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Analyzing on-Street Parking Duration and Demand in a Metropolitan City of a Developing Country: A Case Study of Yogyakarta City, Indonesia

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Abstract: On-street parking is an urgent issue to address in a fast-growing city of a developing country, such as Yogyakarta City in Indonesia. However, this issue has not been satisfactorily studied due to a lack of relevant parking data. Using a sample of 21 street segments that are currently used for on-street parking in the central district of the city, this study analyzes how the parking duration and demand are differentiated by street and land use characteristics. The characteristics are evaluated through a field survey, which is supplemented by remote sensing and GIS. Specifically, QuickBird imagery is used to roughly examine the length and angle of the street segments and GIS data to calculate parking capacity and demand as well as to confirm the street length and angle. Regression models find that the parking duration is affected by the street length, parking volume, and commercial type of land use, while the street length also differentiates the parking demand. Although the model for the parking demand has only one significant variable—street length—its variation is better accounted for by the same set of variables than the variation in the parking duration. Regarding the street length, it is found to be the only significant variable in the demand model, but it becomes the weakest among those significant in the duration model, where the land use type has the highest magnitude.

Keywords: on-street parking; parking duration; parking demand; mobile mapping; multiple linear regression; Yogyakarta

1. Introduction

Indonesia is among the fastest-growing economies. Private mobility such as motorcycles and passenger cars function as the main modes of road transportation in major cities like Yogyakarta City, which was previously underdeveloped compared to other cities, and is now experiencing a more rapid economic growth, even in this booming economy. In the city, the numbers of registered motorcycles and passenger cars increased for three years (2012–2015) by 20.12% (from 45,410 to 54,546) and 17.41% (340,350 to 399,615), respectively [1]. This subsequently resulted in a skyrocketing demand for parking spaces. However, due to a lack of off-street parking lots and easy access to final destinations, most vehicles were parked on the street. Subsequently, on-street parking became overloaded, and it reduced traffic safety, air quality (narrowed streets worsened traffic congestion), and public space; ultimately, it is believed to harm the economic potential of the city [2]. At this juncture, as an initial step to address the parking issue, this study attempts to analyze the characteristics of on-street parking.

In this study, on-street parking is evaluated in terms of the parking duration as well as the parking demand. As characteristics that are expected to affect the two measures, this study analyzes the street segment length and land use types as well as the parking volume while taking into account the parking angle on the street segment. Some of the variables are evaluated with high-definition remote sensing data such as QuickBird imagery and others through first-hand field surveys. In fact, as with other developing countries, Indonesia is not equipped with data on parking volume and other parking-related characteristics, and these were manually collected by the researchers. Moreover, the manual counts of parked vehicles were considered more reliable because most on-street parking spaces do not have parking lines and signs (see Figure 1), and cannot be correctly captured in remote sensing data.

This study was limited to vehicles parked to passenger cars and motorcycles, which account for 96.52% of all registered vehicles as of 2015: passenger cars = 54,546 (11.59%), load vehicles = 13,875 (2.95%), buses = 2233 (0.47%), special purpose vehicles = 273 (0.06%), and motorcycles = 399,615 (84.93%). The study area for this study is the Gondokusuman District, which is located in the center of Yogyakarta City. As a regional center of the residential, economic, and social/leisure activities, it has experienced a rapid growth in the parking demand and subsequent on-street parking issues.

As shown on the left of Figure 1, two lanes on St. Urip Sumoharjo are used for illegal on-street parking: one for motorcycles and pedicabs and the other for passenger cars. Due to excessive parking demand, vehicles are sometimes parked in two lines on each side and even on sidewalks. The middle and bottom photos of Figure 1—which were taken on St. Prof. Herman Yohanes, another main street of the Gondokusuman District—show that passenger cars as well as motorcycles are parked on sidewalks. This sidewalk parking forces pedestrians to walk on automobile roads, which critically harms traffic safety [3–5].

