	0.761
Distrito Federal (DF)	CW	1	444,7	0.824

Figure 1[a]. Administrative political division and population density.

There are also works focused on dimensions of quality of VGI database. For example, Haklay (2010) conducted research on the positional accuracy and complete-

[a] Municipality (Mun.), Habitant(Hab.) and Human Development Index(HDI).

ness of the roads in OSM, and compared with the official database of England. He concluded that OSM data offer reasonable accuracy and did some considerations and suggestions for future developments and research directions. Girres and Touya (2010) investigated the dimensions of the quality of the Open Street Map database in France and suggested mechanisms of automatic quality assurance in the process of match open data for mapping. Cooper and Coetzee (2012) evaluated two volunteered databases in South Africa and analyzed the dimensions of information quality of these bases. They highlighted that differences between developed and developing countries should be take into account when considering volunteered contributions. Goodchild and Li (2012) stated that VGI suffers from a general lack of quality assurance. They discussed issues involved in determining the quality of volunteered geospatial data and described three approaches to support quality assurance.

Some researchers investigated the use of volunteered database into official or commercial databases. For example, GeoConnections (2012) and Saunders et al. (2012) summarize early technical advice and raise important legal and data licensing considerations in this regard for organizations considering such integration. Coleman (2013) raises some questions regarding VGI and suggests that, while this mapping initiative is not a solution to all kinds of problems of creating and updating official or commercial geographic database, it is an important resource that should be taken into consideration. Haklay et al. (2013) and Lauriault et al. (2014) provide recent examples of research into the acceptance of VGI into public sector programs.

In Brazil, institutions such as IBGE produce geospatial information for different types of products and applications. Thus require different quality levels in terms of, for example, positional accuracy and completeness. Therefore, the use of a hybrid database derived from open and official databases depends on a variety of factors such as the purpose and context in which this hybrid base is used.

Some OSM layers are already being used as one of the options in a visualization tool of NSDI in Brazil. However, program managers in Brazil still lack a study regarding the integration and/or use of the OSM database with official databases. In this sense, this work examines how, in a Brazilian context, this open database could be incorporated into official databases, thus creating a hybrid database taking into account selection criteria and quality-based filters. In this way, a study about OSM Brazilian database could be answering the following questions:

(1) In which regions do these open solutions provide more information? Which regions offer less information? What is the relationship with the user community?
(2) What is the quality of that open database? Is it possible to generate a hybrid base from a combination of bases to official?

(3) What requirements must be fulfilled in order to accept the whole or only part of this database? Or discard it?
(4) Following the directives of open government and open data, what could be done to create a symbiotic relationship between open and official mapping?

The first question will be answered by this paper, seeking the region where there are greatest concentrations of OSM Brazilian data through an exploratory analysis. First, the OpenStreetMap data model is revisited in Section 2. Section 3 describes an analysis of OSM data and Section 4 contains the summary and concluding remarks.

2. OpenStreetMap

OSM is a collaborative web mapping tool and project that makes free and open crowdsourced geospatial data available to anyone with access to the Internet (Curran *et al.*, 2012). Any user can view, edit, upload, download and use geospatial data. Steve Coast founded OSM in 2004, initially focusing on mapping the United Kingdom. Today, this initiative has more than 2,000,000 registered users around the world (OpenStreetMap Statistics, 2015) and is growing as illustrated in *Figure* 2. According to Mullen *et al.* (2014), while this data is becoming widely used, the understanding of the quality characteristics of such data is still largely unexplored. Therefore, this paper takes into account the volume of OSM Brazilian data to choose an area to assess the quality of their fitness for NSDI applications.

