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HARNESSING OPEN DATA AND TECHNOLOGY FOR THE STUDY OF ACCESSIBILITY: THE CASE OF INDONESIA'S CAPITAL SITE CANDIDATE

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Accessibility has garnered substantial attention from transport and urban planners as the objective of modern transportation systems. However, analyzing accessibility is often challenging in practice due to extensive data requirements and computational complexity. The rapid growth of open data and technology provides new opportunities to perform such analysis in greater details. This study offers a framework for harnessing open data to support accessibility analysis. We applied the proposed framework to the greater area of North Penajam Paser, which is the candidate site to be Indonesia's future capital. The results suggest that accessibility mapping using open data could be an important toolbox in regional analysis, especially during the early planning phase. It encourages discussions around the problems and alternative solutions for improving citizen access to various opportunities.

***Key words*: accessibility; regional planning; open data; transportation network.**

INTRODUCTION

Nowadays, many urban and transport planners have started to shift the focus from traffic and mobility to the perspective of accessibility. Accessibility, especially in transportation, is defined as the ease with which goods, services, or activities, together called opportunities, reach their destinations (Steiniger *et al*., 2016; Talen, 2003). The sprawling growth of urban areas has made it difficult for people without private vehicles to access essential services in large cities (Marks *et al*., 2016). Although, in this digital era, some opportunities can be acquired virtually, geographical proximity still plays a significant role (Cervero, 2005). Therefore, accessibility studies are essential in city and regional planning as a way to measure spatial equity issues, especially to understand who has access to particular goods or services and who does not (Gonçalves *et al*., 2017; Talen, 2003).

Accessibility has been considered as the ultimate goal of any modern transportation system (Duranton and Guerra, 2016; Venter, 2016). The concept is perceived as a more balanced, holistic view focusing on the system as a whole, rather than the transport infrastructure alone (Cervero, 2005). Accessibility as a performance indicator encourages the development of facilities, thus allowing people to reach more opportunities with less mobility. This concept contrasts the view of mobility that mainly focuses on efficient movement. Mobility-based planning often neglects the crucial role of infrastructure networks and limits its focus to the efficiency of the transport system (Venter, 2016). Consequently, the plan makes people spend more resources (e.g., money, time, energy) on commuting, which opposes sustainable development principles.

The accessibility concept has been adopted in various

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transportation studies (Duranton and Guerra, 2016; Karou and Hull, 2014) and healthcare planning (Lu *et al*., 2019; Plachkinova *et al*., 2018) for improving social services and equity in cities and regions (Kompil *et al*., 2019). Accessibility is also one of the rising concerns in urban logistics and distribution studies (Cattaruzza *et al*., 2017; Janjevic and Winkenbach, 2020). As cities have become more congested and fragmented, several new challenges have arisen with regard to accessing last-mile destinations, such as high transport costs, air pollution, and traffic congestion, thus reducing the citizens' quality of life.

While accessibility itself is a simple concept, it is often difficult to measure in practice. To date, there has been no unified approach to measuring transport accessibility. Various dimensions have been proposed as proxies, such as availability, affordability, proximity, acceptability, adequacy, and awareness (Saurman, 2016). Among them, geographical proximity is the dimension that is most used for measuring accessibility, since it serves as the basic requirement for making other dimensions possible (Logan *et al*., 2019). Talen (2003) classifies proximity-based accessibility measurement methods into five major approaches: (a) the container approach, which measures the number of facilities within a given unit; (b) the coverage approach, which measures the number of facilities within a given distance from the origin; (c) the minimum distance approach, which measures the distance between the origin and the nearest facilities; (d) the travel cost approach, which calculates the average distance between an origin and all facilities; and (e) the gravity-based approach, which measures the sum of all weighted facilities divided by the decayed distance cost. Each approach has its advantages and disadvantages. Therefore, the data availability and the purpose of the study play significant roles in justifying the method.

