ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2990-9295 (Online)
CODEN: MAGACU

Malaysian Applied Geography (MAGG)

DOI: http://doi.org/10.26480/magg.02.2023.55.61

RESEARCH ARTICLE

THE USE OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN DETERMINING PEDESTRIAN ACCESSIBILITY IN THE HISTORICAL CITY OF MALACCA

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ARTICLE DETAILS

Article History:

Received 08 July 2023
Revised 12 August 2023
Accepted 15 September 2023
Available online 21 September 2023

ABSTRACT

Accessibility for pedestrians is the interdisciplinary study of accessibility that does not rely on automobiles or other motorized modes of transportation. The research was carried out in the historical district of Malacca City, which is the destination of different tourist access locations and activities. The method used is network analysis and the analytical hierarchical process (AHP), which relies on Geographic Information System (GIS) as the primary database platform. This method estimates the pedestrian accessibility score in the study region. Four variables were considered: residential density, commercial or historical density, road connectivity variables, and land use. The research findings can demonstrate the percentage of people in the area who have a high, medium, or low walking ability. In addition, with the help of GIS and walk score data, one can ascertain that the placement of the downstream city is in an area with an exceptionally high level of walkability and unrivalled accessibility. As a result, the findings of this study have the potential to benefit sustainable urban planning in terms of the economy, the environment, and the layout of cities that do not use motor vehicles.

KEYWORDS

Geographic Information System (GIS). Accessibility, Walkability, Transportation, AHP

1. INTRODUCTION

Malacca City is a state in Malaysia situated in the waters of the Strait of Malacca. It has a significant amount of potential in terms of its role as a tourist destination. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has designated Malacca City as a World Heritage Site (WHS), and it was the first city in Malaysia to receive the Walk Score (WS) certification that confers the title of "Walkable City." As a result of this acknowledgement, Melaka is now a sustainable city that can improve pedestrian accessibility and ease of access to a location with the availability of pedestrian walkways. According to the information provided by Walk Score, the state of Malacca is in the first stage of becoming a "Walkable City." This is followed by the cities of Georgetown (Penang Island), Kuala Lumpur, Ipoh (Perak), Kuching (Sarawak), and Putrajaya. The town of Malacca, which now holds the position of champion, amassed a total of 86 points to earn the maximum possible score. Access for pedestrians is both a beneficial activity and a sustainable means of transportation because it can lessen the impact of pollution on the environment, improve the amount of greenery in the surrounding area, and decrease the number of vehicles on the road.

Hassan et al. (2022) describes several criteria that the state must achieve to receive the title of "Walkable City." These criteria include easy access to various forms of public transportation, greenery and shaded landscapes along sidewalks, roads with marked pedestrian crossings to slow down and warn drivers, and many more (Hassan et al., 2022). Accessibility for pedestrians can assist users in carrying out their day-to-day activities, including helping those with disabilities (OKU). A study of Jalan Hang Jebat in the old city that was carried out by Ja'afar et al. (2017) identified it as a pedestrian promenade destination that did not provide access to people with disabilities. Based on the findings of other researchers, it was discovered that active pedestrians can walk along the sidewalks along the Malacca River, Kota A Famosa, and Jalan Jonker (Ja'afar et al., 2017). This is because as the sun goes down, the location transforms into the most popular tourist destination in the area. According to recent studies, tourists have the misconception that walking is both a cost-effective and sanitary activity that positively contributes to economic development and health (Amado et al., 2013).

Using Geographic Information System (GIS) applications in pedestrian accessibility mapping can create a clearer image of the availability of favourable places for pedestrian activities and become guides for the public. According to previous study, GIS can evaluate both the index and the level of pedestrian accessibility. Accessibility from one area to another can also be measured based on pedestrian accessibility, resulting in time, energy, and money savings. In addition, going for a walk can positively impact a person's quality of life and their plans for sustainable development (Maghelal et al., 2011). Thus, advances in the field of geo-space involving pedestrian accessibility and accessibility are closely associated components of urban design that give the most significant services for future use (Gargiulo et al., 2021). According to Dinda et al. (2018), urban transport management should significantly emphasise accessibility and connection. According to D'orso and Migliore (2018), these two factors can, in a roundabout way, supply walking activities as the primary form of transportation based on a fair distance.

2. LITERATURE REVIEW

Numerous studies are being undertaken by scholars all around the world and all over the country about pedestrian accessibility. According to other research, walking is frequently related to other forms of physical exercise, including health (Nazim, 2013). According to previous study, *pedestrian accessibility* is defined as a level of efficacy in promoting walking and cycling activities as an alternative to using cars to get to a site such as shopping centres, schools, or specified destinations (Esri, 2012). Pedestrian accessibility may also be considered the ease with which people can walk from one place to another. According to the World Health

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Organization (WHO), increasing pedestrian accessibility can improve health, safety, and fitness, reduce obesity, and contribute to the sustainability of the environment. Using GIS techniques as a spatial platform, others investigated the capacity of pedestrians to maintain a healthy lifestyle and reduce the risk of developing chronic diseases (Horak et al., 2022).