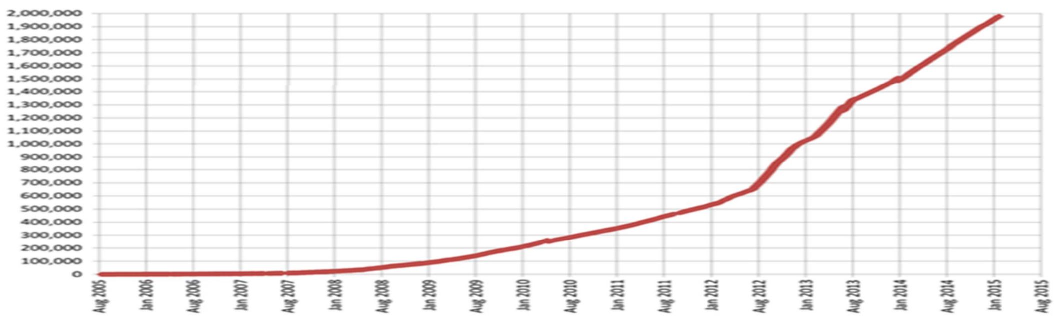


Figura 2. OpenStreetMap registers users (OpenStreetMap Statistics, 2015)

OSM has basic functionalities such as pan, zoom, search, uploading GPX, export data and editing data accessible to any user (Haklay and Weber, 2008). Furthermore, OSM project offers community-wiki, which contains information about the project and guidance on best practices to casual and advanced mapping contributors and an extensive documentation of technical infrastructure (Haklay and Weber, 2008). A remarkable feature of OSM is the data sources, featured two-way, that come from different actors as depicted in *Figure* 3. Furthermore, it have been used in different contexts such as earthquake that struck Haiti in 2010 (Zook et al., 2010), mapping bicycle trails (Hochmair *et al.*, 2013), official mapping (Wolf *et al.*, 2011) and others.

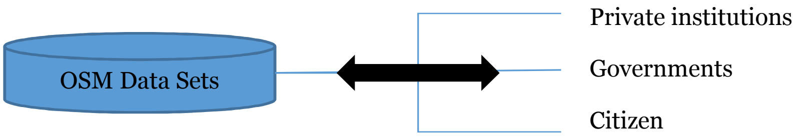


Figure 3. OpenStreetMap data sources

Indeed, OSM is frequently cited as one of the most successful VGI projects in the context of GIS community (Budhathoki and Haythornthwaite, 2013) and a large part of the success has been due to its diverse user base around the world (Curran et al., 2012).

2.1. Data Model

In OSM, elements are described through tags. OSM uses, at the moment, a total of 29 primary feature classes such as building, highway, leisure, sport and tourism. It is an open platform that covers the largest variety of feature classes (Hochmair and Zielstra, 2013).

Understanding the data model of OSM is important because any stakeholder could interact with data in its raw form and manipulate it into formats that are more useful for personal purpose (Bennett, 2010).

The database schema is designed to support requirements such as versioning and rollbacks and the core model of feature classes are following (Bennett, 2010; Haklay and Weber, 2008;

- Node - Point on Earth which contains the latitude and longitude coordinates along with user name and timestamp information. Examples: bus stops, benches etc.
- Way – is a list of ordered nodes (between 2 and 2,000) that represents polyline or polygon (closed way). Examples: roads, rail lines, trail, forests etc.
- Relation – is an ordered list of nodes, ways or relations. This data structure documents a relationship between two or more data elements (nodes, ways, and/or other relations).
- Tag - is a dictionary (key-value pair of strings) optionally attached to each geographic feature (represented by Node, Way or Relation). Any feature can contain zero or more tags describing it. Each tag can be any pair of strings up to a maximum of 255 characters, with the only restriction that keys be unique inside one element.

It is noteworthy that a "polygon" is not explicitly defined in the database schema. Polygon is defined implicitly by restriction (the first node of a way is the same as the last one) and explicit tagging conventions (using the tag area=yes) (Haklay and Weber, 2008).

2.1.1. Others Characteristics

OSM data files are usually distributed in an XML format representing the three types concepts (node, way, and relation) using a simple schema, usually in compressed format as gizp and bz2 (Bennett, 2010). Other formats are PBF, O5m and JSON. The Horizontal *Datum* used by Open Street Map is WGS-84 ("OpenStreetMap Wiki-WGS84," n.d.) and the coordinate system is latitude and longitude geographic.

OSM uses two types of licenses: Open Data Commons Open Database License and Commons Attribution-ShareAlike 2.0 license ("OpenStreetMap copyright and license," n.d.). Anyone is free to copy, distribute, transmit and adapt the OSM data.