Many traditional accessibility studies have used simple proximity measures and a low resolution of spatial data due to limitations in data availability and computational power. These limitations have discouraged decision-makers from adopting the concept in practice. In this digital era, better-quality data and tools are available to support a more complex accessibility study. However, some of them are owned by private enterprises which cost money to use, making them less accessible for most people. The rise of the open-source community has allowed people to contribute a wide range of geographical information through an open platform. The size of such volunteered data is growing over time, providing opportunities for more advanced studies in transport and spatial planning. It enables transport and urban planners to measure accessibility with greater precision and higher resolution, even in street-level analysis. Open data can also be a useful input for conducting spatial analyses, especially in remote areas where official data is scarce. Such information helps to address the limitations in previous accessibility studies, which have often ignored the tail end of the distribution in places where most of the population with low accessibility reside (Logan *et al*., 2019).

Our study aims to provide a framework for harnessing open data and technology for accessibility analyses. We provide a case-based study in the greater North Penajam Paser area to illustrate the efficacy of the proposed framework. The methodological aspect of this study offers a generic workflow that can be replicated in other geographical areas. The results from this study also provide empirical insights for stakeholders on the accessibility profile of Indonesia's future capital, which could serve as a basis for supporting sustainable development in the region.

The rest of the paper is organized as follows. We cover the empirical context of the study. Then we describe the materials and the proposed framework. After that, we provide the results of the analysis. The discussion and recommended actions are given prior to conclusions. Finally, we discuss the conclusions of the study.

EMPIRICAL CONTEXT

In 2019, Joko Widodo, as the President of Indonesia, announced the plan to relocate the capital of Indonesia from Jakarta to two regencies in East Kalimantan: part of North Penajam Paser and part of Kutai Kartanegara (Gorbiano, 2019). The new capital is intended to serve as the seat of the national government, while Jakarta would remain the country's economic center. The decision to relocate the country's capital was driven by the motivation to address Indonesia's regional disparity caused by Java-centric development, and to relieve the heavy burden on Java (Coca, 2019). As one of the largest islands, Java is home to around 56% of Indonesia's population (see: Figure 1) and it generates more than half of the gross domestic product (GDP). Each year, it attracts substantial migration from other regions due to its economic appeal, worsening the disparity in the country.

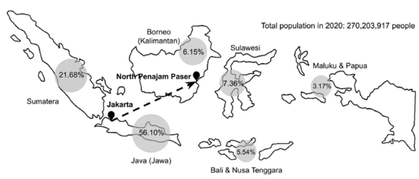

Figure 1. Location of Indonesia's Future Capital Site and Indonesia Population Distribution

It is expected that the official relocation will start around 2024 (Nathalia, 2019). In 2019, the government ran a design and planning competition for the capital city. Three winners were announced and the official city masterplan will combine all of the innovative and sustainable aspects from the winners (Ministry of Public Works, 2019). Due to the Covid-19 pandemic, the masterplan has been delayed and is still in the production process (Nirmala, 2021). Relocation of the capital is expected to redistribute the urbanization trend to other islands and improve regional development. It is also motivated by the fact that Jakarta is continuously sinking, at a rate of 25 centimeters per year due to subsidence (Lin and Hidayat, 2018). Jakarta has also suffered from chronic urban problems such as overcrowding, intensive floods, severe air pollution, and traffic congestion, which frequently disrupt business and government activities (Niniek, 2019). The capital's relocation to East Kalimantan offers some solutions to the problem. The site is geographically located in the center of the archipelago, providing better access to reach outer islands in Indonesia. The island is also less populated and less prone to earthquakes than Java. Therefore, the relocation would help to relieve the burden on Java island and accelerate regional development.

