SPATIAL ACCURACY ASSESSMENT OF BUILDINGS IN OPENSTREETMAP

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ABSTRACT:

The aim of this paper is to assess the spatial accuracy of OpenStreetMap (OSM) with respect to the Turkey Topographic Vector Database (TOPOVT) within the context of 'building' layer. Being an open-platform, anyone can access to OSM and add geographic entities as well as update them. Since there is no stringent standards, spatial accuracy assessment of OSM is an open research area. TOPOVT, on the other hand, is produced by the General Directorate of Mapping by following a standard procedure, where the maps are produced for 1:25000 scale or larger scale. Updating this database is a costly process and could only be conducted at specific time intervals. Therefore, automatic detection of the locations requiring update in TOPOVT would be an effective operation, which would eventually reduce the overall cost of the database update. However, the spatial accuracy of the geographical features have to be analysed in order to support such a motivation. Therefore, the aim of this paper is to assess the spatial accuracy of 'building' layer by calculating the Hausdorff distance between the matching (homologous) polygons in OSM and TOPOVT. The proposed methodology consists of two methods to detect the matching polygons: 'overlap method' and 'centroid method'. Hausdorff distance is calculated for only those intersecting buildings in both of the layers. Since it is safe to assume that the intersecting polygons refer to the same geographic object, the calculated distance could be used to indicate the spatial accuracy of the building. The developed software is tested on an urban and a rural environment in Ankara, Turkey. The results indicate that the quality of OSM could well match with TOPOVT. Specifically, the average Hausdorff distance is approximately the same for both of the methods: approximately 9.5 metres. Considering that OSM and TOPOVT are generated through completely different processes', the spatial accuracy is considered to be 'good' and 'useful' for many practical and operational purposes. In order to increase the effectiveness of the developed methodology in a real-life context, the whole process is integrated into an ArcMap extension and the code is made available on GitHub.

1. INTRODUCTION

Volunteered Geographic Information (VGI) is one of the emerging topics of geospatial science in the last few years. The ease of access to internet as well as the wide use of mobile devices led millions of people to share their geo-tagged data with the entire world, and benefit from what others have shared. Consequently, World Wide Web became the hub of geospatial information (Goodchild, 2007). The progress in VGI matches well with the progress in "Open Science", "Open Data" and "Citizen Science" as all different approaches aim to democratise the access to scientific material, from data to publications (Haklay, 2013; Sevinç and Karaş, 2018).

The acceptance of VGI for operational and scientific purposes brings some notable advantages (Feick and Roche, 2013). First, the economic cost of data collection could be reduced dramatically. The contribution of hundreds or even thousands of people could effectively reduce the time and money spent on data collection. Big companies have already been utilizing VGI. For instance, in Google Maps, anyone could "Add a Missing Place" or in Garmin people could "Report a Map Error". Government agencies also benefit from VGI, since a mapping project could be achieved in shorter times (Çabuk et al., 2015). Similarly, researchers develop mobile technologies to assist local municipalities by adopting VGI (Taşkanat et al., 2018).

The second advantage of relying on VGI for operational purposes is it being up-to-date. The people living in a neighbourhood could potentially obtain the most current situation regarding that neighbourhood in a timely manner. For instance, Fan et al. (2014) identified more than 1200 newly constructed buildings that are present in OSM but not available in ATKIS, reference data set of the German city Munich. Hachmann et al. (2018) investigated the use of VGI for the purpose of urban upgrading through better monitoring of slums and informal settlements. Obtaining current data, by official agencies, in such dynamic environments is not feasible and only could be possible with the support of locals living there. Gupta et al. (2018) investigated how to optimise the location of air quality sensors to assess exposure by considering VGI contributions. In this way, systematic planning of the size and location of VGI campaigns could better be carried out to obtain higher resolution and more realistic air quality maps. Last, but not least, Qi et al. (2018) evaluate how VGI could be used regarding disease prevention and post-outbreak care. They suggest that '*VGI is becoming a more convenient and efficient method for the prediction and reporting of foodborne illness*'.

VGI is extensively used in many different research areas. However, data quality remains to be the main concern regarding the acceptance of VGI, which has some valid arguments. Primarily, data are collected on a voluntary basis and that practically anyone could contribute to VGI. As a result of being an inclusive process, there is lack of a standard procedure for collecting data and data quality assurance. A thorough survey discusses how a range of methods could be used to evaluate the quality of textual, image and map based VGI (Senaratne et al., 2017). Consequently, the current knowledge base allows a researcher to assess the quality of VGI.

