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Estimating Walk Score and Examining Its Association with Safety Factors of Neighborhood Environment in Kumamoto, Japan

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Abstract: With the increase in urban sprawl and traffic congestion, an increasing number of cities have committed to building compact, walkable cities. Accessibility of facilities and safety of the walking environment is regarded as the two most important conditions for convincing people to walk. The Walk Score is an effective walkability measurement tool confirmed in many studies. However, no study has explored the relationship between the Walk Score and pedestrian traffic safety. This research aims to estimate the Walk Score of each residential address in Kumamoto City and explore the relationship between Walk Score and the safety of the neighborhood environment with data on pedestrian traffic accidents and crime. Based on urban network analysis in GIS, by focusing on the diversity of facilities and fitting Gaussian distribution in Python to obtain the distance decay function, the Walk Score of all 215,309 residential addresses in Kumamoto city were calculated. Subsequently, pairwise Pearson correlations were conducted to determine the association between the Walk Score and neighborhood environment safety. The results showed that Kumamoto City had reached a certain level of walkability, with an average score of 63.16. However, the possibility of pedestrian traffic accidents and crime in places with higher Walk Scores may also increase, with the correlation coefficients reaching 0.613 and 0.588, respectively. The correlations revealed that the use of the Walk Score to measure walkability has some limitations and warns us that it is crucial to improve the safety of walkable environments while increasing the accessibility of facilities.

1. INTRODUCTION

With the intensification of urban sprawl, acceleration of climate change with the greenhouse gas emissions of private cars, and exacerbated severity of traffic congestion with the increasing number of private car ownership, cities are prompted to change the development mode into being more environmentally friendly, sustainable, compact, and people-oriented. In Japan, many cities face a series of challenges, including a lack of vitality in the central city, a declining birth rate, and an aging population. Under such a circumstance, the concept of "compact city," an efficient and sustainable city that has been gathered to improve the convenience of walking and public transportation, has attracted great attention and was widely incorporated into urban development plans. In addition, with the development of information technology, lifestyles are likely to change from real space to cyberspace. From the perspective of a city's prosperity and revitalization, building a convenient and walkable city that makes people want to walk naturally is necessary. Walkable cities have become a concern in many fields, including economics, environmental science, epidemiology, urban planning, and transportation planning. A walkable city is significantly reflected and affected by the urban form. In addition to being economically beneficial, environmentally friendly, and reducing obesity and physical diseases, it represents liveable, convenient, safe, and people-oriented urban planning.

Facility accessibility and environmental safety are regarded as the two most important conditions that convince people to walk. The Walk Score, an international web-based walkability measurement tool, is mainly used to identify walking-friendly residential areas by assessing the accessibility of nearby facilities (Liu and Wei, 2018). Previous studies have demonstrated the validity and reliability of the Walk Score as a measure of neighborhood walkability. Lucas manually calculated Walk Scores of 379 residential/non-residential addresses in Rhode Island and found significant correlations between Walk Score and all categories of aggregated walkable destinations within a 1-mile buffer (Carr, Dunsiger et al., 2011). Based on GIS (objective) indicators of neighborhood walkability with addresses from four US metropolitan areas (n=733), Duncan found that the Walk Score is a valid measure for estimating certain aspects of neighborhood walkability, particularly at the 1600-meter buffer (Duncan, Aldstadt et al., 2011). In another study, Duncan found that Walk Score is a good, convenient tool to measure certain aspects of neighborhood walkability and works best at larger spatial scales using complete residential address information of a school-based sample of public high school students in Boston, MA (n =1292) (Duncan, Aldstadt et al., 2013). Nykiforuk conducted a field validation of network-based metrics and found high to very high correlations between derived scores and the Walk Scores field across small, medium, and large population centers in Alberta, Canada (n=2181) (Nykiforuk, McGetrick et al., 2016). In Japan, a study found that the Walk Score is a valid estimate of walkability for residential addresses in two localities, Nerima Ward and Kanuma City (n=1072). However, each residential address was manually entered into the Walk Score website, and there were some addresses where the Walk Score was not available (Koohsari, Sugiyama et al., 2018). These studies confirmed that the convenience and accessibility of facilities play a leading role in walkability. On the other hand, Lucas revealed the incompleteness of Walk Score by observing the positive correlations between crime and Walk Score of 296 residential addresses in Rhode Island (Carr, Dunsiger et al., 2010). Tarek found that comfort factors can cause significant changes in walkability in the city of Madrid, measured at different times of the day and during different seasons (summer and winter) (Al Shammas and Escobar, 2019).