Nonetheless, cities are both complex and socio-technical. They are made of people, facilities, and services interacting with one another. The status of North Penajam Paser as the site of the capital would also attract massive urbanization from other regions as people arrive seeking better opportunities. Unfortunately, the transport infrastructure and public facilities in East Kalimantan are far less developed than in Jakarta. This creates additional challenges for the authority to provide and maintain a high quality of life for future citizens. Poor access to public facilities has been known to have a strong association with social inequality (Su *et al*., 2019). Without a proper development plan, massive urbanization and social inequality could lead to subsequent problems in the future, such as poverty, overcrowding, and chronic traffic jams (Hidayati *et al*., 2019). Therefore, there is a need for a comprehensive accessibility assessment in the region to support its role as the nation's new capital.

MATERIAL AND METHODS

Data Collection

Our study focuses on accessibility in the greater area of North Penajam Paser in the east of Kalimantan island, Indonesia. The area covers 4.09 km^2 of land, including five adjacent subdistricts: Penajam, Samboja, Balikpapan Barat, Balikpapan Utara, and Balikpapan Timur. Using the overpass API from OSMNx software (Boeing, 2017), we acquired the open data from the OpenStreetMap (OSM), including the road network, district boundaries, and the points of interest (POIs) for the study area. Figure 2 shows the map of the study area along with the existing facilities. The figure was created using OSMNx.

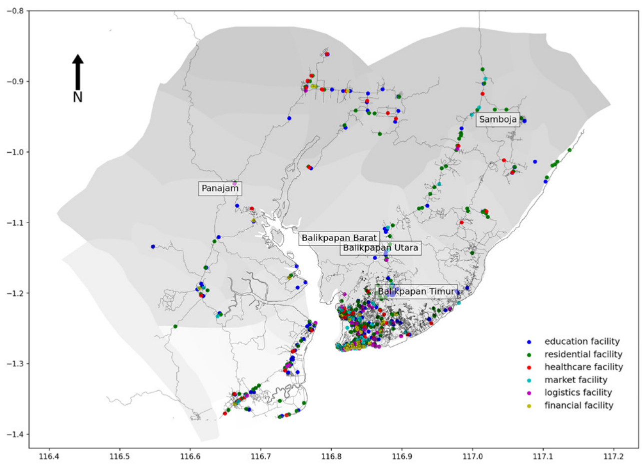

Figure 2. The street networks and the POIs in the greater area of North Penajam Paser

OSM is a Volunteered Geographic Information (VGI) platform, where people can openly contribute to add, edit, and even delete information in the database. The information consists of several elements of spatial data in the form of nodes, ways, relations, and tags. Nodes denote a certain point on the earth's surface defined by its latitude and longitude. Nodes can represent places, road intersections, or point of interests (POIs). Each node comprises at least an ID number and a pair of coordinates. Ways represent networks on maps such as roads, rivers, or coastlines. Relations refer to a multi-purpose data structure that documents the relationship between two or more data elements. The meaning of a relation is defined by its tags, which provide information on the particular elements to which they are attached.

Like other databases, the data from OSM are not guaranteed to provide the most comprehensive information. Some POIs or street features can be missing from the database due to its voluntary nature. OSM also often lags behind in updating infrastructures such as the street network and the existing POIs. However, it typically provides large enough samples to represent an accessibility map for a given area (Steiniger *et al*., 2016). A study by Barrington-Leigh and Millard-Ball (2017) shows that globally, OSM has covered 83% of the world's street networks, and about 42% of countries in the world are more than 95% complete. The results indicate that in many places, researchers and policymakers can rely on the completeness of the OSM.

The data retrieved cover 24,276 street segments, with 13,761 crossroads and 748 POIs identified. The total length of the streets is 3,084 km, with a mean of 126.94 meters and a median of 67.36 meters per road segment. We considered that the POIs represent opportunities and divided the tags into six categories: residential, education, healthcare, market, transportation, and financial services, as shown in Table 1. We attempted to assess the completeness of the data. However, the only authoritative report available from Statistics Indonesia refers to education facilities. Therefore, there are still some uncertainties regarding the data completeness for other facilities. Nevertheless, the rate of completeness for education facilities might be a good indication for other facilities. For education facilities, the data completeness rate is 70.23%.

