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Kuala Lumpur Green Space Fragmentation Index Analysis and Green Corridors Suggestion using Geographic Information System

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Abstract – More than half of the world's population lives in urban areas, and the United Nations has projected that nearly all future global population growth will occur in urban areas. Urbanization has caused rapid industrial, transportation and residential development at the expense of environmental deterioration. Activities involving large-scale land clearances are conducted to satisfy human needs for expansion. The clearances have caused green area fragmentation and patches, especially in the rapidly developing urban areas. This study is aimed at detecting the current coverage of green space in the metropolitan city of Kuala Lumpur (KL), the capital city of Malaysia and monitor its fragmentation using a very high spatial resolution satellite data. Green cover which includes trees, grass, and shrubs of KL was first extracted from the SPOT 6 data using Object Oriented method which can classified the green covers. The fragmented green spaces in KL were analyzed using a range of fragmentation indices namely Number of Patches, Edge Density, Class Area, Total Landscape Area, Mean Patch Size and Mean Shape Index using the Patch Analyst tool embedded in the ArcGIS software version 10.0 to study the patterns of green patches. The connectivity of the green patches was studied and proposed to overcome the fragmentation problems. Kuala Lumpur (KL) was chosen as the case study as it is a rapidly developing city with a significant loss of green space. The urban green spaces were more fragmented as there were more built-up areas. Results of the green cover extraction reveal that the KL city centre had the lowest percentage of green cover (2.09 %) area to the urban area compared to the other five zones (Sentul Manjalara 5.03 %, Wangsa Maju Maluri 6.09 %, Damansara Penchala 11.22 %, Bukit Jalil Seputeh 7.07 % and Bandar Tun Razak Sg Besi 7.42 %). Since KL's urban growth predominantly consists of compact building blocks, the highest land use was believed to be for commercial purposes. Around 66% of industrial and commercial activities are concentrated in the KL city centre, resulting in a diverse green space structure and a growing gap between patches in the city centre zone. The green patches were then connected to create green corridors in the city centre. Several parameters were involved in the analysis, including area, distance, types of land use (green areas and place of interest for the origin and destination), slopes under 7% value (topology with flat surfaces) and road networks. The origin and destination points were analyzed using the network analysis method in Quantum GIS to produce routes with the shortest path algorithm. Results showed that six routes were suitable for designing green corridors in the KL city centre area connecting green spaces and places of interest. All six routes were analyzed every 400 meters using Google Earth Street View to see the surrounding facilities. The Green Corridor Route 6 was the most appropriate for people, as it included parks and places of interest for city dwellers. The green corridor could then be promoted as a walkable area to minimize carbon emissions in the urban area, reducing the urban heat island phenomenon and increasing green connectivity for a better urban life.

Keywords – *Green Space, Green Corridor, GIS, Remote Sensing, Fragmentation*

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1.0 Introduction

Global warming has become a trending and widely researched area in the 21st century (Binet et al., 2020; Zhang and Zhou, 2020). The emission of greenhouse gases due to land cover/land use change and urbanization are among the key factors contributing significantly to this global concern (Khan et al., 2022). Urbanization is occurring all around the world (Zhang, 2016) due to the increase in the human population (Luo et al., 2018) and human activities causing urban land expansion (Bai et al., 2014). The main activities of urbanization, including industrial, transportation, and residential sectors, have led countries to enhance their development (Salvati and Carlucci, 2014) and have resulted in a large human population, causing urban areas to expand (Vimal et al., 2012). People strive to create better living conditions, which have caused environmental changes (Morris et al., 2016). As urbanization increases due to migration from rural to urban areas (Zope et al., 2016), large-scale land consumption and clearances (Diksha and Kumar, 2017; Zheng and Walsh, 2019) have been conducted to satisfy human needs and demands (Deng et al., 2008; Shi et al., 2016).

Green areas, which include trees, grass, and shrubs, have become smaller and fragmented due to these clearance processes by humans. Further reductions are expected as the urban population increases and uses more green areas (KLCH, 2004). Such clearances have sadly contributed to the destruction of the green regions where open spaces, wetlands, gardens, cemeteries, and waterways are part of the green infrastructure in urban areas. The rapid population increase contributes to converting vacant fields and other open areas, such as parks and woodlands, into housing and industrial developments (Kanniah, 2017).

Due to large-scale land clearances, studies on the connectivity of green spaces have increased (Lindenmayer et al., 2020) and have become a challenging issue, especially since the early 21st century (Cobbinah et al., 2015). Connectivity studies involve establishing corridors to connect one area or space to another, addressing landscape changes (Haas and Ban, 2014). Connectivity studies are essential for restoration planning, which needs to be well-executed to maximize the overall success of restoration efforts and minimize costs (Pastorok et al., 1997). Restoration planning for fragmented landscapes is a crucial action needed to reverse species declines caused by urban expansion (Lethbridge et al., 2010), and its contribution to sustainable development relates mainly, although not exclusively (Fu et al., 2023). Additionally, ecological restoration has become an increasingly important tool for managing and improving highly degraded and altered environments (McBride et al., 2010). The ideal components of restoration planning include the development of restoration goals, restoration design, implementation of the design, and monitoring to evaluate progress (Kapustka et al., 2015).

Kuala Lumpur has witnessed a significant loss of green space due to high industrial and housing activities (Kanniah and Ho, 2017). Losing green coverage causes air, visual, and noise pollution, temperature, and environmental changes (Guneroglu et al., 2013). In Kuala Lumpur, Malaysia, due to unparalleled growth in population density, the gross per capita green area decreased from 13 m^2 in 2010 to just 8.5 m^2 in 2014 (Kanniah, 2017). Such green places have adversely impacted the planning department, flora, and fauna, resulting in the loss of animals and plants (Banaszak-Cibicka et al., 2016) and a significant biodiversity decline (Farinha et al., 2016). These patches or scattered areas can contribute to the extinction of biodiversity. Biodiversity conservation is essential to maintain and preserve it (Parmehr et al., 2016).