Malaysia is a developing nation that has tried to implement pedestrian accessibility practices, particularly in developed states, in terms of decent amenities and accessibility. These methods have been adopted in Malaysia. This effort is to solve the quality-of-life problem, particularly in metropolitan regions facing transportation challenges such as increased traffic accidents and pollution problems (Shah et al., 2010). Specifically, this project is to solve the problem in urban areas experiencing traffic congestion.

The research focuses on the elements of tourism destinations that appeal to visitors, particularly in Kuala Lumpur (Ujang and Muslim, 2015). As a result of the substantial number of traffic jams that occur in urban areas, out-of-town visitors frequently choose to engage in activities that require them to walk. Accessibility for pedestrians can offer visitors from other countries a more enriching experience in Kuala Lumpur, allowing them better to appreciate the city's natural and cultural attractions. In addition, there is research carried out the region of tourist attractions and World Heritage sites (WHS) in and around George Town, Penang, which has the potential for high pedestrian accessibility (Yahya and Samat, 2020). The strategic and central location in the city's centre has transformed the city into a bustling tourism destination for both domestic and international visitors.

Various ways are used to test the capability of pedestrians, particularly at the local level, by providing a rating score or index that demonstrates the highest possible degree of quality. The research strongly emphasised the idea of the P-index, which focuses on four essential factors, including mobility, safety, amenities, and accessibility (Shah et al., 2010). Due to the grading, five distinct groups or divisions within the research area can differentiate between the various levels of pedestrian competence. According to other studies, four primary criteria determine the assessment of pedestrian accessibility: a high population density, a diversity of land use, the closeness of sites of interest; and a network of road connections. High population density is one of the most critical factors (Leslie et al., 2005; Fang et al., 2015; Qureshi et al., 2022). According to recent research, five factors go towards determining pedestrian accessibility. These factors are the population density, the availability of public transportation, the connectivity of roads, the level of crime, and the variety of land uses (Pentella, 2009). According to a study in Putrajaya, Precinct 18 has the highest pedestrian accessibility, followed by Precincts 9 and 8 (Qureshi et al., 2022). In addition, other research used GIS applications to determine pedestrian accessibility based on density maps of an area utilising open data sources. This was done by analysing the data (Telega et al., 2021). The kernel density and line density methods are utilised to analyse the density values obtained from each place in points and polygons. This classification considers characteristics related to location, including public transportation, parks and recreation, public amenities, and retail outlets, in addition to factors related to road infrastructure.

According to previous study, a GIS technique may be used to evaluate the degree of accessibility to a site, such as public services such as public transit, stores, banks, restaurants, supermarkets, recreational areas, and so on (Javed et al., 2013). This evaluation is based on examining spatial distribution patterns using network analytic methodologies. This decision of accessibility considers the average walking distance of around sixty meters, equal to one minute. It is based on the distance between your primary location or residence and the site you wish to travel destination. The spatial distribution pattern that is present around the study region that was taken was obtained via the use of a buffer analysis method that was approximately half a mile in width.

However, there is a study that was carried out and verifying the 'walk score' as an appropriate tool to measure pedestrian accessibility in areas with density in terms of businesses, public recreational spaces, road junctions, population, and stopping places (Duncan et al., 2013; Horak et al., 2022). This study used the 'walk score' to measure pedestrian accessibility in areas with density in terms of businesses, public recreational spaces, and road junctions. His research considered components of buffer analysis based on two distinct lengths of 400 and 800 meters each. According to a study, this walk score evaluation is determined by the network buffer distance, which can range anywhere from 400 meters to 1600 meters (Duncan et al., 2011). The evaluation is based on the address that was provided. On the other hand, Hinckson et al. (2017) used two distinct distance techniques, one covering 500 meters and the other covering 1000 meters. According to the conclusions of the research that was carried out, an area with a concentration of companies and roads is favourable for walking (Hinckson et al., 2017).

Walkscore.com is widely used among individuals searching for residential properties and conducting research, as evidenced by the substantial number of citations it has received in the Google Scholar database, totalling over 2800 documents. A land-use-based methodology provides a straightforward scoring system that ranges from 0 to 100 to assess walkability within a given neighbourhood (Figure 1). A neighbourhood with a score of 0 to 49 is classified as "car-dependent," while one with a score of 90 to 100 is classified as a "walker's paradise."

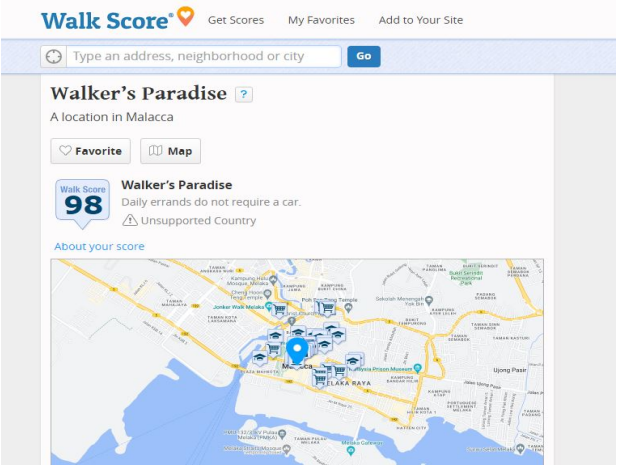

Figure 1: Screenshot of the place search section using Walkscore.com

In conclusion, the determination of GIS applications in assessing pedestrian capacity can be broken down into two distinct categories: density calculations, which include things like residency, land use, connectivity, and access, and distance calculations, which are based on moving from one location to another (Ribeiro & Hoffimann, 2018; Weliange et al., 2020). These categories can be broken down further into subcategories.