In Brazil, data from Public Institutions, even though open, have a distinct type of license and this issue needs to be addressed to create a hybrid database.

3. OpenStreetMap Brazilian database

To accomplish the exploratory analysis, relevant OSM data were acquired on January 30th, 2015 from the site http://download.geofabrik.de/south-america/brazil-latest.osm.pbf.

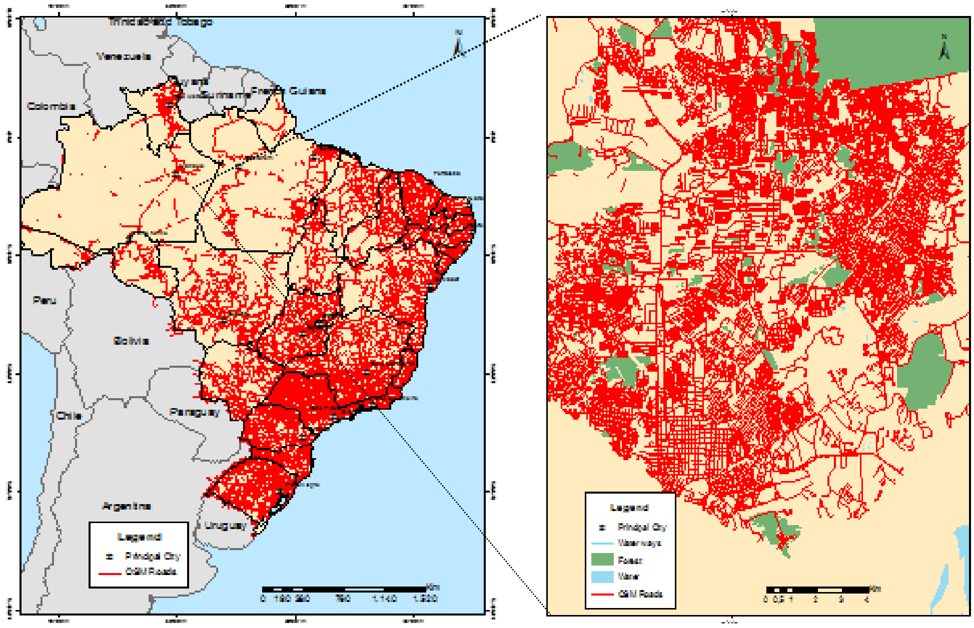
3.1. Voluntary contributions overview by Brazilian states

A total of 2,507,689 mapped feature records were acquired in the following categories described in *Table* 1: Building, Land Use, Natural, Places, Points, Railroads, Roads, Waterways

Layers	Feature Type	Records	%	Categories	%
Building	Polygon	263,552	10.51	279	24.65
Landuse	Polygon	74,273	2.96	77	6.80
Natural	Polygon	89,339	3.56	4	0.35
Places	Point	37,728	1.50	21	1.86
Points	Point	181,472	7.24	661	58.39
Railways	Line	11,447	0.46	18	1.59
Roads	Line	1,789,314	71.35	42	3.71
Waterways	Line	60,564	2.42	30	2.65
Total	-	2,507689	100	1132	100

Table 1. OpenStreetMap - Brazilian data

As shown in Table 1, the category which has the most individual feature records is "Roads" (71.35% of the overall total records) followed by "Building" (10.51%). The layers that have the most different categories identified are "Points" (58.39% of the overall total categories) and "Building" (24.65%). Figure 4a shows the spatial distribution of OSM Roads in Brazil. The researchers involved can verify data concentration in the states of South and Southeast, but in Brazil there are data from north to south. By checking this data in more detail through pan and zoom operations, the researchers identified that the cities, even in the Amazon region, have the Roads in urban areas mapped with detail such as the names of the roads. Figure 4b illustrated the Manaus city with the "Natural", "Roads" and "Waterways" categories.