According to the Kuala Lumpur City Hall, many patches of green areas have been created by human activities, which ultimately lead to the formation of habitat patches, landscape changes, and endangerment of flora and fauna. However, these issues could be prevented with the implementation of green corridors. Another reason this study focuses on the city area is because previous research has shown that most urbanized cities have experienced surface air temperature increases. For example, temperature increases of 0.27 °C for US cities (Kalnay and Cai, 2003), 0.5 °C for Chinese cities (Zhou et al., 2004), and 2 °C for Japanese cities (Huang et al., 2009) have been recorded in the last decade, which may be the effects of both global and urban warming.

According to the United Nations (2020), climate variability and weather events threaten achieving the Sustainable Development or Global Goals. Therefore, combating climate change is one of the global initiatives, and Malaysia is one of the countries committed to this goal. The alarming climate change that is occurring is mainly caused by increasing urbanization. Urbanization poses a significant challenge to the environment (Cobbinah et al., 2015) as it increases air temperatures and dramatically affects the atmosphere and global climate (Souza et al., 2016). It is the primary source of urban floods (Shi et al., 2016), land use and ground use changes (Zope et al., 2016), and rising energy use in power and road transport (Belloumi and Alshmi, 2016).

2.0 Study Area

The research area in Kuala Lumpur occupies an area of 24,300 hectares. Kuala Lumpur was studied because it is a rapidly growing area with a substantial loss of green space due to rising industrial development (Kanniah and Ho, 2017). Green Space Fragmentation was evaluated based on six strategic zones in Kuala Lumpur (Figure 1), consisting of Sentul Manjalara, Wangsa Maju Maluri, Damansara Penchala, City Center, Bukit Jalil Seputeh and Bandar Tun Razak Sg Besi.

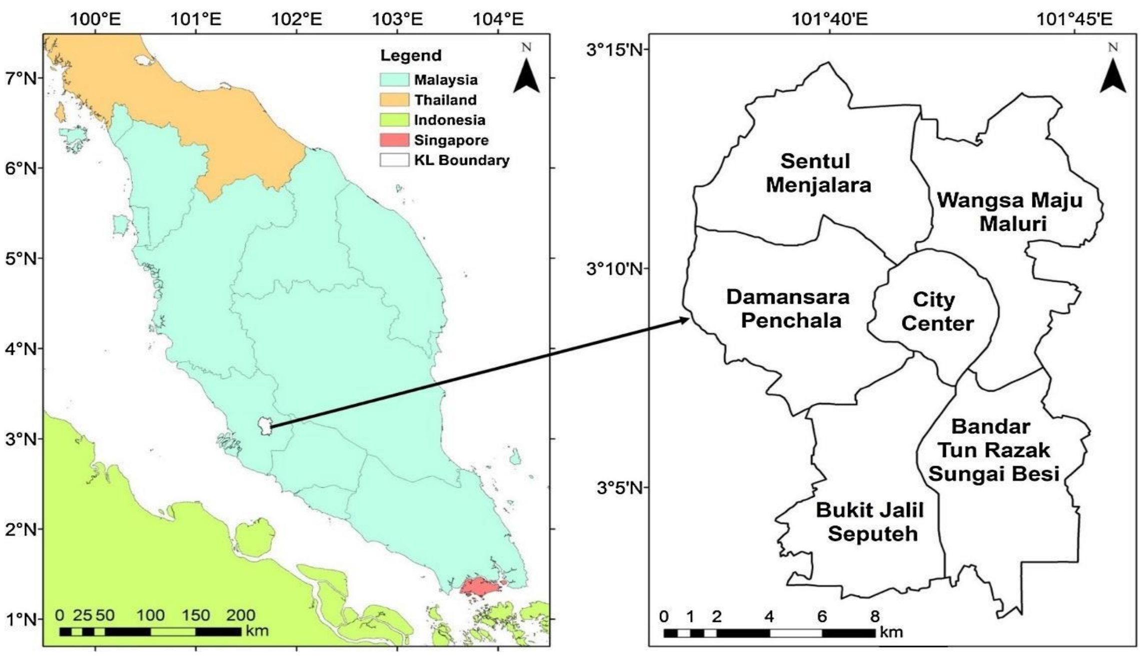


Figure 1. Kuala Lumpur area and its Six Strategic Zones

The current metro area population of Kuala Lumpur in 2023 is 8,621,724, a 2.34% increase from 2022, which is 8,419,566 (United Nations, 2023). Kuala Lumpur, Malaysia, covers an administrative area spread over 24,300 hectares. The majority of the land cover and land use patterns consist of built-up areas (residential, commercial, industrial, institution, recreational area, road, infrastructure, and utilities) and unbuilt areas (agriculture, forest, bare land), open space (recreational area) and water bodies (Rosni et al., 2018).

Most (67%) of the population are in the 15–59 age group (Nath et al., 2017). Many people emigrate to Kuala Lumpur to seek jobs. Around 83% of the total workforce is the most significant portion of the tertiary or service sector in Kuala Lumpur (DBKL, 2017). Kuala Lumpur's strategic high-growth investment sectors, which are on the radar of investors, both local and international players, include global business services, engineering construction services, aerospace (aviation, avionics and maintenance, repair and overhaul), halal products/services, financial services (including Islamic finance) and oil and gas activities (DBKL, 2020).

3.0 Materials and Methods

Kuala Lumpur SPOT-6 image was analyzed into five classes: water, trees, grass, urban and bare land (Rasli et al., 2019). Then, further analysis was conducted to derive the fragmentation of green spaces in Kuala Lumpur. Fragmentation refers to converting formerly continuous landscape elements into many discontinuous patches (Li et al., 2020). In this study, fragmentation analysis was done on all six zones in Kuala Lumpur to see which zone shows the highest number of green space fragments. Fragmentation was run for only the green space layer of trees and grass. The raster layer of the classified image of SPOT-6 was extracted and converted into a vector layer to be inserted in the Patch Analyst plugin for fragmentation processing. The Patch Analyst is a plugin for the Esri product ArcMap in version 10.0. It is primarily possible to analyze vector data with this plugin. Using patch analyst version 3.2, an extension in the ArcGIS environment. The spatial statistics for the vector layer run in the tool. The table displays indices related to the patch's characteristics. Six indices were used to define the fragmentation in Kuala Lumpur based on the six zones and were tabulated as in Table 1.