Table 1. Category of facilities based on amenity tags from OSM Paser

Category	Amenity tags	Total POIs
Residential	'place of worship', 'community center', 'police stations'	215
Education	'school', 'university', 'kindergarten', 'library'	236
Market	'marketplace', 'industrial', 'supermarket', 'kiosk', 'restaurant'	121
Healthcare	'clinic', 'hospital', 'pharmacy', 'dentist', 'nursing home', 'doctors'	78
Transportation	'ferry terminal', 'bus station', 'parking', 'fuel', 'post office', 'taxi'	54
Financial	'bank', 'atm'	44

Accessibility Measurement

We followed the minimum distance approach to measuring accessibility. The accessibility was evaluated based on the location's proximity to the second nearest facilities. The farther they need to travel to reach the second facility, the weaker the accessibility in that location. The rationale to limit the threshold to the second nearest facilities is based on the assumption that it provides a minimum alternative for people to have reliable access to specific services. Hence, when the service in one facility is unavailable, people can still get a service from another facility. In this study, we limited the search range of facilities to 5 km. Assuming that the walking speed is around 5 km/hour, the specified range is equal to about 1-hour walking time. If driving is preferred, then the range should cover about 10 minutes of travel time, assuming that the average vehicle speed is around 30 km/hour. Therefore, when the second facility cannot be reached within the range, we considered the location to have poor accessibility.

To perform the analysis, we used OSMNx (Boeing, 2017) and Pandana software (Foti *et al.*, 2012) in the Python programming language. OSMNx is an open-source software that utilizes overpass API to acquire geographical data from OSM (e.g., POIs, street networks, and related information) and transform it into a street network model (Boeing, 2019). It allows the user to download spatial geometries, and to model, project, analyze, and visualize real-world street networks. In OSMNX, the street networks are modeled as a graph consisting of edges and nodes. The edges are the street segments, and the nodes are the street crossroads. By default, the weights of the edges are equal to the physical distance between each node pair. The model allowed the researchers to utilize graph theory and network science for urban analysis. Some network statistics could be derived easily from the model, such as the average degree, the shortest path, and the node centrality in the street network.

Once the required information was obtained, we continued the analysis by measuring the accessibility of each road segment to all the available facilities based on the existing transport network. The analysis was conducted using Pandana software. The software provides a fast proximity analysis on a large-scale network (Blanchard and Waddell, 2017). With regard to the POIs, Pandana estimated the shortest routes between a set of origins and destinations using the street networks, directions, and turn restrictions (e.g., one-way streets). Analyzing the shortest paths from such a large-scale network requires extensive computational resources. Fortunately, Pandana is equipped with an efficient data structure and contraction hierarchies to speed up finding the shortest paths in a graph. The performance benchmark of Pandana has been provided by Foti *et al.* (2012), the authors of the software. By default, the routing algorithm in Pandana does not consider traffic congestion, vehicle speed, or public transit availability. Extra information on road traffic is needed to convert the travel distance into the expected travel time. OSM provides a 'maxspeed' tag to inform the user of the maximum legal speed limit for general traffic on a particular road. However, in our case, the information was not available for most road segments. Less than 3% of the street data are equipped with maximum speed information. Therefore, in this study, the shortest path analysis is solely based on the travel distance.

To measure the shortest paths, we defined the origins as all the street intersections (nodes), and the destinations as the specified facility locations. Our study assumes that the shortest path analysis only considers the road network. Other possible transport networks, such as canals and rivers, are out of scope. Besides, we also only accounted for drivable and walkable streets. No roads with walking restrictions are included in the graph. For example, when analyzing healthcare access, we set all healthcare facilities, such as hospitals, clinics, and pharmacies, as the destination points. Pandana then computed the travel distance from 13,761 nodes to n number of the nearest facilities (in our case, n = 2) within the study area. The longer the travel distance to reach the second nearest facilities, the worse the accessibility in that particular location is. The workflow of the accessibility analysis is shown in Figure 3 and the example of the accessibility measurement is given in Figure 4.