a) OSM Roads of Brazil b) Manaus City

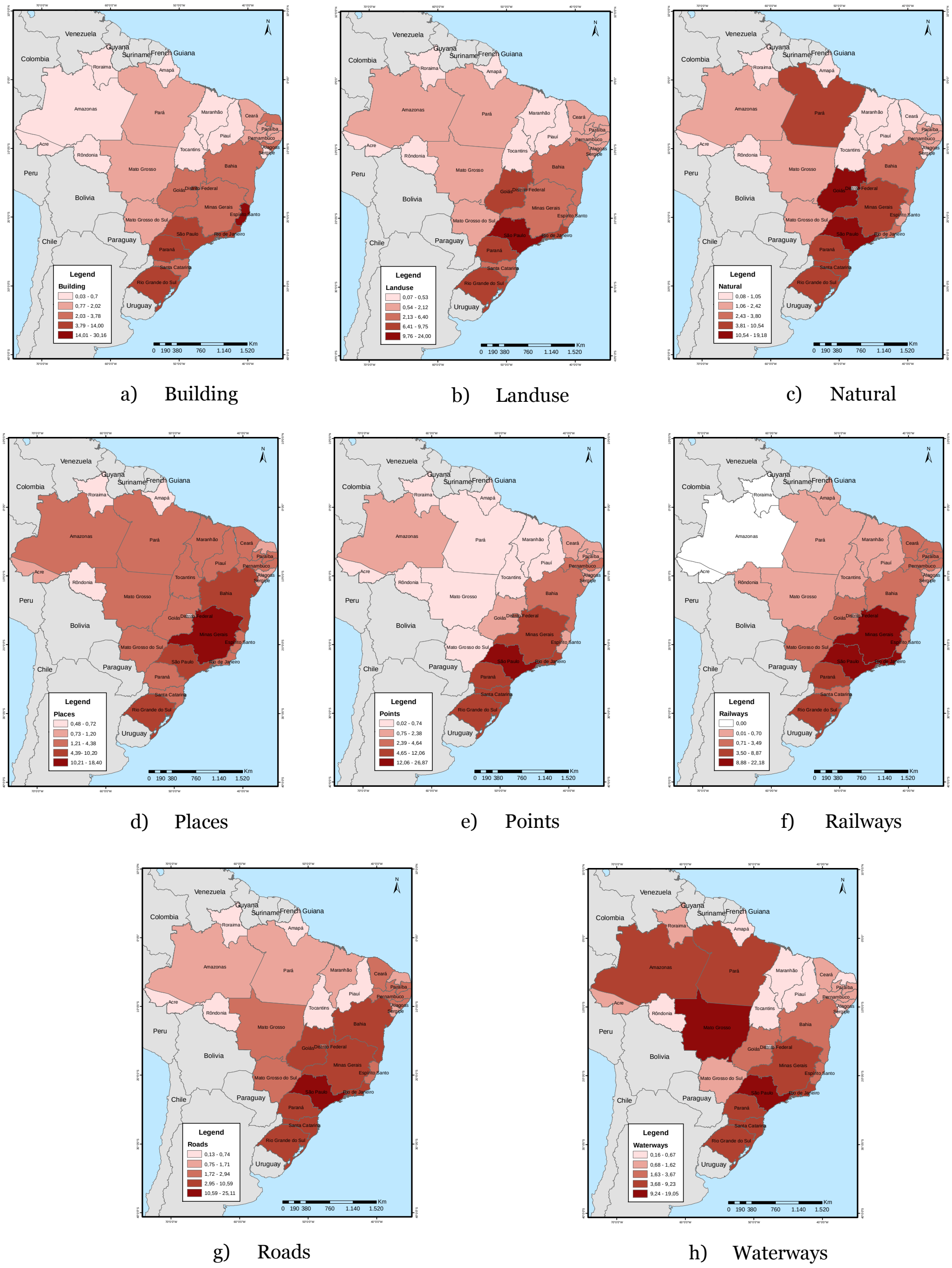
Figure 4. Roads of OpenStreetMap data in Brazil and in Manaus city.

In *Table* 2, we verify that the layer that has the largest number of identified names is "Places" (99.11%). On the other hand, there are layers with missing names: specially "Natural" (9.87%), "Building" (10.30%), "Railways" (16.77%) and "Landuse" (21.65%).