Table 1. Indices showing landscape fragmentation

ID	Full Name	Details	Formula
NumP	Number of Patches	Number of Landscape Fragments presented in the area	Patch 1+ … + Patch (n)
ED	Edge Density	Amount of edge relative to the landscape area	ED = Total Edge (perimeter of patches) / Total Landscape Area
CA	Class Area	Sum of all patches in a class	-
TLA	Total Landscape Area	Sum areas of all patches	-
MPS	Mean Patch Size	Average patch size	Patch 1+…+Patch (n) / Number of Patches
MSI	Mean Shape Index	Shape Complexity. MSI is equal to 1 when all patches are circular (for polygons) or square (for rasters (grids)), and it increases with increasing patch shape irregularity	MSI = sum of each patch's perimeter divided by the square root of patch area (in hectares) for each class (when analyzing by class) or all patches (when analyzing by landscape), and adjusted for circular standard (for polygons), or square standard (for rasters (grids)), divided by the number of patches

Next, in preparing data for finding new corridors in Kuala Lumpur (Figure 2), the output, which is the raster layer of classified land use in Kuala Lumpur, was used to integrate with the database. The data was DEM, land use, specifically green areas, water bodies, and road networks. For the Digital Elevation Model (DEM) production, the polyline layers of contour lines were converted in ArcGIS using conversion tools, and the model was produced by creating the raster layer. The raster layer underwent a weighted overlay to divide the data into slopes below and above 7 degrees. All records of pixels higher than 7 degrees were eliminated as this was not the suitable slope for designing accessible open space (JPBD Guidelines, 2016). Therefore, only pixels below 7 degrees were maintained and used. The green spaces and water layers were extracted for land use to select the origin and distances for the network analysis—the polyline data of road networks in Kuala Lumpur underwent a process of building the topography distance calculation.

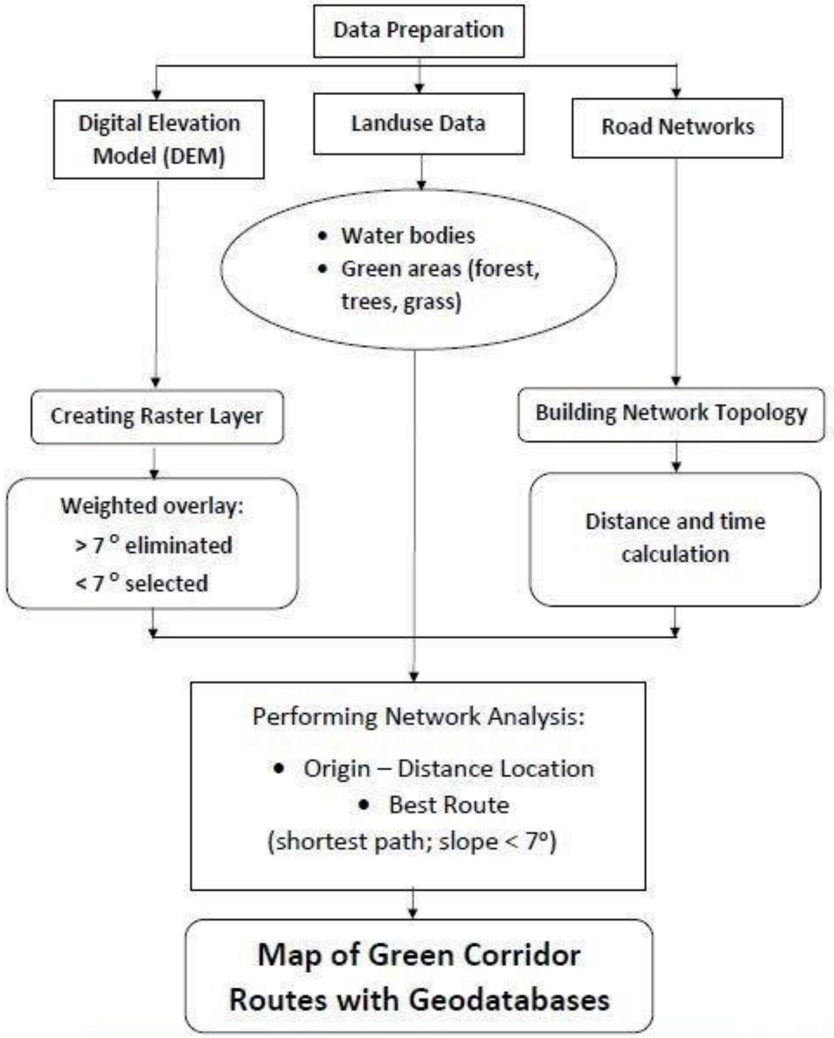


Figure 2. Flowchart to obtain Green Corridor Routes

All these three data were integrated with the Quantum GIS (QGIS) environment for the calculation by the shortest path tools. The shortest path tools include ways to determine either the shortest or the fastest path between two points of a network, given: (1) start point, and end point chosen on the map; (2) start point chosen on the map and end points taken from a point layer; (3) start points taken from a point layer and endpoint chosen on the map. The network analysis of point-to-point then calculates the shortest distance between two manually selected points on the map. In this example, the tool calculates the shortest path between two points. In the map, they integrated these three data; two points were selected as the starting and ending points for the analysis. These two points used the origin and destination from DBKL and Yusof's suggestions (Yusof, 2012). This algorithm then computes the optimal shortest route between given start and end points by selecting the points manually in the map. The Shortest option in the Path type was chosen to be calculated. This means that the cost, in this case, represents the distance between the origin and destination locations. A route was computed (and added as a new layer in the Layers Panel showed the shortest distance between the selected points. This step was repeated for all six routes by manually selecting the origin and destination of the green space and the places of interest.