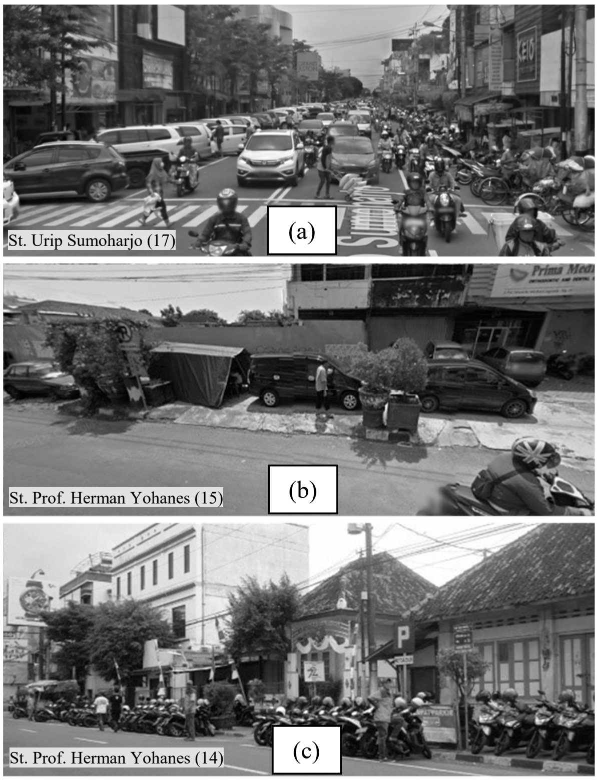


Figure 1. On-street parking in the Gondokusuman District. (**a**) Traffic congestion caused by parking on both sides of the street, (**b**) Illegal parking on the sidewalk (passenger cars), (**c**) Illegal parking on the sidewalk (motorcycles). The first two pictures are from Google Images and the last one is from a field survey. The name and location of each street is shown on the bottom left of each picture (see Figure 5 and Table 3).

2. Remote Sensing and GIS Studies on Parking

There are an excessively small number of studies that have used remote sensing and GIS for parking research [6]. Similar to this study, Fauziati [7] evaluated the degree to which QuickBird remote sensing data can be used to assess parking service conditions in eight street segments of Yogyakarta City. He found that the imagery was capable of predicting land use and parking patterns, street lengths, and street widths at the accuracy rates of 85.14%, 100%, 97.65%, and 93.18%, respectively. Li and Guan [8] used GPS PDOP (Position Dilution of Precision) data in order to improve the efficiency of the parking space search on the campus of University of Nebraska–Lincoln. In the City of Bat Yam, Levy and Benenson [9] evaluated parking patterns, particularly the fit between residential overnight parking demand and parking capacity, using a GIS-based technique called PARKFIT. Compared to them, this particular study evaluates all types of parking, not just residential parking and it considers not only passenger cars, but also motorcycles, which make up about 85% of the registered vehicles in Yogyakarta City. Lastly, Levy et al. [10] applied an ArcGIS application called the PARKAGENT model to the case of a Diamond Exchange area in Tel Aviv, Israel. In contrast to this study, they examined a search for parking spaces by a driver, not parking demand. In general, previous studies have used remote sensing and GIS approaches for parking space searches and the match between the supply and the demand of parking spaces, but few studies have analyzed through inferential statistics the relationship that parking characteristics have with land use and street characteristics [11,12].

3. Analysis

3.1. Case Study

Yogyakarta City is the capital of the Special Region of Yogyakarta; this province is located in the central part of Java Island. In 2015, Yogyakarta City had a population density of 12,698 persons/km^2 (area = 32.5 km^2 and population = 412,704 persons) [1]. Yogyakarta City is the center of economy, education, tourism, and culture in the province. As presented in Figure 2, the Gondokusuman District (area = 3.99 km^2) is one of 14 districts in Yogyakarta City. Around 85% of the district is built-up areas, mostly low-rise buildings. The district has the highest population in Yogyakarta City, 11.35% of its population [1].