3. Materials and Methods

The study's methodology was based on the variables and parameters of geospatial data gathered through Open Street Map (OSM), map data from Google, satellite image data, and demographic statistics. Malacca had a total population of 1,004,5 thousand people in 2021, according to data provided by the Department of Statistics Malaysia (2022). According to the Department of Statistics Malaysia, Malacca saw 3.9 million domestic visitors and 1.0 million tourists from outside countries in 2012 (Department of Statistics Malaysia, 2022). The state of Malacca was chosen for the research because it is Malaysia's most popular tourist spot. It possesses a diverse uniqueness in the design of old buildings, such as historic cultural diversity, and it is situated in the strategic area of the Strait of Malacca (Shamsuddin et al., 2010; Rahman et al., 2012).

Additionally, Malacca City is home to a magnificent port. The core zone and the buffer zone together encompass a total area of 288.1 hectares, and they are the two places included in the UNESCO recognition of Malacca's cultural sites in 2008. The area surrounding Bukit St. Paul and Jalan Tun Tan Cheng Lock, as well as Kampung Morten, Jalan Hang Jebat (Jonker Walk), and numerous other roads leading to Jalan Kampung Pantai, are included in the 45.3-acre core zone (Zainol et al., 2013, titled, 2022). According to Solihah Mustafah et al. (2015), the buffer zone encompasses a total land area of 242.8 hectares. It is situated around Jalan Merdeka, Jalan Kota Laksamana, Jalan Munsyi Abdullah, kampung Banda Kaba, and several other localities, including Bukit Cina. Malacca may be found at a latitude of 2.11.222 degrees north and a longitude of 102.15.00 degrees east. According to specific estimates, the total land area of Malacca is 166047 hectares. Unique artefacts and archaeology can be found throughout the city of Malacca, which has been designated a World Heritage site. Some of the areas adjacent to St. Paul's Hill that are included in this designation include the Stadthuys History Museum, Democratic Government Museum, Cheng Ho Gallery, Literary Museum, Architecture Museum, The Islamic Museum , The UMNO Museum, Ethnographic Museum, Kite

Museum, Stamp Museum, Fort House, New World Museum of the Islamic World, A Famosa Bandar Hilir Melaka is both a well-known landmark for visitors and residents of the city, with a distinct historical character, and a fast-growing neighbourhood. The fact that Menara Taming Sari, Dataran Pahlawan Melaka, Museum Samudera, and Mahkota Parade all exist makes (Hussain et al., 2014) so appealing to visitors. There are four local authorities (PBT) in Malacca, in addition to 28 Dun and 211 Mukim. The local authorities, Dun and Mukim, are depicted in Figures 2, 3 and 4.

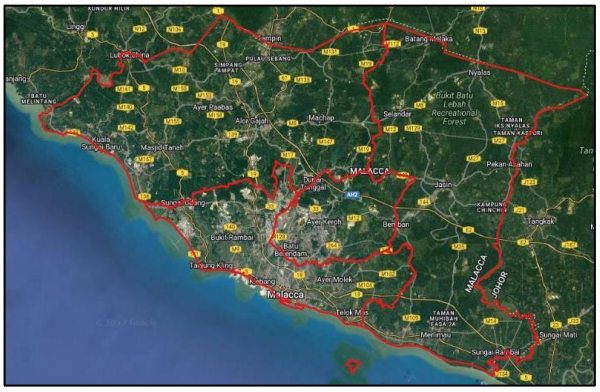

Figure 2: Map of local authorities in Malacca

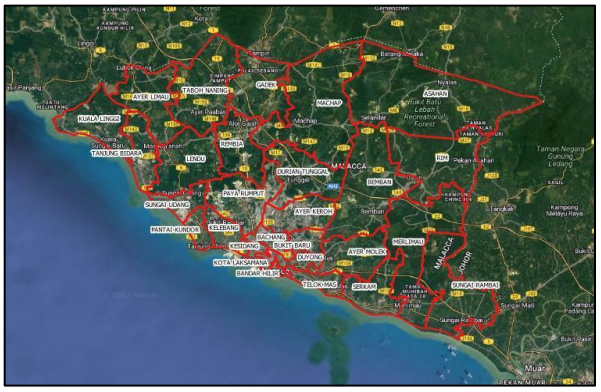

Figure 3: Map of Dun in Malacca

Figure 4: Map of Mukim in Malacca

The measurement of pedestrian accessibility can be categorized into five levels namely very high, high, medium, low, and very low (McGrath et al., 2016). These five stages can showcase the behaviour and lifestyle of the community in promoting walking activities. De Siqueira et al., (2023) used a pedestrian accessibility index score from low to high.

The parameters employed.