Layers	Identified Category	%	Identified names	%
Building	65443	24.83	27158	10.30
Landuse	74273	100.00	16078	21.65
Natural	89339	100.00	8819	9.87
Places	37728	100.00	37392	99.11
Points	181472	100.00	65415	36.05
Railways	1147	10.02	1920	16.77
Roads	1048575	58.60	408693	22.84
Waterways	60564	100.00	16953	27.99

Table 2. Total of Categories and names identified

Analyzing the categories by state in Brazil (*Figures* 5a, 5b, 5c, 5d, 5e, 5f, 5g and 5h), it is observed that each state contributes voluntarily to each layer in a different manner as summarized in *Table* 3. São Paulo State has more contributions in all categories. Rio de Janeiro, in 4 categories/layers, is among the three states with largest contributions.



a) Building b) Landuse c) Natural

d) Places e) Points f) Railways

g) Roads h) Waterways

Figure 5. Distribution records by layer and state

Layers	More records in order	Less records in order
Building	Espírito Santo, São Paulo e Rio de Janeiro	Roraima, Piauí and Amapá
Landuse	São Paulo, Rio Grande do Sul and Paraná	Roraima, Amapá and Acre
Natural	São Paulo, Goiás and Paraná	Roraima, Piauí and Acre
Places	Minas Gerais, São Paulo and Bahia	Amapá, Roraima and Distrito Federal
Points	São Paulo, Rio Grande do Sul and Rio de Ja-neiro	Acre, Rondônia and Piauí
Railways	São Paulo, Rio de Janeiro and Minas Gerais	Acre, Amazonas and Roraima
Roads	São Paulo, Rio de Janeiro and Minas Gerais	Amapá, Roraima and Acre
Waterways	São Paulo, Mato Grosso and Minas Gerais	Amapá, Piauí and Rio Grande do Norte

Table 3. Brazilian States with more and less OSM records.

In this analysis we conclude that the more volunteered contributions to the OSM database coverage have been made over the years in states located in the Southeast and South Regions than in the North and Northeast Regions. Possible reasons for this may be: (1) the low population density in the states of North region as depicted in *Figure* 1; and (2) information and communication technology access in most of municipalities in this region needs to be improved.

Analyzing the Roads layer and cities by state through a spatial join operation, the ten states, which have more cities missing streets OSM Roads records are Amazonas (HDI=0.674), Acre (HDI =0.663), Amapá (HDI =0.708), Pará (HDI =0.646), Maranhão (HDI =0.639), Paraíba (HDI =0.658), Piauí (HDI =0.646), Rondônia (HDI =0.690), Tocantins (HDI =0.699) and Mato Grosso (HDI =0.725). Note that all states of the northern region are in this list. São Paulo, Rio de Janeiro, Espírito Santo and Rio Grande do Sul are the states that more cities are mapped. To detail this analysis, we chose the State of Rio de Janeiro to assess the quality of data.

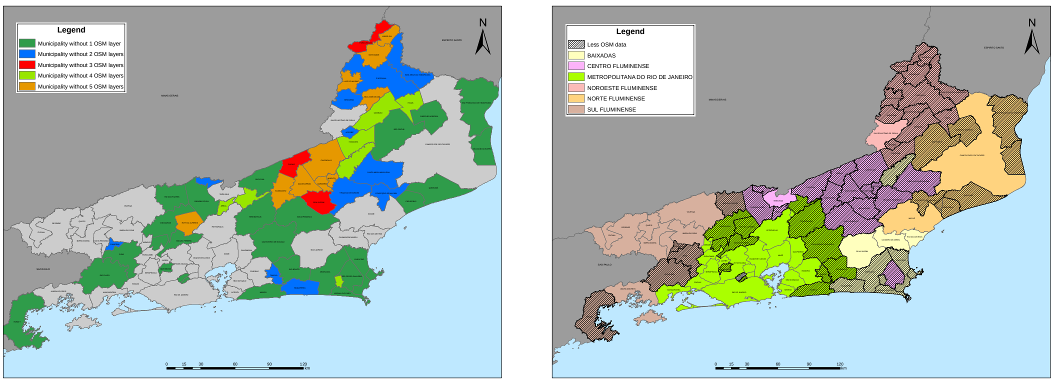
3.2. Voluntary contributions overview in Rio de Janeiro State