3.2. Data and Methods

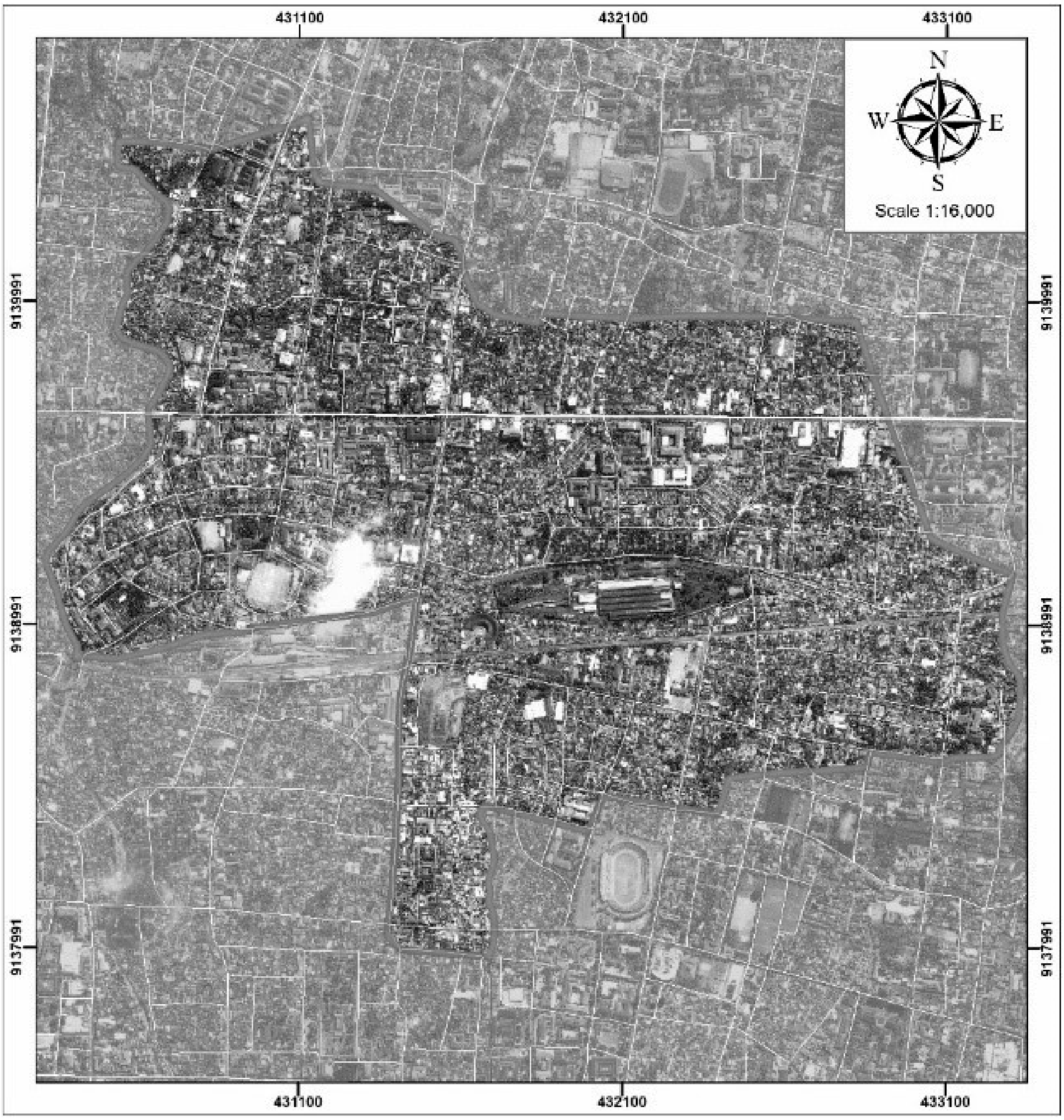
QuickBird imagery of 2014 (geometrically corrected) was used to evaluate parking angle and land use of each street segment, as with Fauziati [7]. Because the imagery has no geometrical error, it can help to interpret objects. (Strictly speaking, every image has in some sense geometrical errors according to the type of analyzed data; terrain coverage almost always has radial distortions.) This study used the segment as the unit of analysis. The city government defines the segment considering the function of a block and its land use. Then, the digitization of the segment was conducted on a screen after the visual interpretation of the imagery, particularly for the initial identification of land use and street characteristics. Land use was evaluated by examining such characteristics as color, shadow, and pattern. Also, GIS tools were employed to evaluate parking characteristics such as parking angle, street length, and land use. Since the imagery is outdated by three years (i.e., 2014 imagery, but 2017 parking characteristics), the current Administration Map of Indonesia—two 1:25,000 scale maps, each of which was for Yogyakarta City and Timoho—and the road network map of the Yogyakarta City Master Plan of 2015–2035 were used to update the values of the variables. The field survey was conducted for 10 hours in each segment—on the same Friday from 8 AM to 6 PM—to confirm the accuracy of the imagery interpretation through visual examination and to compute or confirm parking capacity such as parking demand, volume, duration, and angle. Then, this study used multiple linear regression to identify land use and street characteristics that affect parking duration and demand.

To evaluate on-street parking service and related issues, this study manually collected data on the following parking characteristics: street length, parking demand, parking volume, parking duration (time), parking angle, and parking capacity. As shown in Figure 3, the *street length* is defined as the length of a street segment used for parking. The *parking demand* in this study means the maximum number of vehicles that are parked at the same time on the segment. The *parking volume* is the sum of the parked vehicles in the survey day. The *parking duration* refers to the average time span during which a vehicle is parked on the segment. The formula of each parking characteristic is as follows:

$$Street\ length = distance\ between\ the\ two\ (marked)\ endpoints\ of\ a\ parking\ area$$

(**a**)

Figure 2. *Cont.*



(**b**)

Figure 2. Study area. (**a**) Administration Map of Yogyakarta City; (**b**) QuickBird Imagery Map of the Gondokusuman District.

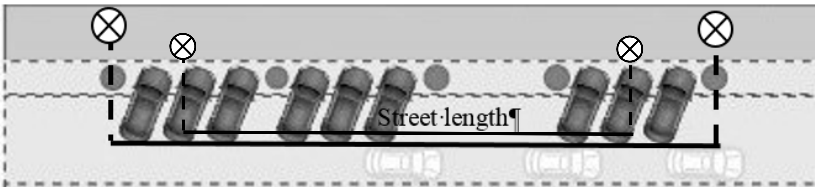


Figure 3. Street length measurement.

$$\begin{aligned} &Parking\ demand \\ &\quad = max[count(passenger\ cars) \times 11.5 \\ &\quad + count(motorcycles) \times 1.5] \end{aligned}$$

$$\begin{aligned} &Parking\ volume \\ &\quad = sum[count(passenger\ cars) \times 11.5 \\ &\quad + count(motorcycles) \times 1.5] \end{aligned}$$

The *parking angle* refers to the angle between the side of a parking space and a line parallel to the street. As in Figure 4, on-street parking has either a parallel (0 degrees) or an angular system with four slopes: 30, 45, 60, and 90 degrees. The angle has an impact on the parking capacity of the street segment and subsequently on its traffic congestion. Lastly, the *parking capacity* is defined as the maximum number of vehicles that the segment can carry at the same time. As shown in Table 1, the capacity was officially calculated based on the street length, parking angle, and vehicle type by the Yogyakarta City Department of Transportation in 2011.

$$Parking\ capacity\ (m) = \frac{street\ length\ (m)}{number\ of\ vehicles\ (counts)}$$

Table 1. Yogyakarta City official parking capacity calculation.