There are four characteristics used to analyse and measure pedestrian accessibility in Malacca City as the main region of walking activity (Frank et al., 2010). The neighbourhood's-built environment was analysed using a GIS database and the QGIS 3.18 software, as described by (Badland et al., 2009; Hinckson et al., 2017).

3.1 Density of Road Connections.

The evaluation of this parameter is conducted by considering the density of intersections, which refers to the number of intersections per square kilometres. Road junctions are acquired from publicly available data sources, such as OpenStreetMap (OSM). The assessment of the density of these road links is based on five outputs, ranked in descending order. The rating is determined by the quantity of intersections where three or more roads intersect at varying angles. A positive correlation exists between the density of road connections and the efficiency of travel between residential areas, commercial establishments, and workplaces. Figure 5 illustrates the network of road vectors inside the geographical boundaries of the state of Malacca.

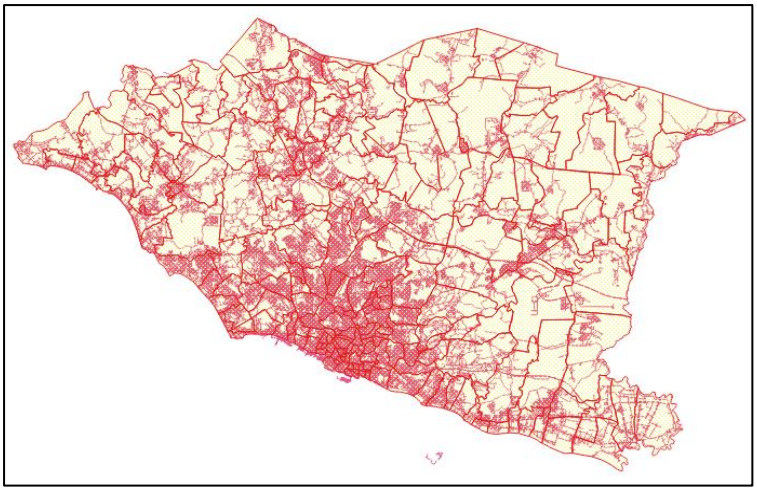

Figure 5: Distribution of roads in Malacca

3.2 Density of Residence / Population

When determining the density of residential areas, the distribution of the number of residential land areas throughout each block is analysed and taken into consideration. The information regarding people's places of residence comes from the Department of Statistics in Malaysia. In the context of this study, each individual block serves as a stand-in for one of the states of Malacca's mukim. The output is produced in a variety of levels, ranging from low to high. The location of various residential regions in and around the state of Malacca.

3.3 Density of Land Use Diversity

When evaluating the accessibility of the study area for pedestrians, the land use element emerges as an important component to consider. The commercial, residential, industrial, and public space uses of land are some of the land uses that are being considered here. The entropy index is the method that was utilized in this computation (Leslie et al., 2007). This index ranges from 0 to 1, with 0 indicating homogeneity of land use (little land use) and 1 indicating heterogeneity (high land use). Walking can be used for a variety of purposes, and the increasing usage of land in an area can impact and promote these activities. Very low, low, medium, high, and very high are the five levels that are used to express density. Very high density is the highest level. The point distribution map of the variety of land uses is displayed in figure 6, and it can be utilized for analysis.

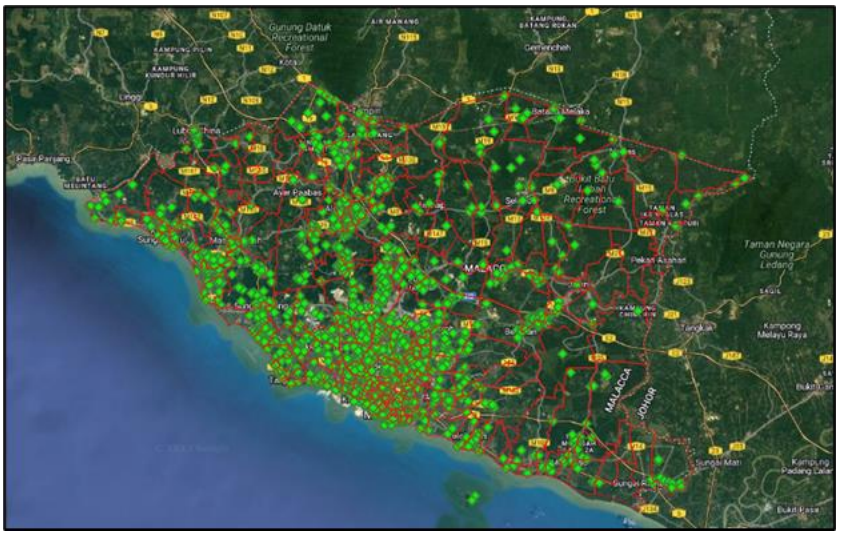

Figure 6: Map of the distribution of land use diversity points in the state of Malacca

3.4 Density of Commercial / Historical Buildings

The presence of commercial buildings at the research site is one factor that should be considered when evaluating pedestrian accessibility. This is because pedestrians, whether they are locals or tourists, will have an easier time getting to the construction site to fulfil their requirements. Existing buildings in the area can facilitate easy access and do not incur significant additional costs. The study location is depicted on a map in Figure 7, which includes a representation of the commercial buildings there.