Existing research have already demonstrated that data collected by volunteers could well match the authoritative data and could be used for official purposes (Haklay, 2010). This situation is especially valid for OpenStreetMap, where millions of volunteers collaborate to map the world in an open way (Brovelli and Zamboni, 2018). Considering the advantages of relying on VGI

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and that the main concern, data quality, not being a true limitation, it is not surprising to see United States Geological Survey (USGS) relying on VGI in their Center of Excellence for Geospatial Information Science (CEGIS) programme, which has been going on since 2006 (USGS, 2019).

This paper aims to assess the spatial accuracy of building footprints in OpenStreetMap by comparing it with the reference dataset produced by the General Directorate of Mapping, namely Turkish Topographic Vector Database (TOPOVT). The matching (homologous) polygons are identified using two different approaches, which are referred to as the 'Overlap Method' and the 'Centroid Method'. Those matching buildings are then compared using the Hausdorff Distance (Avbelj et al., 2015). In order to feasibly apply the developed methodology in a real-life context, an ArcGIS extension has been developed and shared with the online community (Küçük, 2019).

The outline of this paper is as follows. Section 2 reviews the relevant literature. Section 3 is the methodology of the paper. Section 4 describes the datasets used in the study and presents the results. Finally, concluding remarks and future research areas are presented in Section 5.

2. LITERATURE REVIEW

Spatial data quality is a well-studied topic due to an international standard devoted to it. It covers different aspects including completeness, commission/omission errors, logical consistency and spatial/temporal/thematic accuracy. Nevertheless, 'fitness-for-use' has been considered as a valid data quality parameter for over 20 years. Though being subjective, it might be the most important parameter for many applications (Venegin, 1999).

Data quality assessment of OSM is an on-going research area due to two main reasons. First, contributions to OSM are increasing and some European cities have already been well mapped. Second, since anyone could contribute, there is no data production standard. Consequently, it is necessary to assess to what extent the VGI generated maps correspond to reality. Even though there are international standards such as ISO 19113 or ISO 19157, researchers rely on two main strategies to assess the data quality of OSM: intrinsic and extrinsic measures (Barron et al., 2014).

Intrinsic measures do not assume the availability of a reference dataset and derives methods to assess the quality only by relying on how a geographical object has evolved. The main rationale behind relying on intrinsic measures is that reference datasets are usually available at high costs or have restrictive licences. Therefore, researchers rely on the data itself and the historic records to estimate the data quality. For example, Haklay et al. (2010) confirmed that 'Linus' Law' applies to spatial accuracy assessment. Specifically, as the number of volunteers increase to map a given spatial object or region, so does the spatial accuracy. Another research investigated the ratio of buildings with a house number/name to the total number of buildings in order to provide a proxy for attribute completeness. However, as Barron et al. (2014) states '*absolute statements on data quality are only possible with a high quality reference dataset as a basis for comparison*'.

Extrinsic measures assume the availability of such reference datasets. Consequently, there is a substantial research evidence analysing the data quality relied on extrinsic measures. Specifically, OSM dataset are compared with a reference dataset, whose data quality is assumed to be better than OSM. Such reference datasets are usually generated by legal bodies. Recent research evidence suggests that incorporating both intrinsic and extrinsic measures could even be used to overcome the limitations of each strategy (Touya et al., 2017).

3. METHODOLOGY

The aim of this paper is to assess the spatial accuracy of the OSM buildings with respect to the official data in Turkey, TOPOVT. While doing so, it is intended to ease this process and deploy the developed methodology in a real-life context. Consequently, the majority of the methodology is arranged as an ArcGIS extension. The main reason for relying on ArcGIS is that the TOPOVT is built on ArcGIS. The methodology of the paper is illustrated in Figure 1. In addition, no data preprocessing step has been carried out in order to have a better understanding of the datasets. Specifically, no data cleaning process has been carried out and all the available data are used in both OSM and TOPOVT.