Vehicle Types	Angles	Capacities (m^2)
Motorcycles	90°	Length/0.75
Passenger cars	0°	Length/5
	30°	(Length − 0.88)/0.75
	45°	(Length − 1.91)/3.25
	60°	(Length − 1.84)/2.65
	90°	Length/2.3
Buses and trucks	0°	Length/12.5
	60°	Length/3.93

Source: Yogyakarta City Department of Transportation [13].

Notably, different types of vehicles are parked together on a street segment. Thus, in statistical analyses, this study did not directly use the counts of the vehicles, but the summed area (m^2) based on the actual size of each vehicle, which was manually measured by fieldworkers.

QuickBird imagery has been reported to reliably provide information on the ground surface, especially on large-scale land use with the interpretation accuracy of above 90% [14–16]. However, the degree of object recognition and the accuracy and reliability of photointerpretation may vary according to the place of image registration, type of identified objects, current position of the satellite sensor, etc. Therefore, a field survey was somewhat necessary in order to check the accuracy of imagery interpretation, particularly to take into due consideration motorcycle sizes and parking angles. First, compared to passenger cars, motorcycles could not be fully captured in QuickBird imagery because while the definition of the imagery pixel is 60 × 60 cm, motorcycles are typically 50 × 80 cm in size and its length is about 175 cm, denoting that a motorcycle cannot be represented by more than one pixel. Second, GIS raster geometry was also not highly useful in interpreting the parking angle, in the sense that trees and building shadows in the imagery sometimes made it difficult to identify parking angles.

Figure 5 presents street segments that are used for parking in the study area and its demand. Figure 6 shows an example of how this study calculated parking angles. Through the field survey, the authors found that parking angles are either 0° or 45° for passenger cars while motorcycles on all street segments were parked orthogonally (90°), except for those motorcycles that were parked along St. Urip Sumoharjo; their parking angle was consistently 45°.

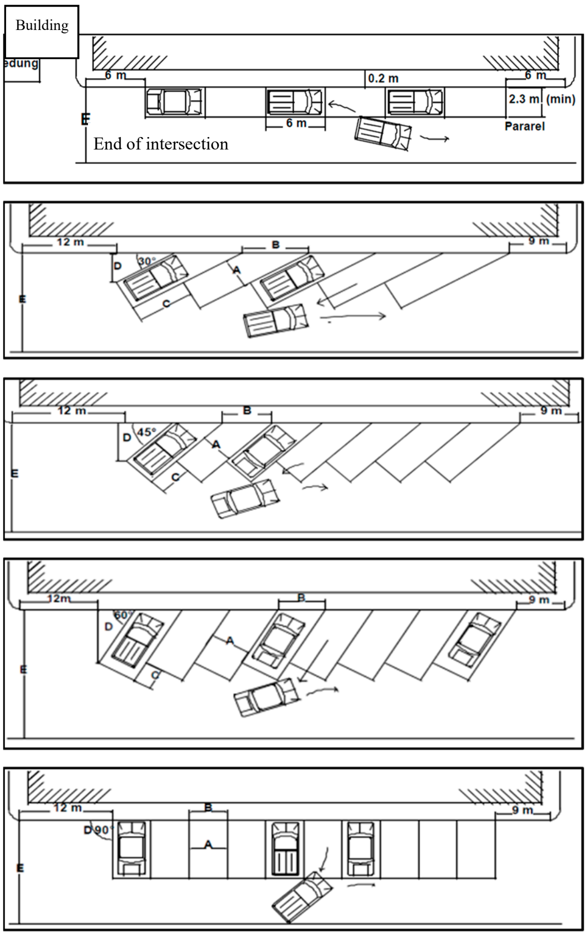


Figure 4. On-street parking angles. The figures are from the Indonesian General Directorate of Land Transportation [2].

Figure 5. Street segments for parking and its demand in the Gondokusuman District. For street and street segment names, see Table 3.

Figure 6. Parking angles: satellite imagery (**left**) and field survey by the researchers (**right**).

In the following section, this study will first present the descriptive statistics of research variables in relation to whether their variations are wide enough for statistical inference. The descriptive statistics will also be used to describe unique parking conditions in Yogyakarta City inasmuch as it is relatively unfamiliar to Western researchers. Then, multiple regression models will be specified with the same set of explanatory variables in order to explain variations in parking duration and demand. Subsequently, major findings of the models will be discussed to draw policy implications for the city.