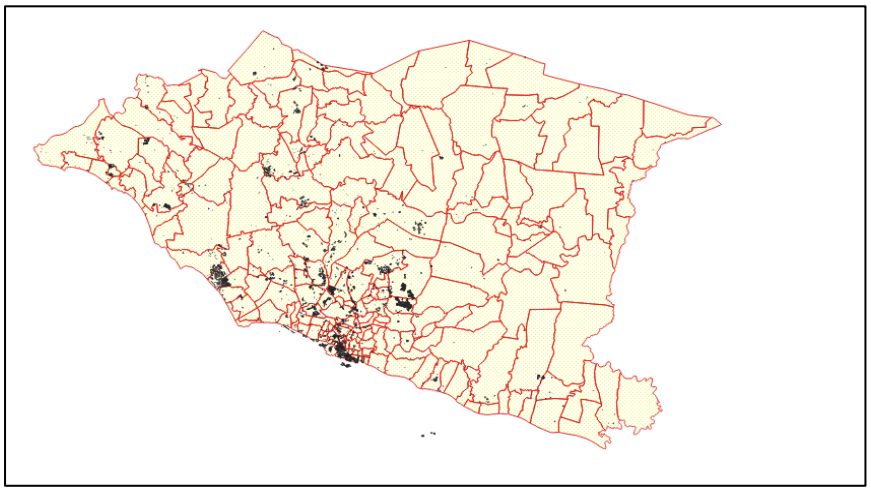

Figure 7: Distribution of commercial buildings in Malacca

The analytical hierarchy process, often known as AHP, is the procedure that is used to integrate these four parameters. A hierarchy that determines the relative importance of various metrics and criteria serves as the foundation for this approach. This AHP approach was utilized to construct a web-based GIS that can describe the total mapping of walking activities by (Joo et al., 2011). In their study of walking behaviours in Seoul, Korea, Lee et al. (2013) employed this method as one of the approaches they considered (Lee et al., 2013). The AHP approach was utilized as a decision analysis of many parameters that assess the accessibility of room suitable to improve quality of life by (Karim & Awawdeh et al., 2020). The approach of network analysis, which included consideration of time disparities of 5, 10, and 15 minutes, was used to the evaluation of 12 service criteria.

All these parameters are then transformed into a raster format that is comprised of five distinct groups. Estimating the output of each parameter in the QGIS program is accomplished with the help of the Kernel Density Estimation (KDE) approach. The distance of the radius is set to 2000 meters, and there are 100 pixels. After the KDE analysis has been finished, the determination of the weighting is carried out, and it is determined according to the priority of the parameters, which are 0.4, 0.3, 0.2, and 0.1 respectively. The 'raster calculator' will make use of this value at some point.

The Walk Score approach is utilized to confirm the primary places that are selected to evaluate the capability of pedestrians to reach a specific destination. The distance between one place and another facility location is taken into consideration by this strategy. This study is based on the work that was done by (Carr et al., 2010), which focuses on the closeness to 13 public facilities. These facilities include places to purchase necessities, coffee shops, restaurants, bars, theatres, schools, parks, libraries, bookstores, health centres, pharmacies, clothes stores, and equipment and hardware stores. The Walk Score ranges from 0 to 100 and is expressed as a percentage. According to the information provided by the Melaka Chief Minister's Department (2013), the list of locations of various tourist attractions that may be found throughout Malacca City is presented in Table 1.

A walk score is applied to each one of these locations to compare the ability levels of pedestrians in the surrounding area. According to Ignaccolo et al.'s 2020 research, this method can describe the data in the form of thematic maps based on the column database either in the form of vector pictures or raster images that are listed so that they can be comprehended through graphic formats.

Table 1: List of Selected Tourist Attraction Locations in Malacca City

Code of Location	Tourist Attraction	Location (Zone)
M1	Jonker Walk	Core
M2	Gereja Stadthuys & Christ	Core
M3	Gereja St. Francis Xavier	Core
M4	Bukit St. Paul	Core
M5	Runtuhan Bukit St. Paul	Core
M6	Porta De Santiago (Kota A Famosa	Core
M7	Chinese Hill (Bukit Cina)	Buffer
M8	Perigi Hang Li Poh (Perigi Diraja) & Tokong Poh San Teng	Buffer
M9	Tokong Cheng Hoon Teng	Core
M10	Jalan Tun Tan Cheng Lock	Core
M11	Masjid Kampung Hulu	Core
M12	Masjid Kampung Kling	Core
M13	Rumah Lama Belanda	Core
M14	Kuil Sri Poyyatha Vinayagar Moorthi	Core
M15	Melaka River Cruise	Buffer
M16	Menara Taming Sari	Buffer
M17	Tapak Memperingati Pengisytiharan Kemerdekaan	Core
M18	Maritime Museum Complex* *consists of Maritime Museum (Flor de La Mar), Maritime Museum Phase II, The Royal Navy Museum	Buffer
M19	Muzium Istana Sultan Melaka	Core
M20	Muzium Warisan Baba & Nyonya	Core
M21	Melaka Duck Tours	Buffer
M22	Muzium Rakyat	Core
M23	Muzium Islam Melaka	Buffer
M24	Galeri Pahlawan Cheng Ho	Core
M25	Muzium Remaja Malaysia	Buffer
M26	Muzium Setem Melaka	Buffer
M27	Muzium Melayu & Dunia Islam	Core

4. Results

Following the processing of vector and raster pictures for each parameter using AHP and GIS integration methods, the parameters were named as follows: road connection density, residential density, land use density, and commercial building density. Figure 8 through 11 each have a density map depicting the findings of the study, which can be viewed by clicking on the respective diagram. All these density maps are shown and interpreted based on a scale that consists of five levels: very high, high, medium, and low. Very low is the lowest level.