Making an exploratory analysis on OSM data in the State of Rio de Janeiro, as presented in *Table* 5, we could verify that the contributions by layers are dissonant between municipalities, as shown by the high standard deviation, especially in the "Roads" layer. The categories that have more contributions are "Roads" (41,660) followed by "Points" (14,937) and "Building" (6,872). However, in the Building layer there is 25 municipalities without information as in "Landuse" (39), "Natural" (17), "Points" (16), "Railways" (38) and "Waterways" (2). The contribution occurs according to the experience of the citizen in the living space. Furthermore, there are municipalities in this State where specific information does not exist in the OSM database (e.g., there are no railways in some municipalities).

Layers	Minimum	Maximum	Mean	Standard Deviation	Total
Building	0 (25)	6,872 (1)	180.32	793.28	16,590
Landuse	0 (39)	449 (1)	11.75	47.69	1,081
Natural	0 (17)	643 (1)	33.51	81.97	3,083
Places	1 (9)	239 (1)	16.57	30.88	1,525
Points	0 (16)	14,937 (1)	225.01	1,548.48	20,701
Railways	0 (38)	1,384 (1)	25.20	143.41	2,319
Roads	21 (3)	41,660 (1)	1,535.57	4,505.90	141,273
Waterways	0 (2)	582 (1)	35.60	75,28	3,276

Table 5. Exploratory analysis of OpenStreetMap data in Rio de Janeiro State

The number of municipalities in Rio de Janiero State without voluntary contributions of mapping varies, with some municipalities possessing contibutions in specific categories but not others. The respective numbers of municipalities where no feature contributions exist are summarized as follows (by layer): Building – 25; Landuse – 39; Natural – 17; Points – 16; Railways – 38; Waterways – 2. Volunteered contributions to the "Places" and "Roads" categories are present in all municipalities of Rio de Janeiro state. This result is shown in the map of *Figure* 6 where the municipalities are illustrated in map legend with the label describe one, two, three, four or five layers without information in one of these layers ("Building", "Landuse", "Natural", "Points", "Railways" and "Waterways”). Analyzing the administrative political division of Meso region (Fig. 6b) shows that the Centre and Northwest Fluminense are the regions where more layers without information exist. In the future, with the dissemination and the practice of voluntary contributions to the OSM, other layers are likely to have more information in all municipalities.



a) Municipalities without one ou more OSM data

b) Meso Region

Figure 6. Analisys of Rio de Janeiro state

The Rio de Janeiro city is an outlier in contributions in all layers as shown in *Table* 6, which are described by the municipalities that have more contributions.

Layers	More records in order
Building	Rio de Janeiro (6,872), Angra dos Reis (2,584) e Niterói (2,111))
Landuse	Rio de Janeiro (449), Cabo Frio (84) e Araruama (56)
Natural	Rio de Janeiro (643), São Gonçalo (363) e Niterói (261)
Places	Rio de Janeiro (239), Campos de Goitacazes (123) e Resende (82)
Points	Rio de Janeiro(14,937)), Niterói (1,116) e São Gonçalo (401)
Railways	Rio de Janeiro (1,384), Duque de Caxias (76) e Quatis (57)
Roads	Rio de Janeiro(41,660), Nova Iguaçu (8,384) e São Gonçalo (7,358)
Waterways	Rio de Janeiro (582), Porto Real (336) e Angra dos Reis (191)

Table 6. Municipalities with more records.

2.3. Local analysis of Roads layer in the city of Rio de Janeiro

The city of Rio de Janeiro has 160 neighborhoods. Among the neighborhoods which has more OSM data are streets registered in the neighborhoods of the west zone. It occurs where new infrastructure and access construction projects are taking place in support of the 2016 Olympics Games. Approximately 35% of the OSM "Roads" feature records were concentrated in the Campo Grande and Barra da Tijuca neighborhoods.