3.3. Results

Table 2 presents the min and max, the mean, and the standard deviation of research variables. As intuitively evaluated, they appear to well represent the parking characteristics of Yogyakarta City. More importantly, the variations of the characteristics are wide enough for inferential analysis and linear regression in this particular study.

Table 2. Descriptive statistics.

Variables (continuous)	**Min**	**Max**	**Mean**	**S.D.**
Parking demand (m^2/hour)	57.50	2,656.50	415.64	581.28
Parking duration (minutes)	60.00	127.57	91.90	20.67
Parking volume (m^2/day)	161.00	1,689.00	654.26	418.82
Street segment length (m)	40.87	384.74	160.14	81.44
Mean parking volume (m^2/hour)	28.11	1,837.44	236.30	393.32
Parking capacity (m^2)	92.00	885.50	375.12	188.67
Variable (discrete)	**Commercial**	**Educational**	**Health**	**Office**
Land use (counts)	12	4	3	2

Table 3 shows the length of each street segment and its parking capacity, which is defined as the maximum vehicles that can be carried for parking. In the areal unit (i.e., meter), the capacity is determined not only by the street length, but also by the parking angle [17]: The steeper the parking angle, the larger the parking capacity is provided. In the sample, the GARDENA of St. Urip Sumoharjo is found to have the largest capacity not only because it has the longest length, but also because its angle is 45° instead of 0°.

Table 3. Street segments for parking.

ID	Segments	Street Names	Street Hierarchy †	Lengths (m)	Angles (°)	Capacity (Counts)	
						Motorbikes	Passenger Cars
1	ELS	St. C Simanjuntak	1	124.60	0	166	25
2	South ELS	St. C Simanjuntak	1	195.24	0	260	39
3	JHS 8	St. Kahar Muzakir	1	97.11	0	129	19
4	JHS 1	St. Cikditiro	0	94.71	0	126	19
5	Pantirapih	St. Cikditiro	0	87.38	0	117	17
6	South Pantirapih	St. Cikditiro	0	97.43	0	130	19
7	SHS STECE	St. Sabirin	1	151.06	0	201	30
8	South SHS STECE	St. Supadi	1	127.13	0	170	25
9	NOVOTEL	St. Jend Sudirman	0	186.26	0	248	37
10	Bethesda	St. Dr. Wahidin	0	120.40	0	161	24
11	LEGEND Cafe	St. Abubakar Ali	1	88.61	0	118	18
12	MUTIARA	St. Dr. Sutomo	0	139.44	0	186	28
13	KEMENDAGRI	St. Argolubang	1	320.69	0	428	64
14	GALERIA Mall 1	St. Prof. Herman Yohanes	0	142.69	0	190	29
15	GALERIA Mall 2	St. Prof. Herman Yohanes	0	205.06	0	273	41
16	XXI	St. Urip Sumoharjo	0	134.44	0	179	41
17	GARDENA	St. Urip Sumoharjo	0	384.74	45	513	77
18	SHS 3	St. Suroto	1	40.87	0	54	8
19	West AFFANDI	St. Affandi	0	255.16	0	340	51
20	East AFFANDI	St. Affandi	0	185.22	0	247	37
21	TOKO EMAS	St. Laksada Adisucipto	0	184.64	0	246	37

† 0 = arterial road and 1 = local road. For the locations of the above street segments, see Figure 5.

Table 4 shows that the parking demand is the highest in GARDENA according to the absolute count (231 cars) as well as to the area (2656.5 m^2). The segment also has the largest volume in terms of the absolute count (793 cars). However, in the areal unit, the largest volume is found in TOKO EMAS partially because the segment is located on St. Laksada Adisucipto, which is the major arterial to the Yogyakarta International Airport (Adisucipto Airport). The street is well known for frequent traffic congestion, especially along those street segments that have double-sided on-street parking, such as TOKO EMAS.

Table 4. Parking demand and volume.

ID	Segments	Street Names	Parking Demands		Parking Volumes	
			(Counts)	(m^2)	(Counts)	(m^2)
1	ELS	St. C Simanjuntak	16	184	59	608.5
2	South ELS	St. C Simanjuntak	26	299	101	1131.5
3	JHS 8	St. Kahar Muzakir	14	161	49	463.5
4	JHS 1	St. Cikditiro	7	80.5	14	161
5	Pantirapih	St. Cikditiro	8	92	26	299
6	South Pantirapih	St. Cikditiro	9	103.5	31	326.5
7	SHS STECE	St. Sabirin	10	115	35	402.5
8	South SHS STECE	St. Supadi	9	103.5	29	333.5
9	NOVOTEL	St. Jend Sudirman	17	195.5	57	655.5
10	Bethesda	St. Dr. Wahidin	5	57.5	24	256
11	LEGEND Cafe	St. Abubakar Ali	9	103.5	33	349.5
12	MUTIARA	St. Dr. Sutomo	15	172.5	71	596.5
13	KEMENDAGRI	St. Argolubang	42	483	176	574
14	GALERIA Mall 1	St. Prof. Herman Yohanes	60	690	204	306
15	GALERIA Mall 2	St. Prof. Herman Yohanes	55	632.5	130	1,495
16	XXI	St. Urip Sumoharjo	19	218.5	49	563.5
17	GARDENA	St. Urip Sumoharjo	231	2,656.5	793	1,209.5
18	SHS 3	St. Suroto	10	115	50	575
19	West AFFANDI	St. Affandi	42	483	143	974.5
20	East AFFANDI	St. Affandi	92	1058	213	769.5
21	TOKO EMAS	St. Laksada Adisucipto	63	724.5	386	1,689