4.1 Density of Road Connections

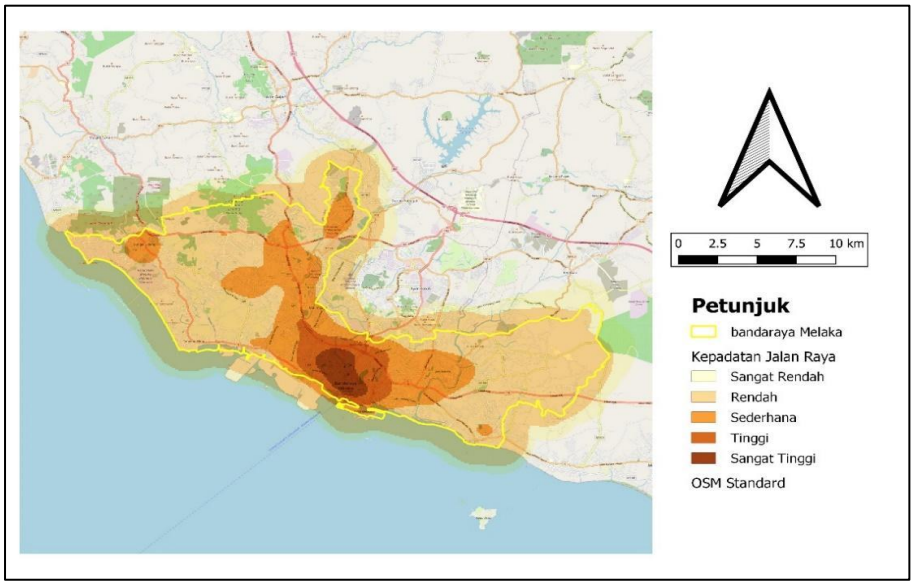

Figure 8: Road Density Map

4.2 Density of Residence / Population

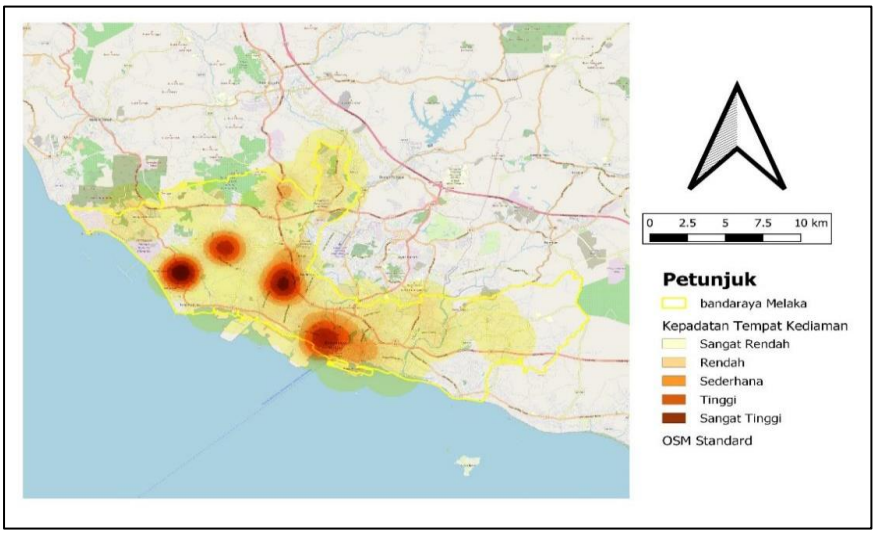

Figure 9: Residential / Population Density Map

4.3 Multi-Use Density of Land

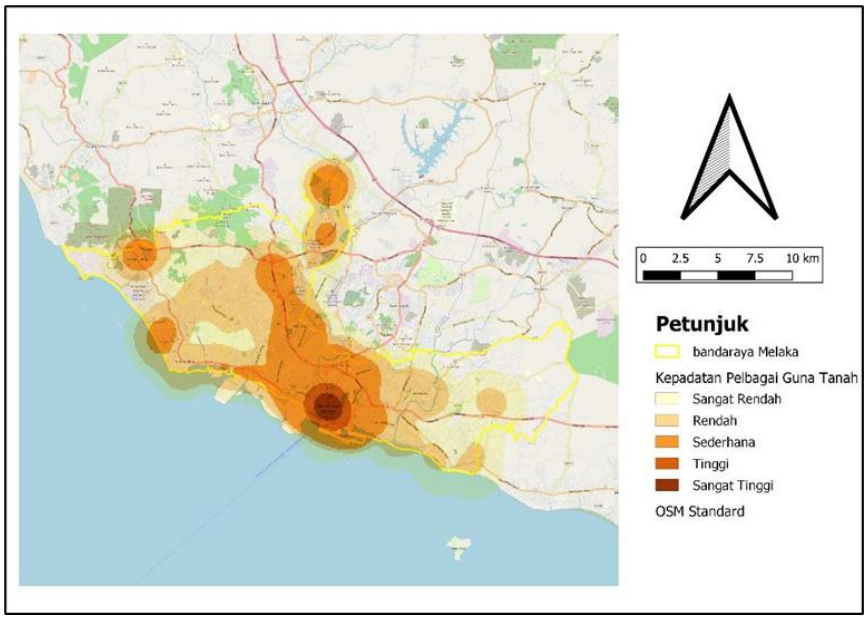

Figure 10: Multi-Purpose Density Map of Land

4.4 Density of Commercial / Historic Buildings

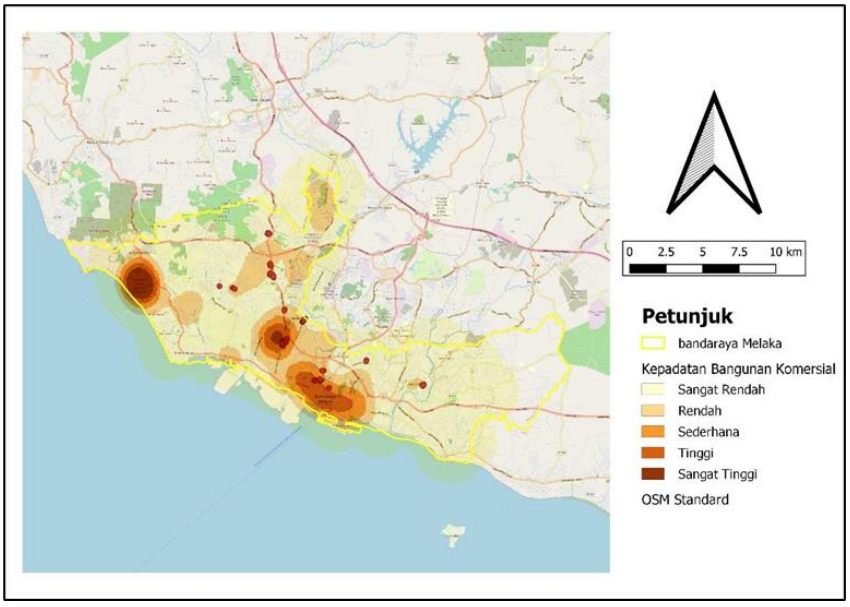

Figure 11: Commercial / Historical Building Density Map

4.5 Pedestrian Accessibility Output

The pedestrian accessibility map in Malacca City is depicted in Figure 12, showcasing the ultimate outcome. The regions that attract walking activities are situated in the downstream city, characterized by a high concentration of commercial structures, residential neighbourhoods including terrace houses, apartments, and shophouses, diverse land use patterns, and several traffic intersections. All these characteristics contribute significantly to the overall value.

4.6 Walk Score

An evaluation of the accessibility for pedestrians can be carried out using the walk score method, which considers the geographical positioning of tourist sites in relation to core and buffer zones. The data presented in Table 2 illustrates the proportion of walk scores obtained from the walkscore.com website that correspond to the location that was specified. The Kampung Kling Mosque, the Dutch Old House, and the Cheng Hong Teng Temple are the top three tourist sites in terms of the percentage of visitors they receive. These three places are all in advantageous positions and offer a variety of access points to choose from. The Hang Li Poh well and the Poh San Teng Temple have a walk score of 67 percent, which is the lowest percentage possible. This is owing to the well and temple's remote location from the city centre as well as their limited access to various forms of transportation and other amenities.