Neighborhood	Roads records	%
Campo Grande	3421	20,27
Barra da Tijuca	2573	15,24
Santa Cruz	2010	11,90
Bangu	1869	11,07
Recreio dos Bandeirantes	1581	9,36
Jacarepagua	1302	7,71
Taquara	1179	6,98
Realengo	1139	6,74
Centro	959	5,62
Pavuna	854	5,06

Table 7. OpenStreetMap Road data – City of Rio de Janeiro

In comparing the OSM Roads to the official data of the Pereira Passos Institute, it turns out that former are more up to date (See Fig. 7). However, it is emphasized that the data is acquired by different processes and there are some geometric and accuracy differences that require an effort to assess the quality of these data. Subsequent research will evaluate the quality of these data using the proposed criteria for Kessie and Fadaie (2004) and implemented by Haklay & Weber (2008) and Girres & Touya (2010)

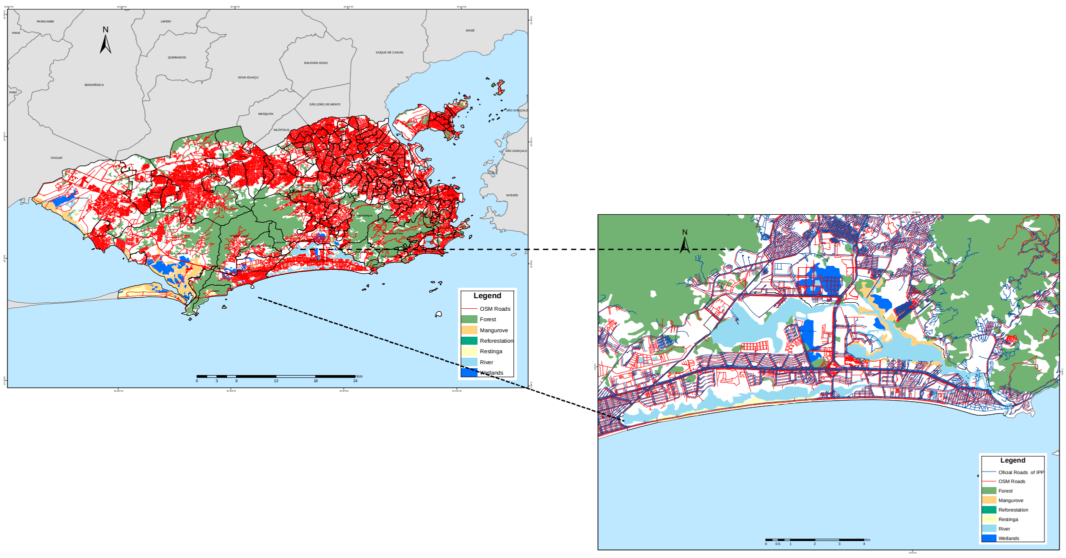


Figure 7. Comparison of official and no official Roads in Rio de Janeiro City

4. Conclusion

This paper presented an exploratory analysis of the OSM database in Brazil. Among the results, it was observed that the Roads layer have more information, particularly in urban areas of the cities; and in the northern region all layers has less information. Another results observed, in state of Rio de Janeiro, that the municipalities in the Centre and Northwest Fluminense are the regions where there are more layers without information. Furthermore, the urban areas in the city of Rio de Janeiro the voluntary contributions are more intense where there are big transformations such as infrastructure projects associated with the Olympic Game event in 2016.

In a time of increasing financial challenges, Brazil must find a way to generate a hybrid database combining open and official databases as a solution to have the country mapped and constantly updated. However, to reach this, it is still necessary to promote openness and a participative culture. This requires improving access to Information and Communication Technology within the country and encouraging the use of such information in every segment of society (universities, companies, organizations etc.).

It is important to highlight that OpenStreetMap database was generate by different processes. So, in this paper, also verify the necessity to develop methods at the local level to analyze data quality with regard to accuracy and geometry so that open data produced voluntarily can be incorporated to generate an official hybrid database. As future work, a methodology will be developed to assess the OSM Roads layer of the city of Rio de Janeiro.

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