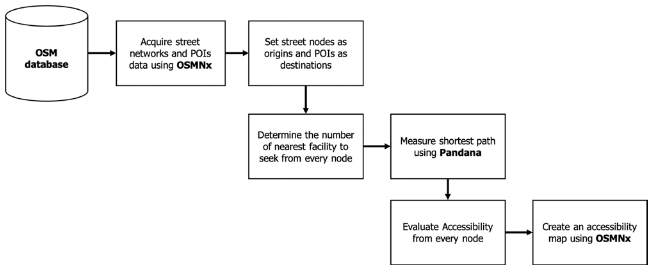

Figure 3. Flowchart of the accessibility analysis

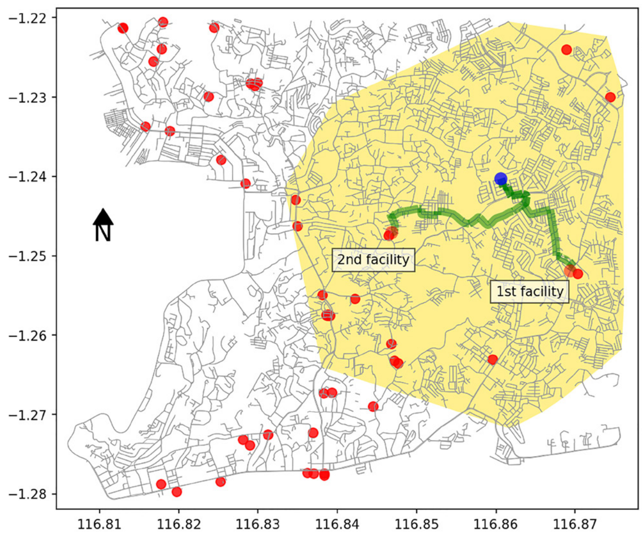

Figure 4. Example of accessibility measurement for a location (blue point). It measures the shortest path to the two nearest healthcare facilities (red points). The green lines indicate the shortest routes to the facilities. The yellow area indicates the iso-distance that can be reached within 5 km from the location.

Cluster Analysis

To discover the accessibility profiles of the study area, we performed a cluster analysis based on the travel distance to six types of facilities. We employed K-Means to classify the available streets into several clusters. K-Means is an unsupervised learning method that seeks to divide *n* objects into *k* clusters. Each object belongs to the cluster with the nearest mean/centroids. It is performed by iteratively adjusting the centroids in the dataset until there is no change in the membership of the cluster. The generic procedure for performing K-Means is as follows:

- Step 1: Determine the *k* initial centroids randomly;
- Step 2: Calculate the Euclidean distance from each object to the centroids;
- Step 3: Determine the cluster for each object based on the nearest centroids;
- Step 4: Calculate new centroids based on the means of the cluster; and
- Step 5: Repeat steps 2-4 until there are no changes in the cluster membership.

This study treats the nodes as the objects for clustering and the travel distance to the second nearest facilities as the attributes. Each object in the dataset has six attributes representing the accessibility of each type of public facility. The optimal number for cluster k^* was determined using the elbow method based on the sum of squared error (SSE) of samples to the nearest cluster center (in our case, $k^* = 4$). The elbow method is a common method in cluster analysis for choosing a cutoff when the diminishing returns of the total SSE are no longer worth the additional cluster (Thorndike, 1953). We used a sci-kit-learn library in the Python programming language to perform the cluster analysis. After the clusters were created, we analyzed each cluster's profile by evaluating the average accessibility scores for each facility type. Lastly, we generated accessibility profiles and recommendations based on regional characteristics.

RESULTS

Figure 5 exhibits the spatial distribution of accessibility in the greater area of North Penajam Paser. The darker the area, the shorter the distance to the second nearest facilities, indicating better accessibility. The figure shows that there is only a small percentage of the study area with excellent access to public facilities. Most facilities are agglomerated in the south region where a large city, i.e., Balikpapan, is situated. The figure also depicts the disparity of accessibility to six types of facilities. Residential and education services are relatively easy to access compared to transportation and financial services.