Parking demand = the maximum of the hourly counts of parked vehicles; parking volume = the total number of parked vehicles for 10 h; for the locations of the above street segments, see Figure 5.

Notably, the highest volume of GARDENA is attributed to motorcycles, as shown in Table 5. On the survey day, only two passenger cars (23 m^2) were parked on the segment. Regarding passenger cars, their volume was the highest on the segment of GALERIA Mall 2, the major upscale shopping area in the city, both in number and area. This indicates that in the city, the passenger car is generally regarded as a luxurious good and for the utilitarian purpose of transportation, the motorcycle plays an important role [18,19]

Table 5. Parking volume by vehicle type.

ID	Segments	Street Names	Counts		m^2	
			(Motorcycles)	(Passenger Cars)	(Motorcycles)	(Passenger Cars)
1	ELS	St. C Simanjuntak	7	52	10.5	598
2	South ELS	St. C Simanjuntak	3	98	4.5	1127
3	JHS 8	St. Kahar Muzakir	10	39	15	448.5
4	JHS 1	St. Cikditiro	0	14	0	161
5	Pantirapih	St. Cikditiro	0	26	0	299
6	South Pantirapih	St. Cikditiro	3	28	4.5	322
7	SHS STECE	St. Sabirin	0	35	0	402.5
8	South SHS STECE	St. Supadi	0	29	0	333.5
9	NOVOTEL	St. Jend Sudirman	0	57	0	655.5
10	Bethesda	St. Dr. Wahidin	2	22	3	253
11	LEGEND Cafe	St. Abubakar Ali	3	30	4.5	345
12	MUTIARA	St. Dr. Sutomo	22	49	33	563.5
13	KEMENDAGRI	St. Argolubang	145	31	217.5	356.5
14	GALERIA Mall 1	St. Prof. Herman Yohanes	204	0	306	0
15	GALERIA Mall 2	St. Prof. Herman Yohanes	0	130	0	1495
16	XXI	St. Urip Sumoharjo	0	49	0	563.5
17	GARDENA	St. Urip Sumoharjo	791	2	1186.5	23
18	SHS 3	St. Suroto	0	50	0	575
19	West AFFANDI	St. Affandi	67	76	100.5	874
20	East AFFANDI	St. Affandi	168	45	252	517.5
21	TOKO EMAS	St. Laksada Adisucipto	275	111	412.5	1276.5

For the locations of the above street segments, see Figure 5.

Figure 7 visualizes parking durations and parking-related characteristics considered in this study. In general, lengthy parking occurs in a commercial area where movie theaters are located while areas near markets show relatively shorter parking spans. This parking time difference somewhat hinges on planned activities after the parking: If people watch movies, they should park their vehicles over the movie running time, about two hours, but if they buy commodities, lengthy parking is not necessary. Areas near hotels were expected to present longer parking durations, but among parked vehicles in the areas, more than 60% spent less than an hour. This may be because the vehicles do not belong to hotel customers, that is, most would be taxis that pick up or drop off passengers or wait for customers. Indeed, hotel employees and visitors usually park their vehicles in a designated parking lot inside the hotel property.

Table 6 shows that at the 90% confidence level, parking volume, street length, and the presence of commercial land use are significantly related to the variation in the parking duration. Based on the standardized coefficient, whether the land use is commercial had the largest effect on the duration (in Table 6, standardized coefficient = 0.560). Notably, R^2 value is relatively low, which implies that there exist other important determinants of parking duration.

In Figure 5, which presents the entire street segments and land uses in the Gondokusuman District, the parking demand of each segment is also illustrated. In general, the highest parking demand is present in areas where the dominant type of parked vehicles is the motorcycle, including St. Prof. Herman Yohanes, St. Urip Sumoharjo, St. Affandi, and St. Laksada Adisucipto. The demand was around 447 m^2 to 2657 m^2, on average 231 motorcycles. The demand of most of these segments was more than twice of its capacity. Such a supply deficit has often led to parking rule violations (e.g., sidewalk parking).