The six routes are then checked for every 400 meters in Google Earth to ensure that the nearest facilities are present and provided so that people can use them comfortably. These distances were used as it was known as ‘walkable distances’ for people (JPBD Guidelines, 2016). Hence, for every 400 meters, the best practice was to have any pit stop or places where people could enjoy and relax before continuing to use the routes. Walkability was crucial in the green corridor concept to ensure it was feasible and effective for dwellers. Using Google Earth (GE), all the routes obtained from the Quantum GIS were overlaid in Google Earth (Figure 3). Then, using the function Google Street, a GE pin was marked every 400 meters, the surrounding of the pin was checked, and the landmarks were tabulated.

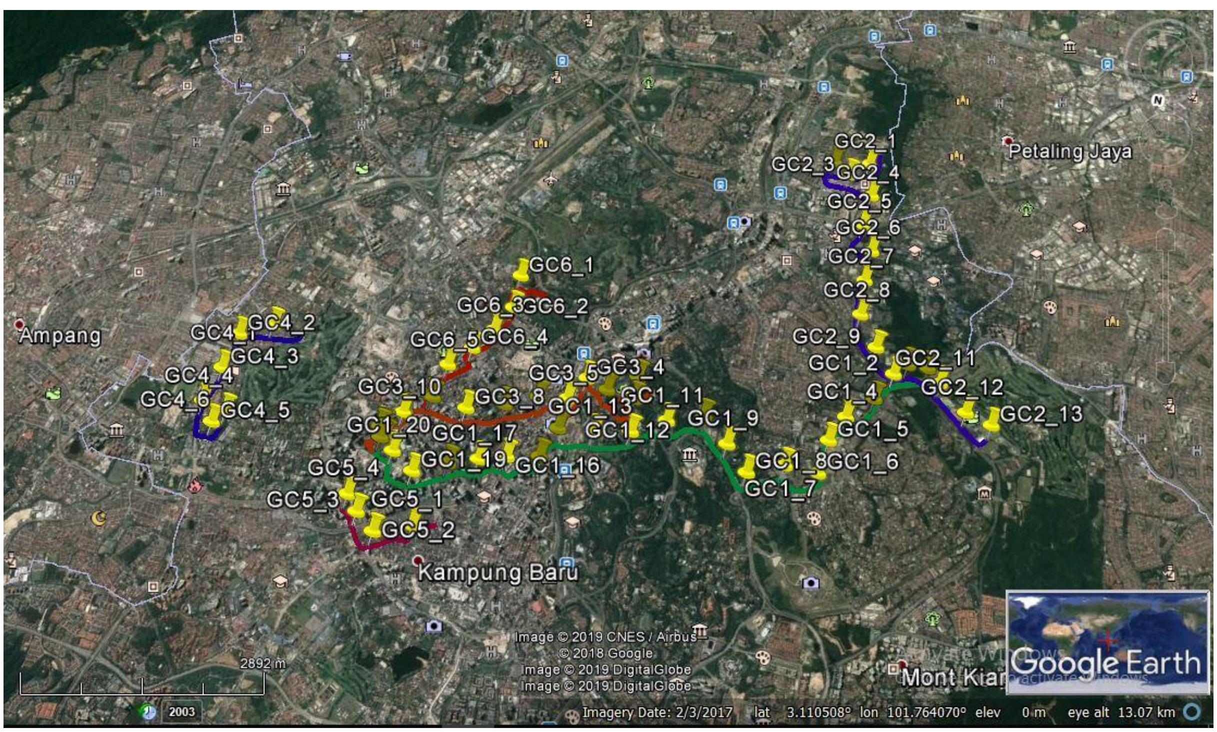


Figure 3. Green Corridor Routes marked at every 400 meters in Google Earth

4.0 Results and Discussion

4.1 Fragmentation of Green Space in Kuala Lumpur

The results of the fragmentation analysis run using the ArcGIS Patch Analyst plugin are shown in Figure 4(a)–(f). Only the green cover layer consisting of trees and grass (Table 2) was considered in the fragmentation analysis. The various indices of fragmentation and their values for each of the six zones in Kuala Lumpur are summarized.

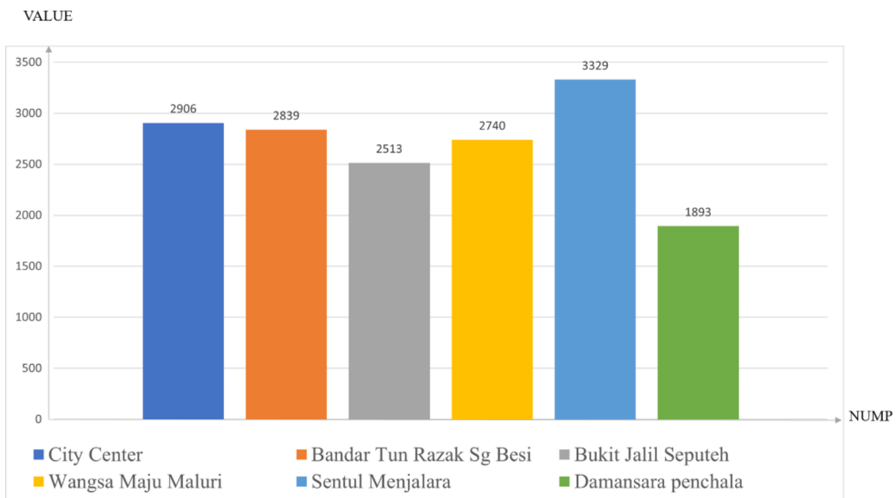
Table 2. Percentage of Green Cover based on Six Kuala Lumpur Zones

Zones	Green Cover Area (hectares)	Green Cover Percentage (%)
City Center	507.75	2.09
Bandar Tun Razak Sg Besi	1,803.29	7.42
Bukit Jalil Seputeh	1,717.41	7.07
Wangsa Maju Maluri	1,479.29	6.09
Sentul Manjalara	1,221.59	5.03
Damansara Penchala	2,727.63	11.22