Based on the proximity analysis, we created an empirical cumulative density function (ECDF) for the travel distance to the second nearest facilities, as shown in Figure 6. Assuming that people live near the streets, the ECDF provides a qualitative and quantitative comparison of the proportion of the population that has access to services (Logan *et al.*, 2019). Figure 6 shows that the majority of the population has good access to residential and education facilities. Nonetheless, there is only a small percentage of the nodes with good access to transportation and financial services. If we take 1 km as the maximum threshold for a walking distance (Yang and Diez-Roux, 2012), less than 20% of the streets in the study area can reach all the services

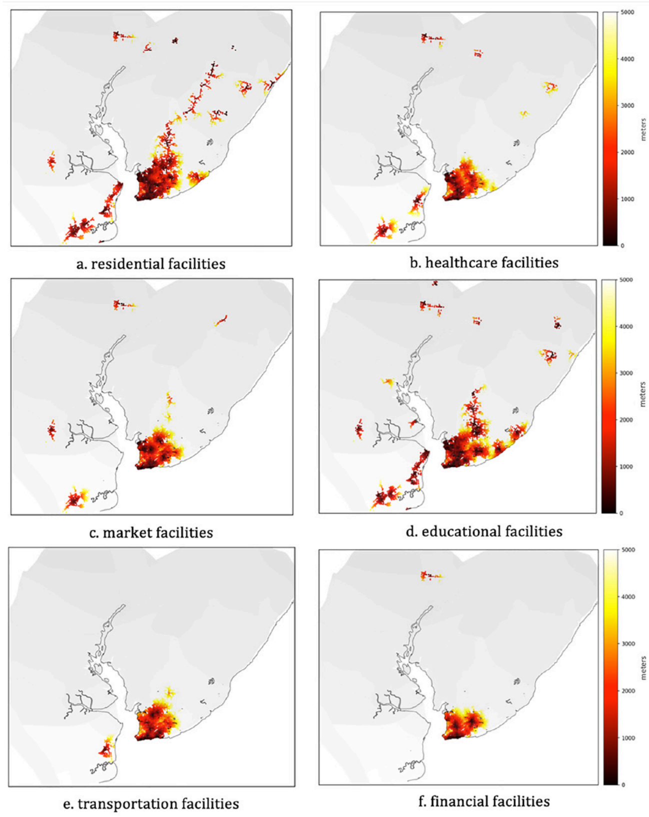

Figure 5. Accessibility maps for each category of facilities. The color shows the distance (in meters) to the second nearest facilities

within a walking distance. The Walk Score™ suggests the maximum threshold of a 30-minute walk (or about 2.4 km) to indicate good urban accessibility (Walk Score, 2011). Using this threshold as a benchmark, we found that only about 65% of the streets has good access to residential and educational services. However, less than 25% of the streets has good access to financial services. These results indicate high inequality in the greater Penajam area, where access to financial services becomes a privilege for a few people.

We performed a cluster analysis in order to better understand the accessibility profile in the greater Penajam area. The analysis suggests four clusters of accessibility profiles (see: Figure 7 and Figure 8). The cluster profiles are given as follows:

- Cluster 1 represents an area with the poorest access (> 4 km of travel distance) to all six urban service types. The cluster makes up about 25% of the nodes in the study area and is mainly located in the Samboja district, as shown in Figure 8. Decision-makers should pay considerable attention to this district since it retains the lowest urban access and is prone to a low quality of life;
- Cluster 2 represents an area with medium access to residential and education services but has poor access to other urban services such as healthcare and marketplaces. This cluster has the largest share, with about 35% coverage of complete nodes. It is characterized as a sub-urban area, which is mainly located near a large city like Balikpapan;

- Cluster 3 denotes a more developed area with good access (< 3 km of travel) to almost all public facilities, except for financial services. Besides residential and education services, the area has an excellent connection to healthcare, and the marketplaces make it ideal for urban living. It makes up about 20% of the nodes in the study area and is mostly close to the primary streets; and
- Lastly, Cluster 4 represents the most developed area on the site, where many opportunities are agglomerated. Most facilities in this cluster can be reached within 2 km, indicating good accessibility. The cluster also retains good access to financial services, which is atypical for the other clusters.

