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Data Quality of OpenStreetMap for Industrial Sites in the Arctic

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Abstract. Climate change is causing rapid warming in the Arctic region, resulting in the thawing of permafrost. This has substantial environmental implications, such as the release and mobilisation of contaminants from past and present industrial activities. However, freely accessible public geographical information is scarce on industrial sites and activities in much of the Arctic, which makes scientific research such as impact assessment difficult. OpenStreetMap (OSM) can be a valuable resource for identifying and assessing industrial sites for contamination. However, OSM data quality is not uniform across regions necessitating our evaluation of its reliability for identifying industrial sites and contamination hotspots in the areas most susceptible to permafrost thawing. Therefore, we examined in our study the object and attribute completeness as well as the currentness of OSM data on industrial sites. Our study focused on the regions defined by the presence of either discontinuous or continuous permafrost located in Canada, the USA, Denmark, Russia, and Norway, as these regions are expected to show strongest impacts of rising temperatures with respect to industrial pollution. The highest object completeness and currentness were obtained in Denmark (99% and 48% respectively). Russia had the lowest completeness (68%) and Canada had the lowest currentness (30%). Despite the promising average completeness of 86% and the average currentness of 35%, only 5.6% of industrial sites mapped in OSM contained information on the type of industry. This finding highlights the need for efforts to enhance attribute completeness gaps to maximize the use of OSM data in comprehensive environmental analyses.

Keywords. OpenStreetMap, Intrinsic Quality Assessment, Permafrost, Volunteered Geographic Information, Ohsome Quality API

1 Introduction

The Arctic region is experiencing unprecedented rapid warming due to climate change, with scientists estimating rates that are up to four times faster than the global average (Rantanen et al., 2022). One consequence of this rapid warming is thawing of permafrost which covers vast areas of the Arctic. Permafrost is defined as ground that is frozen for at least two consecutive years. The permafrost has served as a natural barrier that prevents the spread of pollutants (Miner et al., 2021) as well as a stable and dependable foundation for buildings and infrastructure (Langer et al., 2023). Past and current industrial activities in the Arctic have resulted in the accumulation of hazardous substances in the permafrost region. The thawing of the permafrost potentially releases these accumulated hazardous substances into the ecosystem (Vonk et al., 2015). In addition, the instability of the frozen ground due to the thawing increases the risk of industrial containment structures collapsing (Langer et al., 2023) and further polluting the environment. The spread of these contaminations through the ecosystems poses a severe risk to communities within and outside of the Arctic region. Consequently, the Arctic region has become a focal point for extensive research, including the development of comprehensive risk assessment frameworks (Hjort et al., 2018) and climate models for its rapidly changing conditions, which are causing various issues, including the legacy pollution. Despite the growing attention, there is the challenge of the scarcity of freely accessible public geographical data on industrial sites and activities in the region. In response, many researchers (Liu et al., 2023; Lloyd-Jones et al., 2023; Xu et al., 2022) have turned to OpenStreetMap (OSM) (Bartsch et al., 2020), a crowdsourced geographic database aimed at mapping the whole world.

While OSM data can be a valuable tool for Arctic research, particularly for monitoring and assessing industrial sites and activities in the region, its reliability and accuracy need to be assessed. OSM data can provide useful information on the location, extent, and characteristics of industrial sites along with local knowledge. However, like any Volunteered Geographic Information (VGI) which is mainly generated by non-professionals, OSM carries no assurance of quality (Goodchild and Li, 2012). Accuracy assessments of OSM data in the Arctic regions are largely missing (Xu et al., 2022). The quality of OSM data varies across different regions (Raifer et al., 2019), with substantial heterogeneity in completeness and other aspects of data quality between and within countries (Barrington-Leigh and Millard-Ball, 2017). Factors such as the gadgets used for the mapping, and the skills and motivation of contributors (Barron et al., 2014; Sehra et al., 2017) add to potential inaccuracies. Moreover, the "Any tags you like" policy by OSM which permits map editors to establish their keys and values for tags of entities they are editing also introduces inconsistencies in the data (Mooney and Corcoran, 2012). Addressing the question of reliability becomes paramount, particularly when using OSM data in identifying industrial sites and contamination hotspots for critical applications such as risk assessment frameworks in the Arctic.