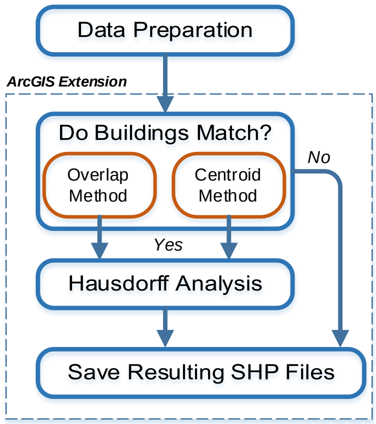


Figure 1 Methodology of the research

First, in the 'Data Preparation' step, TOPOVT data are provided as a personal geodatabase (.mdb) file which contains 128 feature datasets corresponding to the test region. The 'large buildings (area buildings)' layer is chosen as the aim of this research is to assess the spatial accuracy of buildings in OSM. Consequently, the corresponding data should be obtained from OSM. The most straightforward way to do this is to use the relevant functionality in QGIS. Specifically, the QGIS tutorial entitled 'Searching and Downloading OpenStreetMap Data' could be followed to download OSM data of the designated research area (QGIS, 2019). Finally, the necessary coordinate system transformation has to be carried out so that both datasets would have the same spatial reference ID. Both of the datasets were initially in WGS 84 datum and geographical coordinates having an SRID of 4326. However, Hausdorff distance requires a metric system and both of the datasets are converted into SRID: 32636, which is WGS84 with the UTM zone of 36N, which better fits to the local coordinates on which TOPOVT data are collected.

The main component of the methodology is detecting the matching buildings or 'homologous features' in an automated way. A matching building represents the same spatial object (e.g. building) in OSM and TOPOVT. Two different approaches are proposed to detect matching buildings. First approach is referred to as the 'Overlap Method', where two polygons are said to be matching if they are intersecting. Second approach is referred to as the 'Centroid Method', and two polygons are said to be matching if the centroid of the OSM polygon is inside the TOPOVT polygon. An example of these two approaches are illustrated in Figure 2. Hecht et al. (2013) relied on a similar methodology to assess the completeness of OSM data.

(a)

(b)

Figure 2 Detecting matching polygons using the 'Overlap Method' (a) and the 'Centroid Method' (b)

ArcPy is the Python library that provides the capabilities of ArcGIS in a programming environment instead of relying on the commonly known graphical user interface. All the spatial queries including finding the centroid of a polygon or detecting whether two polygons intersect could be carried out in ArcPy. Consequently, the developed methodology is implemented in ArcPy, which is then converted into an ArcGIS extension. Once the extension is executed, it also saves the polygons that are in OSM but not found in TOPOVT in a separate SHP file to indicate the areas that require a possible update. However, the license of OSM should be noted in this regard, which is the 'Open Data Commons Open Database License (ODbL)'. This licence allows everybody to use, distribute and adapt the data for their own purposes as long as OSM and its contributors are credited. In addition, anyone relying on OSM data must distribute the result only under the same license (Brovelli and Zamboni, 2018; OSM, 2019).

Once the matching polygons are determined, Hausdorff distance is calculated to measure the distance between them. Hausdorff distance is a measure between two sets of points representing the corner coordinates of the matching polygons. It determines the maximum distance amongst the closest pair of corner points. Because polygons (and also lines) can be considered as a point set, it is a method that can be used for similarity analysis of such geographic elements. The lower the Hausdorff distance would then mean that the matching polygons are closer. The Hausdorff distance is calculated as shown in Equation 1.

$$\mathrm{H}(\mathbf{A},\mathbf{B}) = \max_{a \in \mathbf{A}} \left(\min_{\mathrm{b} \in \mathbf{B}} \left(\mathrm{d}(a,b) \right) \right) \qquad (1)$$

Two matching polygons representing the same spatial object are denoted as **A** and **B**. Both polygons are set of points consisting of m and n points respectively. Specifically, polygon **A** consists of the points $\{a_1, a_2, \dots, a_m\}$ and polygon **B** consists of the points $\{b_1, b_2, \dots, b_n\}$. Since both of the datasets have the same spatial reference ID, the Euclidean distance between two points is calculated, which is denoted as $\mathrm{d}(a,b)$. It should be noted that there is no mathematical relation between the number of points that each polygon contains (i.e. $m \geq n$ or $m \leq n$). Even though Hausdorff distance is a unidirectional distance measure, it could easily be converted into a bidirectional measure (Schlesinger et al., 2014). Since the aim of this research is to assess the spatial accuracy OSM buildings, polygons **A** and **B** represents the polygons in OSM and TOPOVT respectively. The visual depiction of the distance measure is illustrated in Figure 3. For each of the vertex of the OSM polygon, its closest neighbour in TOPOVT is detected initially and later on the maximum of these distances is considered as the Hausdorff distance.