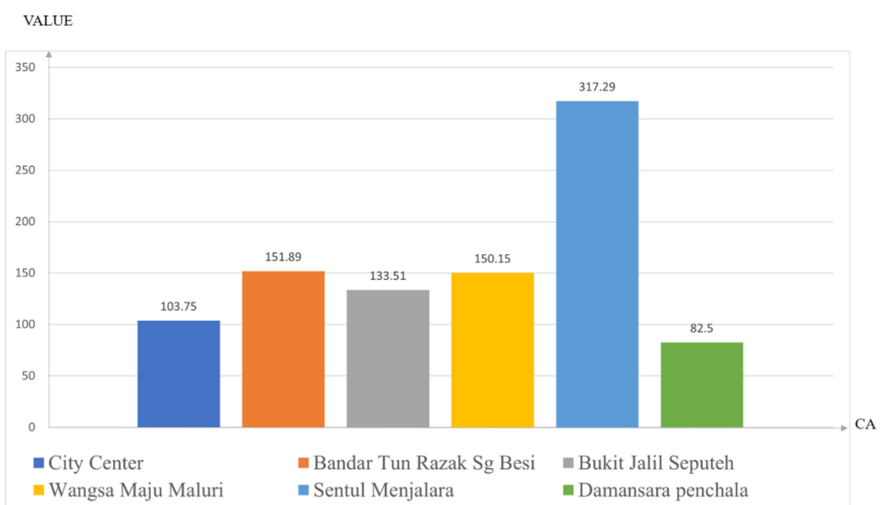
Figure (4a) – (4f) shows the pattern of green patches in Kuala Lumpur. The number of patches (NUMP) was the highest in Sentul Manjalara, followed by the city centre. Sentul Manjalara has the highest number of residential areas, leading to the number of patches in the zone. The number of patches is the lowest for Damansara Penchala because a big forest is in the location. This is also the reason green space patches are lower in the zone. These indices also show the patches within a landscape, where patches can represent the structural types, urban development, and physiographic features where the fragmentation pattern and development activities can be assessed based on the index.

Edge density (ED) was also the highest in the city centre. This is because edge density represents the total of edges that exist in the area—the total of edges showing the irregular pattern of the fragments of green space. The rapid development in Kuala Lumpur city centre contributed to the high edge density of the zone.

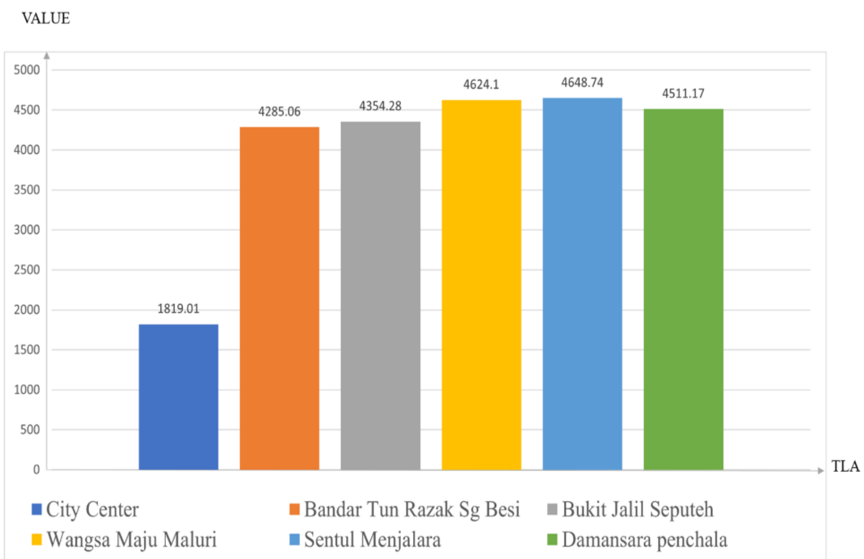
Meanwhile, Class area (CA) and Total Landscape Area (TLA) revealed the area of green landscape present in the area. Based on the result, Sentul Manjalara shows the highest total landscape area in Kuala Lumpur. The lowest total landscape area was demonstrated in the Kuala Lumpur city centre. This revealed that the city centre has the least amount of green space.



a) Number of Patches (NUMP)

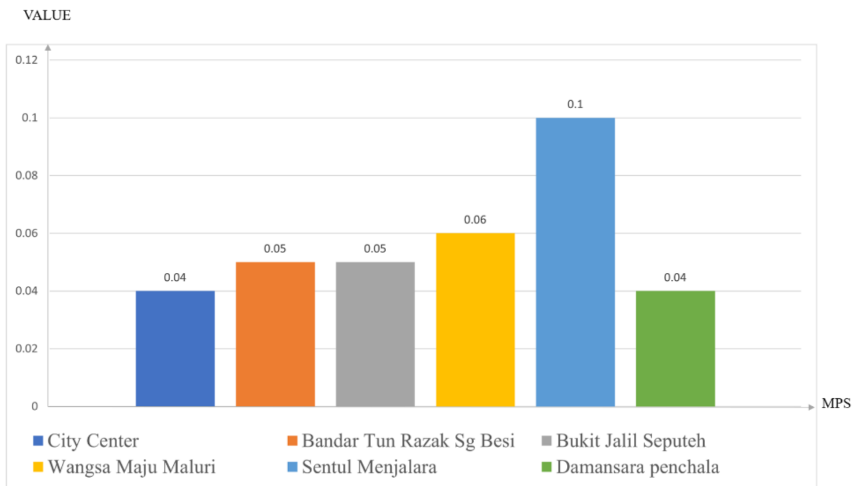


b) Class Area (CA)