We therefore intrinsically assessed the quality of OSM data across our study region to address these concerns. This intrinsic approach considers the temporal evolution of the OSM data within the study area. We aim to spot where extra mapping efforts are required and to give us an idea of the difference in OSM data quality across the countries. This assessment will provide insights into the reliability of OSM data and its fitness for the purpose of identifying industrial sites and contamination in the Arctic.

2 OSM Data Quality Assessment

Defining and evaluating data quality is a complex task as distinct quality criteria and considerations are required for different uses of data (Reda et al., 2023). There are several approaches for the assessment of OSM data quality. A distinction is made between two different methods (Brückner et al., 2021). Extrinsic methods are based on a comparison of OSM data with reference data sources. These approaches are limited by the requirement of external datasets which are not always available due to licensing restrictions or costs (Barron et al., 2014). Intrinsic methods (Barron et al., 2014; Ballatore and Zipf, 2015; Antoniou and Skopeliti, 2015; Barrington-Leigh and Millard-Ball, 2017; Brückner et al., 2021) provide a way to evaluate the fitness for purpose of OSM data by considering just the history of the OSM data itself. With the benefit of the entire editing history of each edit to the OSM database, it serves as a great source for quality assessment (Minghini and Frassinelli, 2019). This has motivated the implementation of several software applications based on the analysis of the OSM history data that provides a way to access the intrinsic quality measures for OSM objects. OSHDB (Raifer et al., 2019), a framework for spatio-temporal analysis of OSM history data, is one realisation of such software optimized for working with OSM history data that makes it easy to assess the intrinsic quality measures of OSM data.

There is a limited amount of research on the OSM data quality in the Arctic region. To the best of our knowledge, only two studies have been conducted to assess the quality of OSM data in this area. Both studies utilized extrinsic methods to evaluate the completeness of OSM data by comparing it to the SACHI (Sentinel-1/2 derived Arctic Coastal Human Impact) dataset. In a study conducted by Bartsch et al. (2021), the completeness of OSM data regarding infrastructure in the Arctic region was examined. The study found that, depending on the specific region, the SACHI dataset contained 8%–48% more information (in terms of human presence) compared to OSM. Another study conducted by Langer et al. (2023) combined OSM data with the Atlas of Population, Society and Economy in the Arctic (APSEA) dataset to assess the logical consistency with the SACHI dataset. The evaluation revealed that OSM-APSEA had a significantly lower number of industrial sites compared to SACHI, with approximately 40% missing. While both studies contribute to the general assessment of OSM data quality in the Arctic, the spatial scope of the SACHI dataset used as the reference dataset is limited to 100 km inland (Langer et al., 2023) and focuses on the Arctic coastal areas. Additionally, Bartsch et al. (2021) analyzed only building footprints in the OSM database while Langer et al. (2023) considered only the OSM tags ‘landuse’=’industrial’ and ‘building’=’industrial’.

For these reasons, we extended the OSM tags considered and performed an intrinsic quality assessment of industrial objects in OSM considering object completeness, currentness and attribute completeness.

3 Methods and Data

3.1 Data

We defined the spatial extent of our analysis based on the presence of either discontinuous or continuous permafrost in five Arctic countries, namely Canada, the USA (Alaska), Denmark (Greenland), Russia, and Norway (Svalbard). The extents were generalised to approximate the areas with permafrost coverage greater than 50%. Figure 1 shows a map of our study area.

In an exploratory analysis, the study examined features within the OSM database that represent industrial activity. Table 1 presents the various tags that were considered most relevant for identifying industrial sites.

Table 1. Tags for describing industrial-related features in OSM used for the study. Source https://taginfo.openstreetmap.org/

Tag	Description
landuse=industrial	Used for areas with predominantly workshops, factories, warehouses, etc
building=industrial	Used for buildings constructed for some manufacturing process
industrial=*	Used to describe the type of industry or the industrial object
man_made=works	For mapping an industrial production plant or factory
landuse=quarry	For mapping open pit mines (area for surface extraction of mineral resources)
man_made=storage_tank	For mapping containers that hold liquids or compressed gases
man_made=flare	For mapping towers constructed to burn off excess gases