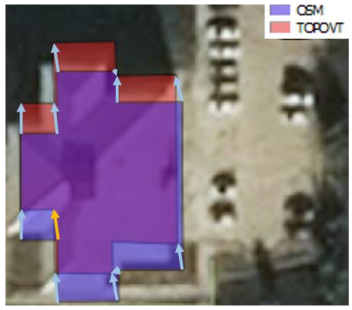


Figure 3 Visual illustration of the Hausdorff Distance

It should be noted that it is possible to observe several polygons in OSM to overlap with a single polygon in TOPOVT or vice versa. In such a situation, the overlap method assumes that only those having the lowest Hausdorrf Distance are matching. In other words, only one-to-one (1:1) and those having the lowest Hausdorff distance are assumed to match and investigated in this research. In order to foster reproducibility of the results as well as provide a sustainable research, all the developed code and test data are available on project's GitHub page (Küçük, 2019).

4. ANALYSIS AND RESULTS

4.1 Datasets

The developed methodology to assess the spatial accuracy of buildings in OSM are evaluated on two different regions. Both of the regions are located in the capital city of Turkey, Ankara, which are shown in Figure 4. One of these regions correspond to a rural environment, and the other correspond to an urban environment. Both of the regions correspond to an area of approximately 150 km^2. The region located on the top represents a rural-environment and the other region represents an urban environment.

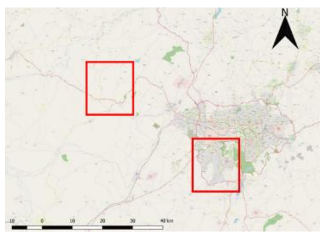


Figure 4 Study area

The quality of the buildings in OSM are assessed by comparing them with the reference dataset produced by the General Directorate of Mapping (HGM). The national mapping institution responsible for the production of 1:25000 scale topographic maps of Turkey is HGM. The reference dataset produced by HGM is referred to as ‘TOPOVT’, which is the abbreviation of ‘Turkey Topographic Vector Database’ in Turkish. The data are captured in 2011 and the photogrammetric evaluation have been carried out in 2012.

TOPOVT was produced by compilation from stereo aerial photos. The database includes 128 feature datasets ranging from roads to buildings and from cemetery to parks. The geometric accuracy is ±3 m in both horizontal and vertical components for TOPOVT. Keeping such a system live and up-to-date requires the mutual will of all the shareholders including governmental bodies as well as citizens (Yılmaz and Canıberk, 2018). Consequently, the way in which VGI could be integrated into the update process of TOPOVT is a challenging research goal. The generic comparison between the datasets and the study areas are illustrated in Table 1.

	Urban		Rural	
	OSM	**TOPOVT**	**OSM**	**TOPOVT**
Number of buildings	6404	1123	20	123
Min area (m^2)	9.56	2.01	93.66	73.14
Max area (m^2)	84740	16496	92383	6941
Mean area (m^2)	1031	778	13065	606
Std Dev (m^2)	4102	885	27110	828

Table 1 Generic comparison of datasets and study areas

The generic comparison outlines several important outcomes. First, there are much more polygons in OSM compared to TOPOVT in the urban environment. This is due to two main reasons. First, the base data for TOPOVT, i.e. aerial imagery were captured in 2011, whereas recent OSM data are investigated. Second, OSM records not only contains singular buildings but also blocks of buildings as well. In the rural area, on the other hand, there are more buildings in TOPOVT compared to OSM, which is in line with the previous findings (Hecht et al., 2013). It is also interesting to observe the variation of minimum building size between the urban and rural environment. This is mostly due to the facts that landscape is used more generously in the rural area as well as the buildings are more heterogeneous in the urban environment.