Regarding the parking demand, the street length was found to be the only significant variable. Nonetheless, the model itself had a relatively high explanatory power, as evaluated by R^2 (= 0.648) (see Table 7). Thus, at least in Yogyakarta City, the length of the on-street parking itself can be a relevant policy measure for effective parking management. Indeed, the longer the street length, the larger the parking capacity, allowing for larger demand for parking. Among the sampled street segments, GARDENA on St. Urip Sumoharjo has the longest length as well as the largest parking demand.

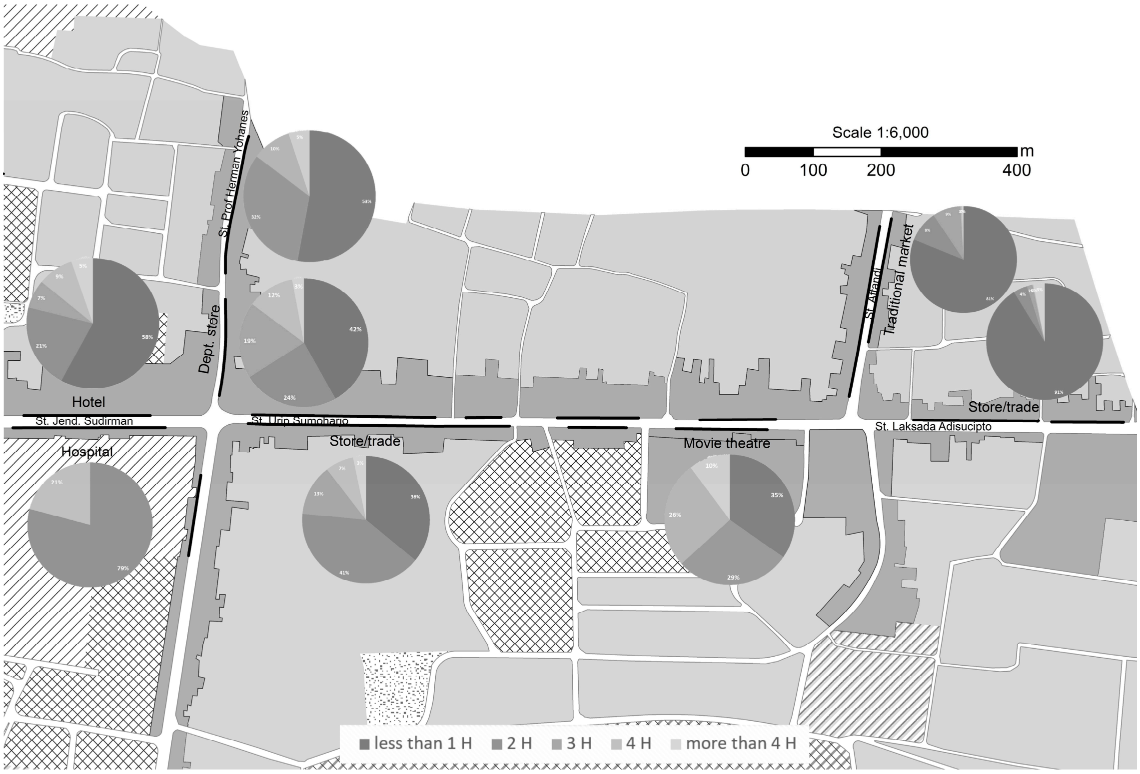


Figure 7. Parking durations: relatively longer durations on local roads than on arterial roads.

Notably, when the parking volume and street length were controlled for, the land use type did not significantly affect the parking demand. In this sense, as opposed to our initial expectation, land use may not be an effective measure for parking management. (It cannot be used as a "proxy," either, in the sense that as shown in the VIF statistic, it has low collinearity with other research variables [20,21].) For mitigating parking demand, the Yogyakarta City Government categorized its jurisdiction into differential parking zones. The categorization is mainly based on land use, specifically whether the parking facility is located in tourism and commercial areas. Given the above finding, they are advised to add the street length criterion to the existing parking fare system.

Table 6. OLS (ordinary least squares) regression on parking duration.

Variables	Coef.	S.E.	Std. Coef.	*t*	*p*	VIF
Intercept	79.256	11.733		6.755	0.000	
Parking volume	−0.025	0.013	−0.514	−1.921	0.074	1.927
Street length	0.118	0.062	0.465	1.905	0.076	1.602
Land use: commercial †	22.814	11.217	0.560	2.034	0.060	2.037
Land use: health †	14.589	12.758	0.284	1.143	0.271	1.660
Street hierarchy: local ‡	−14.340	8.700	−0.345	−1.648	0.120	1.180

† Base = educational and office, ‡ base = arterial road, F(5,15) = 2.382 (p = 0.088), R^2 = 0.443, adjusted R^2 = 0.257, SRMR = 17.821, Durbin-Watson = 2.165, SPSS (Statistical Package for the Social Sciences) data are available online for downloading: https://drive.google.com/open?id=1KTL0Xu7vuk4DpCdeQ-vwgASstyCtk1bH [22].