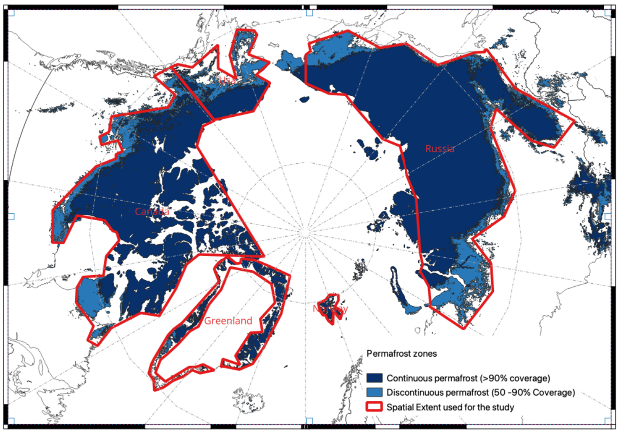

Figure 1. Map of the study area using Permafrost extent data from Obu et al. (2018) Source:https://apgc.awi.de/dataset/pex.

3.2 Methods

We used the Ohsome API and Ohsome Quality API (OQAPI) in a Jupyter Notebook to analyze the underlying rich data source of the OpenStreetMap History Database (OSHDB) (Raifer et al., 2019). The Ohsome API provides endpoints for aggregated statistics on the contributions, users and OSM elements as well as endpoints for extracting them. We filtered the data according to the required features using two Ohsome API endpoints. The elements extraction endpoint was used to extract the map features of interest in the study areas for the attribute analysis. Additionally, the 'elements' aggregation endpoint was used to compute the count of the map features of interest within our study regions.

OQAPI was used to compute intrinsic quality indicator estimates for OSM data in the study areas. This involved assessing the intrinsic completeness and currentness of the map features of interest in the OSM database using a saturation curve approach. The theory behind how OQAPI calculates the completeness quality estimates is thoroughly explained in Brückner et al. (2021). The general idea is that, given a substantial level of activity from contributors over a period, contributions eventually converge with the actual number of real-world objects in the given area. Saturation curves can be used to estimate the level of saturation, which serves as an estimate for the true number of objects in a given region. Saturation refers to the point at which the growth or contribution rate levels off or stabilizes.

OQAPI retrieves the aggregated monthly contributions to the specified topic (a set of features whose completeness we are interested in computing, see table 1) for the period from 2008-01-01 to the latest available snapshot of the OSM database. Six different curve fitting models (logistic and non-logistics curves) are applied to the retrieved data. The best curve is selected based on the one that gives the minimum Mean Absolute Error (MAE). The saturation within the last 3 years is then calculated based on the selected curve.

The currentness indicator is computed by binning edits into three classes: up-to-date (0-3 years), in-between (3-8 years), and out-of-date (over 8 years) based on the timestamps for the edits. The percentage of objects that have received updates within the feature class in the last three years is used as the score to determine the currentness of a particular feature within the dataset. This indicator gives an estimation of the up-to-dateness of features in OSM

We computed the attribute completeness by assessing the user-entered information of specific attributes. As the type of industry is relevant for predicting how industrial sites will be affected by permafrost thaw, we focused on the completeness of the attributes 'industrial' and 'plant:source' (on the two major OSM tags landuse=industrial and building=industrial). The percentage of objects within an OSM feature class that have values populated for the field of interest is used as the measure. Equation 1 is the formula used for the calculation.

$$\text{Attribute Completeness} = \frac{F}{G} \times 100 \tag{1}$$

F is the number of objects within the feature with a value present for the field of interest
G is the total number of objects within the feature

3.3 Software and data availability

The analysis was performed in a Python Jupyter Notebook. All source code, preprocessed data and results can be found at https://gitlab.gistools.geog.uni-heidelberg.de/giscience/big-data/ohsome/ohsome-api-analysis-examples/osm-data-quality-in-the-arctic.

OSM data were extracted using the Ohsome API at https://api.ohsome.org. Intrinsic completeness and currentness quality estimates were computed using a local instance of OQAPI pulled from https://github.com/GIScience/ohsome-quality-api.git. We created a topic by editing the 'preset.yaml' file https://github.com/GIScience/ohsome-quality-api/blob/main/ohsome_quality_api/topics/presets.yaml to suit the context of this research by specifying the map features to be used for the estimation and the aggregation type. The edited 'presets.yaml' file is provided in our working folder to be used to replace the original version that comes with cloning the OQAPI repository.