4.2 Results

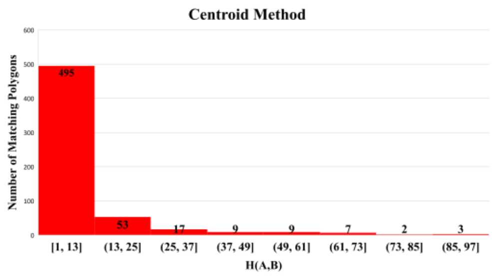
The methodology presented in Figure 1 is applied on both the urban and rural study region. First, the matching buildings are identified using the centroid and overlap methods. For those matching buildings, Hausdorff distance is calculated. The generic results are illustrated in Table 2.

	Urban		Rural	
	Centroid	**Overlap**	**Centroid**	**Overlap**
# matching buildings	595	608	6	4
Mean H (m)	9.65	9.68	61.59	5.51
Std. dev. H (m)	13.15	17.99	98.58	2.29
Max H (m)	93.21	247.90	274.50	8.80
Min H (m)	0.53	0.53	2.61	2.61
Run time (min)	11.00	14.00	0.03	0.03

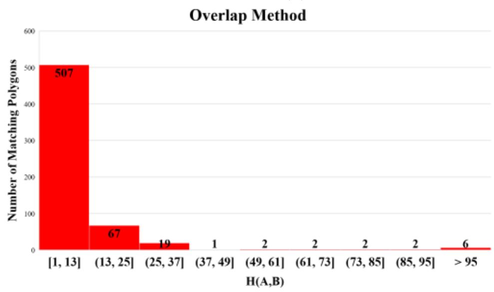
Table 2 Generic results

Several outcomes could be observed by inspecting on the generic results. First, as expected, there are only a few matching buildings in the rural area. However, it is a better idea to rely on the ‘overlap method’ since the standard deviation of the Hausdorff distance H is much lower compared the ‘centroid method’. It should be noted that this is due to the fact that no data cleaning process has been carried out prior to the analysis in order to provide a better understanding of both of the datasets. However, since it is possible to observe large polygons in OSM representing a parcel rather than a building, it is likely that the centroid of a large polygon to reside within a TOPOVT building. Consequently, the Hausdorff distance is large between those seemingly matching polygons. Overall, it is clear to devise new strategies to enrich the OSM content in a rural environment.

Urban environment provides a more reliable comparison between the ‘overlap’ and ‘centroid’ methods since much more buildings are found to match. Centroid method detected 595 matching buildings and the overlap method detected on 13 matching buildings more. Once the average Hausdorff distance is investigated, it appears that centroid method is only marginally better than the overlap method with a 9.65 metres. The main difference between the methods become apparent when the maximum Hausdorff distance and standard deviation of the distances are observed. Specifically, in both of the metrics centroid based method reported much lower results. Furthermore, the execution time of the centroid method is also shorter than its competitor. Considering the advantages of the centroid method in an urban environment, the authors consider that it is better suited for determining the spatial accuracy of matching buildings in an urban environment. The histogram of the Hausdorff Distances for the centroid and overlap methods are illustrated in Figure 5.



(a)



(b)

Figure 5 Histogram of the Hausdorff Distances for centroid (a) and overlap methods (b)

Once the histograms are analysed, an interesting outcome could be observed. Overlap method produces more matched buildings having a low Hausdorff distance. Specifically, 507 matched buildings have a Hausdorff distance between 0 and 13 metres. This number is 495 buildings for the same distance interval if centroid method is used. Therefore, it could be argued that the few erroneous matches of the overlap method is the main reason to derive the aforementioned outcome, that the centroid method outperforms the overlap method. Finally, the developed code is integrated into an ArcGIS extension, which is illustrated in Figure 6.

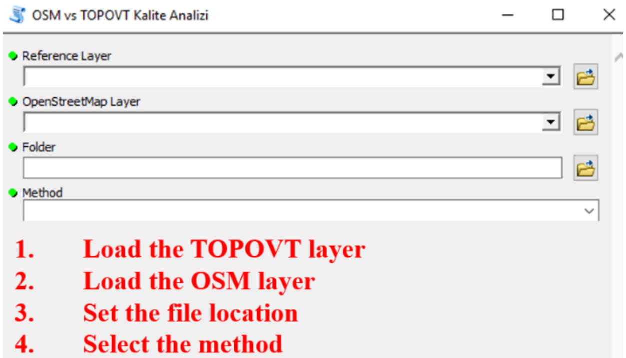


Figure 6 ArcGIS extension

The developed extension is easy to use. First, the SHP files belonging to TOPOVT and OSM are chosen respectively. Second, the folder to create the output shape files is chosen. The output would contain two shapefiles: those buildings that are in OSM but not in TOPOVT and vice-versa. Finally, the method to execute (i.e. overlap or centroid) is chosen in the last step.