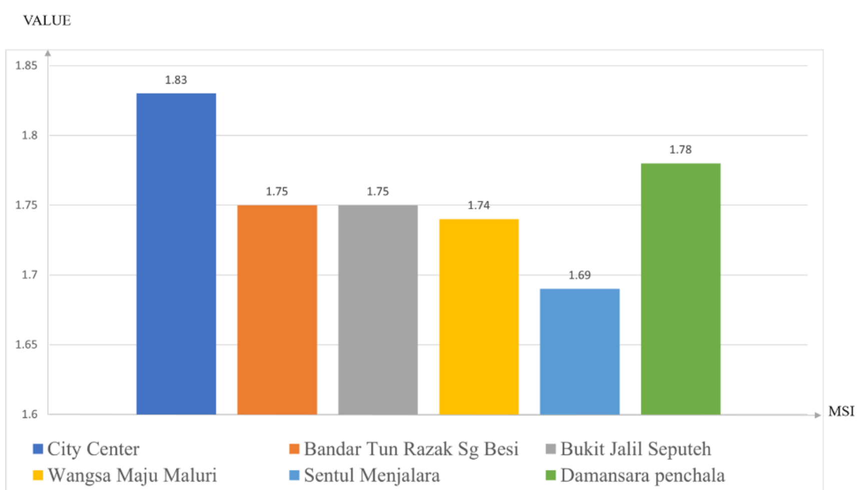


c) Total Lanscape Area (TLA)

d) Edge Density (ED)



e) Mean Patch Size (MPS)



f) Mean Shape Index (MSI)

Figure (4a) – (4f). Fragmentation indices of Green Space in Kuala Lumpur's various zones

Mean patch size (MPS) represents the complexity of the patches. Sentul Manjalara shows the most complex patches compared to all zones in Kuala Lumpur. The mean shape index (MSI) has a value of 1 when all patches are circular and increases in value as the patches become more irregular. Therefore, from the graph, it can be concluded that the Kuala Lumpur city centre portrayed the highest MSI because the zone has the highest value of MSI, meaning the area has the most irregular pattern of green space. Damansara Penchala becomes the second most irregular pattern, followed by Bukit Jalil Seputeh, Bandar Tun Razak Sungai Besi and Damansara Penchala. The lowest value is Sentul Manajalara, but the zone still has an irregular pattern of patches. None of the zones in Kuala Lumpur has circular patches or fragment patterns because the circular pattern will only be represented by the value 1.

The green space fragments in Kuala Lumpur were visualized in Figure 5. The graph reveals that the area of green spaces is minimal and vast, as almost ten thousand green areas in Kuala Lumpur are represented by an area ranging from 0 to 0.05 hectares. Three thousand one hundred fifty-eight (3158) fragments are in an area of 0.05 to 0.1 hectares, 2178 fragments in an area of 0.1 to 0.5 hectares, 505 fragments have 0.5 to 1-hectare area and 490 fragments included in the area of 1.0 to 5.0 hectares. The parks and forest reserves represent big green space fragments in Kuala Lumpur.

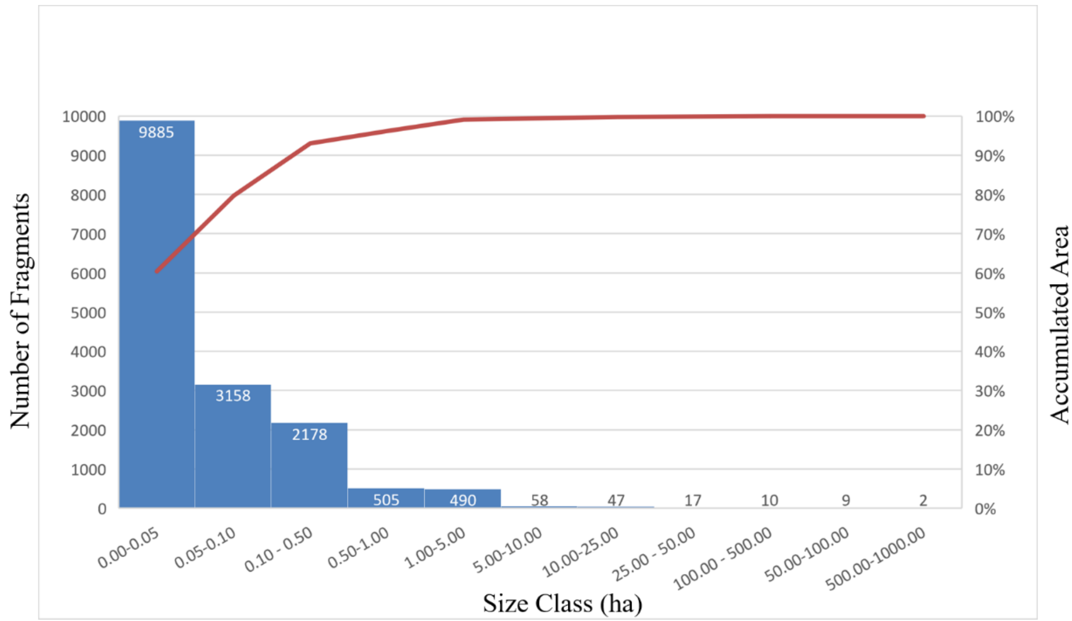


Figure 5. Number of Green Space Fragments in Kuala Lumpur

In some rapidly urbanized countries like Singapore, Malaysia and the Philippines, the challenges are that the countries developed many fragmented spaces where they need to increase the value of green space by overcoming the connectivity issue (Nor et al., 2017). Thus, the approach of developing an ecological network by using efficient models is essential to improve these networks under rapid urban expansion. In the Philippines, specifically Manila New Clark City, the challenge in the design and development of cities is to change the minds of officials involved in traditional planning approaches who may be wary of going green (Riffat et al., 2016). Manila is one of the densest cities in the world, with 14,500 people per square kilometer, nearly three times the London level (United Nations, 2018). The aim is to build a city equipped to deal with climate shocks in one of the world's most cyclone-affected regions and to promote healthy, environmentally friendly, and sustainable living by putting nature at the heart of development. New Clark seeks to challenge conventional urban planning by uniting government, developers, businesses and the public and demonstrating that green and resilient cities can be cost-effective.

4.2 Green Corridors in Kuala Lumpur City Center

The Kuala Lumpur city centre had the lowest ratio of green area to the urban area compared to the other five zones (Sentul Manjalara, Wangsa Maju Maluri, Damansara Penchala, Bukit Jalil Seputeh and Bandar Tun Razak Sg Besi). Therefore, connecting the fragmented green areas in the city centre was essential to increase the area. This study found new green corridors based on the planning guidelines integrated with the area, a walkable distance of 400 meters, maximum slope height of 7%, connecting places of interest, and including water bodies. The results are presented in Figure 6(a)–(f).