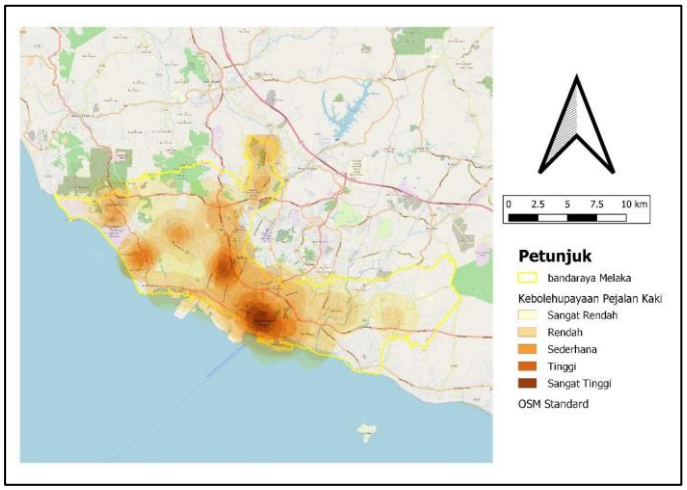

Figure 12: Pedestrian Accessibility Map in Historical of Malacca

Table 2: List of Walk Score Percentages by Location in Malacca

Code of Location	Tourist Attraction	Walk Score (%)
M1	Jonker Walk	98
M2	Gereja Stadthuys & Christ	98
M3	Gereja St. Francis Xavier	98
M4	Bukit St. Paul	98
M5	Runtuhan Bukit St. Paul	98
M6	Porta De Santiago (Kota A Famosa	97
M7	Chinese Hill (Bukit Cina)	89
M8	Perigi Hang Li Poh (Perigi Diraja) & Tokong Poh San Teng	67
M9	Tokong Cheng Hoon Teng	99
M10	Jalan Tun Tan Cheng Lock	97
M11	Masjid Kampung Hulu	97
M12	Masjid Kampung Kling	99
M13	Rumah Lama Belanda	99
M14	Kuil Sri Poyyatha Vinayagar Moorthi	98
M15	Melaka River Cruise	85
M16	Menara Taming Sari	97
M17	Tapak Memperingati Pengisytiharan Kemerdekaan	97
M18	Maritime Museum Complex* *consists of Maritime Museum (Flor de La Mar), Maritime Museum Phase II, The Royal Navy Museum	97
M19	Muzium Istana Sultan Melaka	97
M20	Muzium Warisan Baba & Nyonya	97
M21	Melaka Duck Tours	97
M22	Muzium Rakyat	97
M23	Muzium Islam Melaka	97
M24	Galeri Pahlawan Cheng Ho	98
M25	Muzium Remaja Malaysia	98
M26	Muzium Setem Melaka	98
M27	Muzium Melayu & Dunia Islam	97

Figure 13 illustrates the suppression process by combining data on attraction locations with a map depicting the density of pedestrian accessibility. According to the findings, each of the 27 locations may be reached easily by foot from their respective locations. This region provides convenient access to a variety of facilities, including lodging, transit, and other amenities. The position of this attraction, which holds sentimental value, alters the scenery in a way that draws attention to the exterior and draws attention to the importance of preservation and conservation in terms of safe and clean urban buildings and structures.

The comparison of locations that are accessible to pedestrians and those that aren't can be seen in figures 14 and 15. Walking activities are typically more prevalent in regions that have better access to roads, as this makes

it easier to travel from one site to another. Figure 14 provides a concise summary of the fact that the affected regions in Malacca City are divided into core and buffer zones referred to collectively as World Heritage Sites (WHS). This historic location offers a new perspective that can be utilized in the process of preserving the identity of an artifact and archaeology for use in the future. However, Figure 15 also applies to locales that feature wide land, green landscapes, and hilly terrain. Because of this, moving from one location to another is much more challenging.

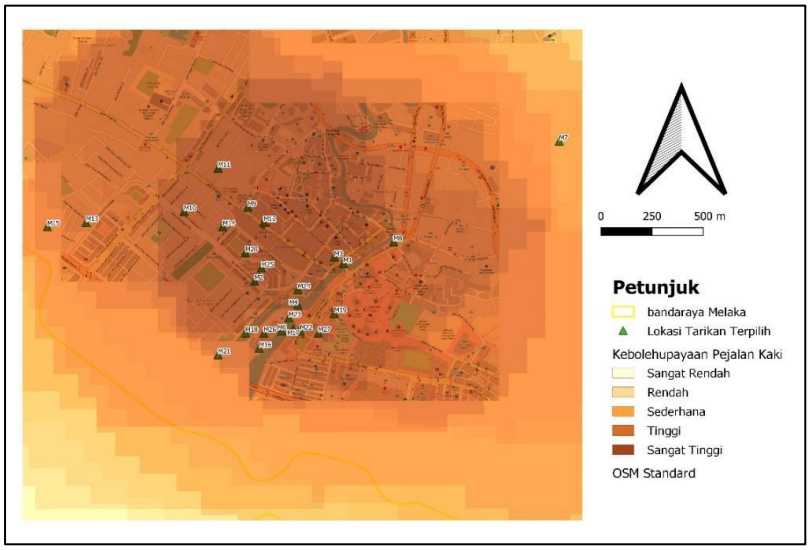

Figure 13: Location of attraction overlay map Malacca City data and pedestrian accessibility data.

Figure 14: Location of High WAI

Figure 15: Location of Low WAI

The creation of pedestrian accessibility maps as a set of principles can help improve both the infrastructure and the urban architecture of a given area. In addition, factors of transportation that connect with each other need to be taken into consideration to ensure that individuals can readily access a site in a way that is rapid, simple, and risk-free.

5. Conclusions

The study's findings indicate that pedestrian accessibility in Malacca City is characterized by a significant and favorable value, particularly in relation to the ease of movement between different locations. The utilization of this sustainable and health-promoting form of transportation might indirectly facilitate the realization, organization, and administration of ecologically conscious urban areas and societies. The act of walking can yield advantages in terms of both health and transportation within the context of urban sustainability. Malacca City boasts excellent accessibility in terms of its road network, infrastructure facilities, commercial establishments, and historical edifices, among other notable features. The designation of Malacca City as a World Heritage Site (WHS) has the potential to draw visitors to the area. The presence of a historical component has resulted in an augmentation of tourist activity and a rise in state revenues. The utilization of Geographic Information Systems (GIS) applications has the potential to enhance pedestrian activities by offering precise information, hence reducing reliance on motorized transportation. This, in turn, can mitigate traffic congestion and its associated environmental implications.

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