The data for the permafrost extent was acquired from Obu et al. (2018) at https://apgc.awi.de/dataset/pex.

4 Results

In our study, we analysed the completeness, currentness and attribute completeness of industrial sites in the OSM database. We found a total of 16,351 objects in the database that were likely associated with industrial activities. Figure 2 shows the distribution of the sites across the countries. The number of objects associated with each tag is captured in table 2.

Table 2. Count of all the features with the specified tags in the OSM database for the study area. Some features may have more than one tag.

Tag	Number of Features
landuse=industrial	6357
building=industrial	3830
man_made=works	483
industrial=*	1118
landuse=quarry	1682
man_made=storage_tank	3705
man_made=flare	463

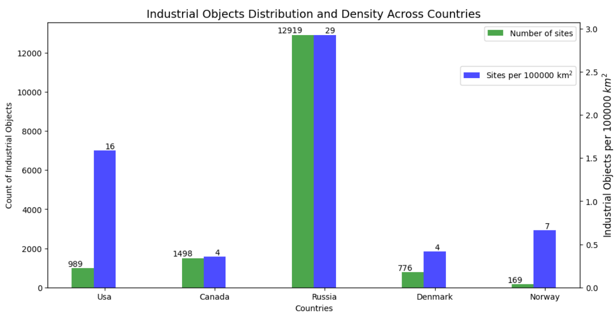

Figure 2. The distribution and density of industrial sites and related features within the study area.

The average intrinsic completeness for the study region was approximately 86%, with a range from 68% to 99%. Denmark and Norway exhibited high estimated completeness, with values exceeding 97%. However, the attribute completeness was much lower, with an average value of only 5.6%. The highest attribute completeness value of 26.6% was obtained for the attribute 'industrial' for objects with the main tag 'landuse'='industrial' in the USA, while Norway had the lowest value of 7.5%. For the main tag 'building'='industrial', the attribute 'industrial', which provides information on the type of industry was missing for both Denmark and the USA. Norway, Canada, and Russia all had attribute completeness values for the field 'industrial' of the main tag 'building'='industrial' that were less than 1%. The analysis for the field 'plant:source' showed that Norway had the highest attribute completeness of 13.3% for the main tag 'landuse'='industrial'. On the other hand, Canada had the highest value of 5% for the main tag 'building'='industrial'. Table 3 shows the results of the attribute completeness analysis.

Even though the results in the intrinsic completeness of the data showed heterogeneity across the countries, the up-to-dateness of the map data, was relatively consistent across the four countries. Denmark stood out with a high currentness score of 48%. The average currentness obtained for the study region was 35%. Figure 3 shows the results of the computed OSM data quality elements for the countries.

5 Discussions

Comparing our findings with a previous extrinsic study by Bartsch et al. (2021) on the completeness of OSM building footprints in the Arctic region, our estimated completeness was approximately +8% more. This relatively high estimate can be accounted for by a mixture of factors. Firstly, the average currentness estimate of 35% suggests approximately one-third of the features were updated in the last three years. Recent updates lead to improved completeness. Denmark with the highest intrinsic completeness received the highest editing updates within the last three years with almost half of the features considered to be current. This explains why the completeness of Denmark improved significantly compared to the previous study. Secondly, the limitation of the intrinsic completeness methodology. The completeness computation uses the best fitting curve from a set of limited growth curves. As described in Brückner et al. (2021), non-logistic curves can lead to lower completeness estimates than sigmoid curves. Denmark's intensive mapping activity in the last 3 years can be described best by a sigmoid curve, which may have benefited the completeness value.

The attribute completeness analysis revealed that secondary fields were barely populated by mappers. The issue of low attribute completeness is one major challenge with OSM data globally. The average attribute completeness of 5.6% hinders the potential of maximising the use of the data for comprehensive advanced spatial analysis. For instance, Langer et al. (2023) could not classify the

Table 3. Attribute completeness analysis of tags 'landuse'='industrial' and 'building'='industrial' in the study area.