Figure 6(a). Result of Green Corridor 1 from Shortest Path Analysis

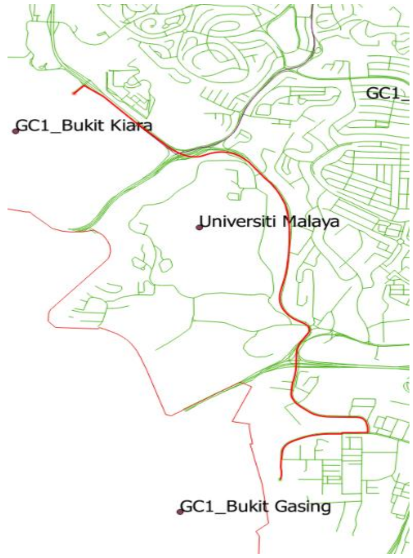


Figure 6(b). Result of Green Corridor 2 from Shortest Path Analysis

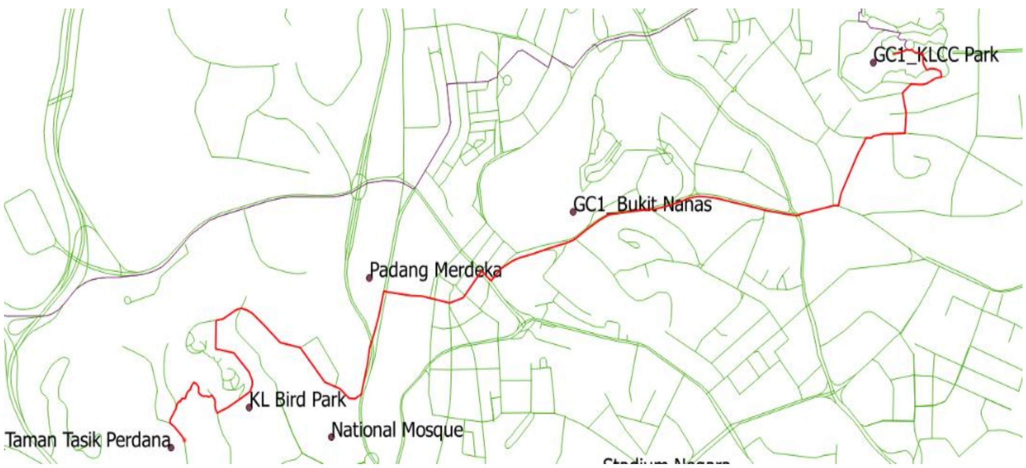


Figure 6(c). Result of Green Corridor 3 from Shortest Path Analysis

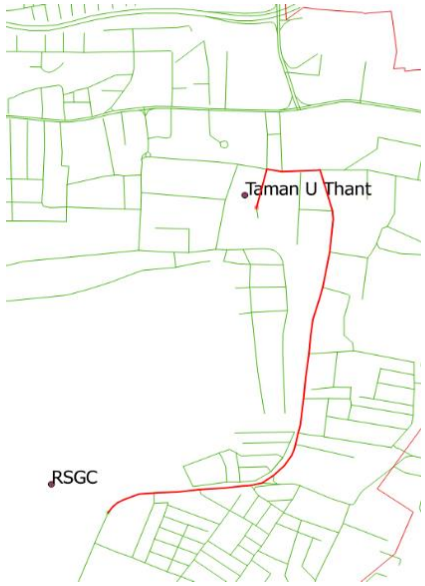


Figure 6(d). Result of Green Corridor 4 from Shortest Path Analysis

Figure 6(e). Result of Green Corridor 5 from Shortest Path Analysis

Figure 6(f). Result of Green Corridor 6 from Shortest Path Analysis

Although there are long and far routes, it is important to check for every 400 meters of what kind of landmark is presented. In route 1 (Table 3), the first three stops are LRT stations. Close to public transport was also crucial as this can give options to the dwellers whether to continue walking or take public transportation if they do not intend to walk anymore along the routes. After a few stops, parks, pocket parks, shops and restaurants are also nearby. These landmarks can serve as a rest stop so that people can take a break or buy some snacks and beverages before continuing the walk.

Table 3. Green Corridors Routes checked for every 400 meters for landmarks

Green Corridor Route	No (every 400 meters)	Landmarks/Place
1	1	Road under flyover
	2	Road
	3	Road
	4	LRT Station
	5	Road under flyover
	6	Road
	7	Road
	8	Road junction
	9	Road
	10	Road
	11	Road Taman Tugu

	12	Road along Taman Tasik Perdana
	13	Police station
	14	Tun Perak Pocket Park
	15	Arked Jalan Bunus (shopping place)
	16	Shops and restaurants
	17	LRT Station Dang Wangi
	18	Tourism Malaysia Office
	19	Laman Veritas KLCC
	20	KLCC Park entrance
	21	KLCC Park
2	1	Road residential area
	2	Road
	3	Road at Bangsar South
	4	Road/ residential area
	5	Highway/flyover
	6	Road/flyover
	7	Highway
	8	Highway
	9	Highway
	10	Highway
	11	Highway
	12	Highway
	13	Kompleks Rakan Muda Bukit Kiara
3	1	Taman Tasik Perdana area
	2	Taman Tasik Perdana Exit/Entrance
	3	Taman Tasik Perdana area
	4	Road with a pedestrian path
	5	LRT Station
	6	Road with the pedestrian path can see Kuala Lumpur Tower
	7	Road with pedestrian path Jln Raja Chulan
	8	Road with pedestrian path Jln Raja Chulan
	9	Small Park in front of Standard Chartered Bank
	10	KLCC Park
	11	KLCC Park
	12	KLCC Park
4	1	Residential area/ eateries
	2	Petrol station
	3	Road in a residential area

	4	Golf club
	5	Cafe
	6	Taman Tasik Ampang Hilir
5	1	Residential area/ eateries
	2	Restaurant
	3	Road under flyover
	4	Fire station
6	1	Road under flyover
	2	Road
	3	LRT station Hang Tuah
	4	Roads with hotels and shops
	5	Convenience store (7E and KK Supermart)
	6	Small Park in front of Standard Chartered Bank
	7	Bicycle rental place
	8	KLCC Park
	9	KLCC Park