4.3 Case Analysis

In order to provide a better understanding of the methods' effectiveness, this section describes the way in which the maximum Hausdorff distance is observed. Specifically, the context in which the maximum Hausdorff distance of 247.90 is observed in the urban environment is illustrated in Figure 7. The large OSM polygon overlaps with a single TOPOVT building on the western border. Because of that single overlapping polygon, the calculated Hausdorff distance is large.

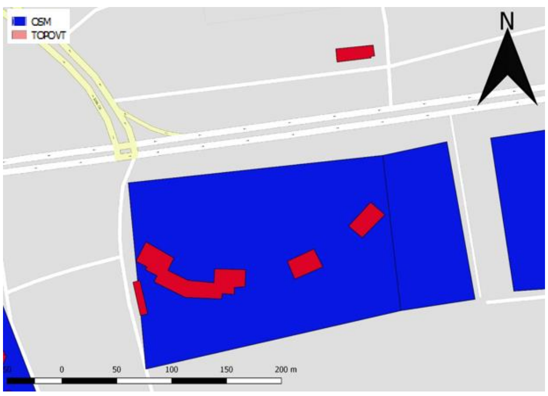


Figure 7 Maximum Hausdorff distance in the urban region

This example also demonstrates the heterogeneous nature of OSM, since polygons of substantially different sizes could be recorded by volunteers. A similar situation was also for the largest Hausdorff distance in the rural environment, which is illustrated in Figure 8.

Figure 8 Maximum Hausdorff distance in the rural region

In this context there are three OSM polygons. The centroid of the largest polygon, which contains the other two polygons, is inside a TOPOVT building. Therefore, the 'centroid method' assumed that these two polygons are matching and the Hausdorff distance is calculated accordingly. Similarly, the second largest OSM polygon's centroid is also found to be within a TOPOVT building as shown on the southern part of the map. Since there are only a few matching polygons, such large distances effect the overall results. Consequently, centroid method failed in this context.

5. CONCLUSIONS

This research assessed the spatial accuracy of building footprints in OSM by comparing with the reference dataset, TOPOVT. The research investigated the effectiveness of two methods, which are referred to as 'centroid method' and 'overlap method'. Centroid method detects a matching building if the centroid of an OSM polygon is inside a TOPOVT polygon. Overlap method detects a matching building if both of the polygons are intersecting.

The experiments are carried out on an urban and a rural region in Ankara, Turkey. The results regarding the urban environment indicate that, on average, both of the methods detect a similar number of matching buildings. Approximately 600 buildings out of 1123 available in the reference dataset are detected with both methods. Similarly, for those matching buildings the Hausdorff distance is calculated and on average approximately 9.5 metres of deviation are detected between the OSM and TOPOVT datasets. Considering that the centroid method is faster and lead to better lower Hausdorff distances, this research suggests the use of centroid method for future studies. However, since the difference between the methods is only marginal, the suggestion is not a final one and should be supported with more experimentation. It should also be noted that the centroid method actually failed in the rural area.

This research also supported the current research evidence regarding the urban-rural distinction and that the rural areas are not well developed in terms of VGI. Even though this research relied on the currently available data on OSM and that the reference dataset dates back to 2011, only 20 polygons are recorded in OSM, whereas this number is six fold more in TOPOVT. Due to the very low number of matches, it is very difficult to come up with a conclusion, but the current results favour the overlap method. It is important to develop new ways to enrich the VGI content in rural areas to draw more reliable conclusions.

The main assumption made throughout the research is that only one-to-one building matches are investigated. However, it is possible, especially for the overlap method, to observe several polygons in one dataset intersecting with a single polygon in the other dataset. In such cases, the matching polygon is assumed to be the polygon leading to the lowest Hausdorff distance. Consequently, as a future research agenda, it is important to analyse such situations in more detail. In addition, no data preprocessing step has been carried out to better understand the situations that arise. It is therefore important to evaluate the effectiveness of different strategies regarding data cleaning and pre-processing. Last, the spatial accuracy of roads could be investigated in a similar manner.

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