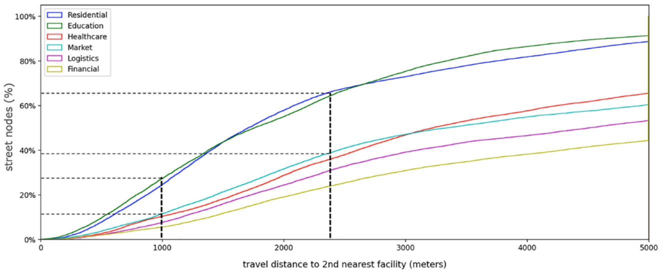

Figure 6. ECDF of street segments with access to the first and second nearest public facilities

DISCUSSION

Our findings show that the current state of accessibility in the greater Penajam area is deficient. Only about 20% of the current population has good access to all services within walking distance (<1 km). Moreover, many services are highly agglomerated in the big city, i.e., Balikpapan, especially markets, transportation, and financial services. With its current form, more than 80% of the population are dependent on vehicles to reach these facilities, indicating poor accessibility in the region. If no action is taken, the condition could impact the existing and future quality of life for the citizens. Therefore, based on the accessibility profile (Figure 7 and Figure 8), we recommend some strategies to improve urban access in the Penajam area.

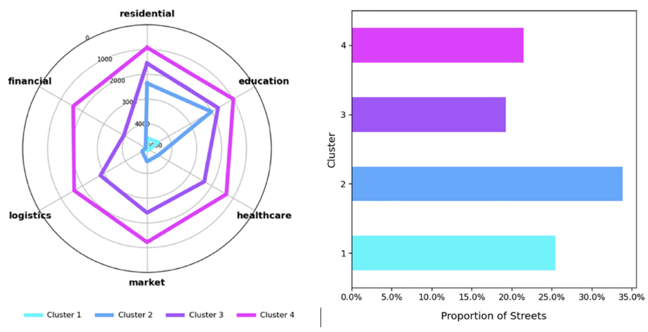

Figure 7. Accessibility profile of the greater Penajam area

Decision-makers should pay considerable attention to Cluster 1, since it covers rural areas and retains the lowest accessibility. In rural areas, accessibility is a crucial factor for improving the quality of life and economic growth. Poor accessibility also affects the health and educational level of the citizens (Laksono *et al*., 2019). Previous studies have found that people in rural areas are willing to travel more to reach jobs in exchange for better access to residential and education services (Manaugh and El-Geneidy, 2011; Yang and Diez-Roux, 2012). Therefore, substantial investment in basic services, such as residential and educational facilities, are urgently needed to improve accessibility. Another strategy is to expand the public transport capacity in the neighborhoods in order to connect these rural areas with the urban areas so that people without cars can still access various types of services.

Cluster 2 has the characteristics of a sub-urban area, which is mainly located surrounding the urban area. People living in Cluster 2 have relatively good access to educational and residential services. However, they have poor access to markets and healthcare services. Gonçalves *et al*. (2017) define the sub-urban area mobility profile as a vehicle-dependent community caused by a longer distance to reach public services that exceeds a walking distance, coupled with the lack of a public transport network. To improve accessibility in the area, we recommend creating a small urban center consisting of mini-markets and healthcare services. This small urban center could help people in Cluster 2 enjoy basic services and suffice their daily needs, while maintaining accessibility.