All the six corridors are combined in Figure 7. For Green Corridor 2, most of the stops are road and highway. These routes may not be preferable to the dwellers but still can be a good choice for joggers and cyclists. For Green Corridor 3, the stops consist of the LRT stations, roads, and a small park. Although the landmarks are mostly roads, the routes provide pedestrian paths, which may encourage dwellers to use the routes safely. For Green Corridor 4, the stops consist of eateries, petrol stations, café, and golf clubs. Dwellers may enjoy the route, walking and can stop to get some food or drinks along the way. Green Corridor 5 is short but does not have much along the route. There are roads, flyovers, and restaurants too. However, Green Corridor 6 has many exciting stops: an LRT station, streets with hotels and shops, convenience stores, a small park, and a bicycle rental place. These stops with useful functions to dwellers can encourage people to use the green corridor routes and effectively promote walkable cities.

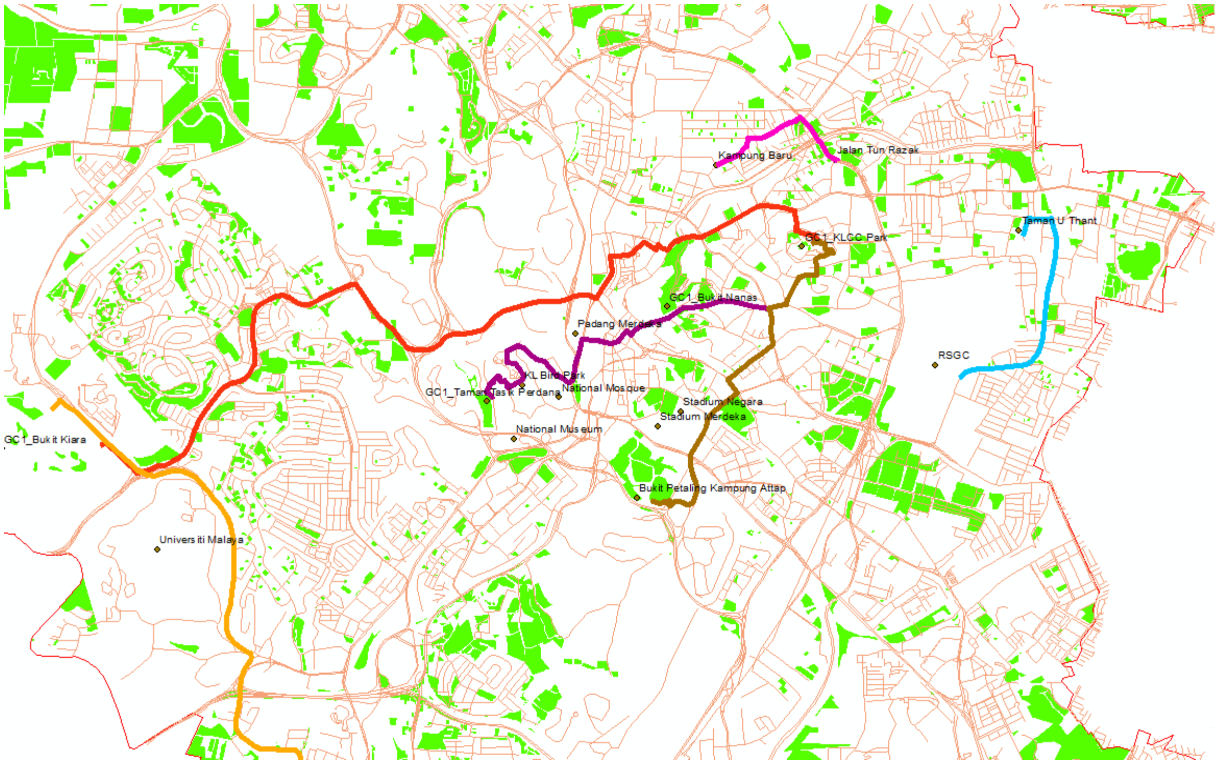


Figure 7. Six Different Route Results from Network Analysis in QGIS Environment (Kuala Lumpur City Center Area)

The green corridors in other countries have set examples of having cafés and eateries for people to enjoy. For instance, in Paris, the Promenade Plantee is one of the green corridors enjoyed by the people. Similarly, in New York, the High Line has become the green corridor many people enjoy as they can use the space to rest, eat, and drink. In Singapore, the green corridors have been using the abandoned railways to enjoy nature and sceneries.

5.0 Conclusion

Green spaces in the city area have become a limited space as the percentage of people living in urban areas will increase from 50% in 2010 to nearly 70% by 2050. The main activities of urbanization, including industrial, transportation and residential, have led countries to enhance their development, resulting in a large human population causing the urban area to expand as people strive to create better living conditions, which has caused environmental changes. Following the effects of large-scale land clearances, connectivity studies seeking opportunities to link fragmented green spaces have become essential. The continued decline in green space causes urban expansion to continue at the expense of green space. Green space management remains uncoordinated in the Kuala Lumpur Framework Plan 2020 and needs continuous control. This issue must be addressed to resolve the decline and decrease of green space in Kuala Lumpur. Besides having the lowest green space record in Kuala Lumpur, the city centre region has the most scattered green space as the area's growth was the highest. Therefore, focusing on the region is important to connect the fragmented green spaces and plan the green corridor to create more green urban areas. The fragmented green spaces were detected using Object-oriented techniques and later connected using network analysis, specifically the shortest path tool in the Quantum GIS environment. Connecting green spaces was significant for several functions, including sustainability and aesthetics. Green corridor routes are important in maintaining sustainability; thus, it is vital to include not only urban dwellers but also flora and fauna species to ensure the city is harmonious by preserving biodiversity in the green corridors. Green corridors are a means to ensure that green spaces are being used optimally. As Southeast Asian towns become more densely populated, the green areas are expected to be reduced. However, increasing city wealth may increase demands for green space among wealthier urban populations, resulting in better protection and creating green spaces.

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