Country	Tag	Number of Objects	Field/Attribute	Values Present	% completeness	average
USA	landuse=industrial	263	industrial	70	26.62%	7.33%
			plant:source	5	1.90%	
	building=industrial	125	industrial	field absent	0%	
			plant:source	1	0.80%	
Canada	landuse=industrial	380	industrial	37	9.74%	5.49%
			plant:source	25	6.58%	
	building=industrial	160	industrial	1	0.63%	
			plant:source	8	5.00%	
Russia	landuse=industrial	5579	industrial	981	17.58%	4.66%
			plant:source	35	0.63%	
	building=industrial	3124	industrial	8	0.26%	
			plant:source	6	0.19%	
Denmark	landuse=industrial	120	Industrial	9	7.50%	4.95%
			plant:source	14	11.67%	
	building=industrial	313	Industrial	field absent	0.00%	
			plant:source	2	0.64%	
Norway	landuse=industrial	15	Industrial	1	6.67%	5.69%
			plant:source	2	13.33%	
	building=industrial	108	Industrial	1	0.93%	
			plant:source	2	1.85%	

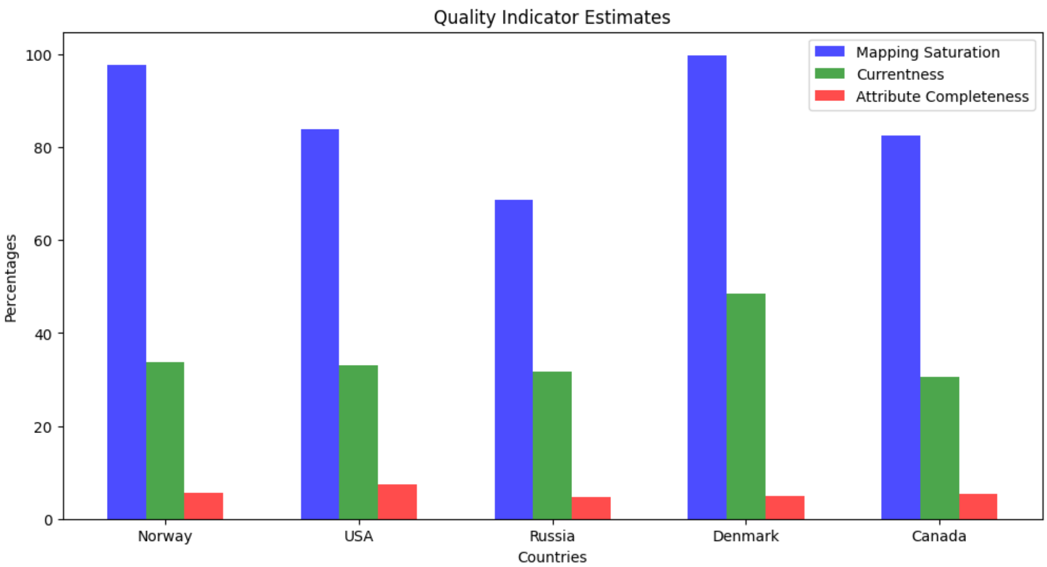

Figure 3. The computed quality estimates for the countries.

majority of features (65% of mapped industrial sites) in their combined APSEA and OSM database due to missing tags. These results indicate the need to complete information about most of the objects in the OSM database to improve the quality and usability of the data for industrial site analysis.

5.1 Conclusion and Outlook

We found variations in OSM data quality across the region. The promising estimated mean completeness level of 86% found in the study shows the great potential to use OSM data in identifying industrial sites to support Arctic research. However, the low mean attribute completeness of 5.6% found is a major concern. This low attribute accuracy poses a challenge in the use of OSM data for tasks like classifying industries and conducting other advanced spatial analyses. This highlights the need for intensified efforts to complete information about most of the objects analysed. This can be achieved through regular organisation of social events such as mapping parties and mapathons in the Arctic region (Hristova et al., 2021; Schott et al., 2021).

Additionally, critical applications like the development of risk assessment frameworks require high positional accuracy and detailed information. Consequently, in terms of future research, we intend to apply extrinsic approaches to check the geometric accuracies of the OSM data. In addition, we would examine the variability of the OSM data quality within the countries.

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