Cluster 3 and Cluster 4 have similar characteristics as urbanized areas. People in Cluster 3 and Cluster 4 can reach various types of services in less than 3 km on average. The main difference is that Cluster 4 has good access to financial services, while Cluster 3 does not. While these characteristics are commonly found in a big city like Balikpapan, we also found an area in the far north that also belongs to Cluster 4, namely Sepaku town. This indicates that this town has the potential to be a new urban center in the future. Thus, improving the connection between these two sites could improve the attractiveness of the new urban center for economic activities. It would not only result in a better internal balance of opportunities in Sepaku, but also contribute to a more bi-directional and efficient use of infrastructure between the two urban centers.

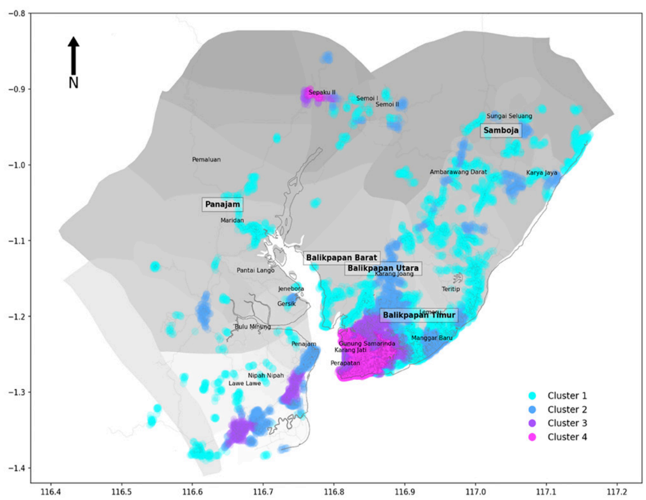

Figure 8. The cluster map of accessibility

Furthermore, since most of the existing population is currently dependent on vehicles, investing in a Transit-Oriented Development (TOD) system could benefit the new capital's development. TOD proposes a physical integration of land use and facilities into a dense area built near a transport hub (Ewing and Cervero, 2017; Marks *et al*., 2016). In this concept, a high density of mixed facilities must be planned near a transport hub within walking distance in order to improve the urban life quality. The transport hub should cover local and inter-local mobilities in the region. For example, dedicated bike lanes will help people move safely within a medium length of movement. The walking and transport infrastructure should also support accommodation for children, women, the elderly, and the disabled. Affordable and accessible public transport will benefit people with no access to private vehicles by enabling them to reach facilities.

CONCLUSIONS

This study shows the efficacy of open-source technology to support spatial planning and accessibility analysis, especially in emerging regions where official data sources are scarce. Our case study demonstrates that open data, such as the OSM database, can provide high-resolution information, such as detailed road networks and available facilities, which are useful for accessibility analysis. Accessibility maps also provide relatively easy-to-understand information, which could help the stakeholders to generate discussions around existing problems and recommend alternative solutions.

Our study also shows that measuring accessibility with open data may serve as an important toolbox in regional planning, particularly in the early planning phase. The accessibility measures shift the planning focus from merely network efficiency to the development of facilities that enable citizens to reach more opportunities with less mobility. The information provided by the accessibility maps can be further explored by linking it with the citizens' socio-economic profiles such as income, health, and education. Such a study would provide more evidence for the decision-makers and related stakeholders on the impact of accessibility on welfare and economic development. Urban and transport planners can also use accessibility measures to stimulate higher accessibility to all groups of populations or evaluate the environmental impact of land use.

Nonetheless, there are also some limitations to the study. First, the proposed framework relies on an open database, such as OSM. While preserving extensive information, OSM is not the most comprehensive database due to its voluntary feature. While it is able to recognize approximately 70% of education facilities in the study area, there are still some uncertainties regarding the completeness of other facilities. Secondly, the proximity in the study is measured solely based on the road network. Kalimantan is known for having both river and road networks as transportation modes. As a result, the study may slightly underestimate the accessibility score in the area. Future research may address one of the limitations by comparing the efficacy of other databases to support regional analysis.

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