Table 7. OLS regression on parking demand.

Variables	Coef.	S.E.	Std. Coef.	*t*	*p*	VIF
Intercept	−503.778	262.235		−1.921	0.074	
Parking volume	0.116	0.295	0.083	0.392	0.701	1.927
Street length	5.074	1.384	0.711	3.665	0.002	1.602
Land use: commercial †	124.156	250.689	0.108	0.495	0.628	2.037
Land use: health †	267.049	285.152	0.185	0.937	0.364	1.660
Street hierarchy: local ‡	−238.086	194.442	−0.204	−1.224	0.240	1.180

† Base = educational and office, ‡ base = arterial road, $F(5,15) = 5.519$ ($p = 0.004$), $R^2 = 0.648$, adjusted $R^2 = 0.530$, SRMR = 398.305, Durbin-Watson = 2.419, SPSS data are available online: https://drive.google.com/open?id=1KTL0Xu7vuk4DpCdeQ-vwgASstyCtk1bH [22].

Figure 8 presents six street segments with a parking demand surplus. On a few segments, the demand for parking is twice as high as its capacity. As shown above in Table 3, the demand-supply mismatch is brought about by excessive motorcycle parking. In fact, in major Indonesian cities, motorcycle parking management is arguably a key to the success of parking management because if a parking area is full, passenger car drivers, unlike motorcyclists, explore alternative areas rather than forcefully parking their cars in the initially considered area. Owing to their small sizes, motorcycles are often parked on the roadway and sidewalk, close to the final destination.

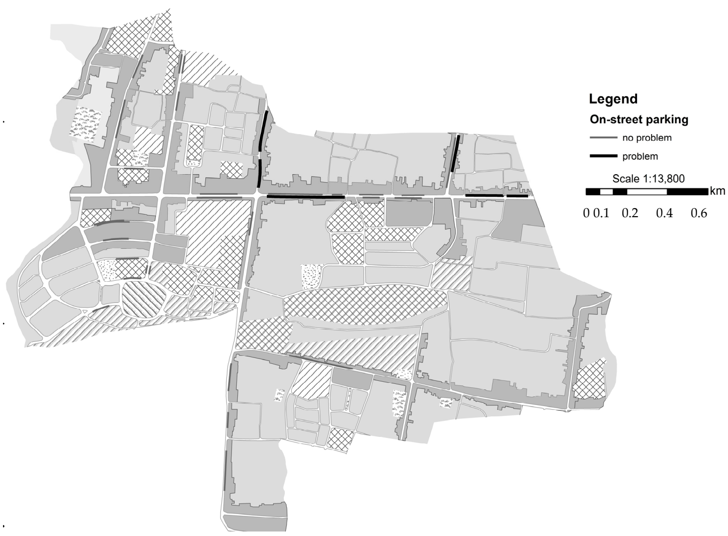


Figure 8. Supply–demand mismatch in on-street parking. No problem = supply surplus; problem = demand surplus; for street and street segment names, see Figure 5 and Table 3.

4. Summary

Despite its considerable impact on the traffic congestion and safety, on-street parking has not been duly investigated mainly because of data limitations [6] and it was particularly so in major cities in developing countries like Indonesia; often, naturally originated on-street parking is not considered in comprehensive transportation plans. At this juncture, this study, using a case of Yogyakarta City, explored the potential of remote sensing imagery in identifying the demand and volume of on-street parking and in analyzing how they are affected by several street and land use characteristics. In its exploratory nature, this study examined a total of 21 street segments for on-street parking and found that difficulties exist in interpreting parking characteristics through QuickBird satellite imagery, specifically in identifying the parking angle, in the sense that most on-street parking segments were covered with trees and they had no parking lines. Also, motorcycles were parked without a fixed angle. A second issue was that small objects—for example, motorcycles—could not be precisely identified since they were too small for the imagery to capture with more than one pixel. In this sense, in order to estimate parking volumes in Asian developing countries in which motorcycles assume a considerable proportion of the mode share, it may be indispensable to conduct a supplementary field survey as with this study.

The empirical regression models found that the (average) parking duration is differentiated by the (daily total) parking volume, street length, and existence of commercial type of land use while the parking demand (i.e., maximum number of parked vehicles in the areal unit) is affected only by the street length. Thus, if planners consider parking time limit—the maximum allowable time for parking—or time-based differential parking fare, they may first consider implementing it in commercial districts or long street segments. To mitigate the demand–supply mismatch, which stands for the situation that the supply is less than the demand, planners are recommended to divide the long street segment into shorter sections.

This study had several limitations. It did not consider possibly important factors on the parking demand and duration including driver's inherent sociodemographic and attitudinal characteristics [23]. Second, while this study intended to apply a remote sensing approach in evaluating the parking demand and supply, neither was successfully measured with high accuracy. This is why a supplementary field survey was adopted as a means of suggesting an alternative for compensation. A further study is recommended to employ different types of airborne images as taken by airplane, drone, and others.

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