We found that there is currently no study measuring the Walk Score of Kumamoto City, and the number of research objects is a few thousand in most of the studies. Moreover, no study has explored the relationship between the Walk Score and pedestrian traffic safety, which is the most important aspect of walking safety. In this study, based on urban network analysis in GIS, by modifying the Walk Score methodology by focusing on the diversity of facilities and fitting Gaussian distribution in the Python platform to obtain the distance decay function, Walk Scores of all 215,309 residential addresses were estimated in Kumamoto City, Japan. Then, pairwise Pearson correlation analysis in SPSS was used to explore the relationships between Walk Score and safety factors of the neighborhood environment in Kumamoto city, including pedestrian traffic safety and city crime.

2. METHODS

2.1 Study area

The study was conducted in Kumamoto City, the capital of Kumamoto Prefecture, on Kyushu Island, Japan. With an estimated population of 731,899, the city is divided into five districts: Central, East, West, North, and South Districts. As shown in *Figure 1*, a residential building was used as the basic analysis unit. Walk Scores of 215309 residential addresses were calculated in Kumamoto City, which included dedicated dwelling residences, common residences, and combined residences.

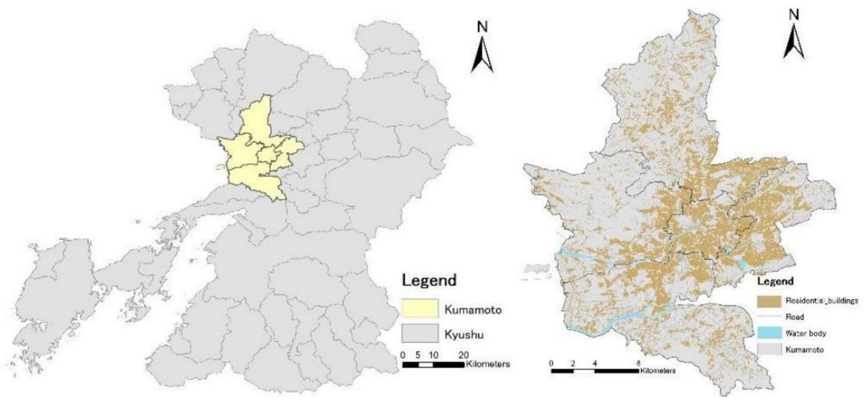

Figure 1. Study area

2.2 Data Source

The data were collected from the National Land Information and various official websites in Japan, and all the data were the latest year data provided. *Table 1* summarizes the data categories, sources, and uses. Traffic accident and crime data were obtained from the official website of the Kumamoto Prefectural Police Department (https://www.pref.kumamoto.jp/site/police/). Shopping facilities, restaurants, and public transit were crawled from the Mapfan website (https://mapfan.com/).

Table 1. Types and Source of Collected Data

Category	Format	Source	Data use
Road network center lines	Shapefile	OpenStreetMap Japan	Network analysis
Residential addresses	Shapefile	Urban planning basic survey of Kumamoto in 2019	Calculating of Walk Score (as origin)
Daily use facilities	Shapefile	National Land Information /mapfan	Calculating of Walk Score (as destination)
Traffic accidents, Crimes	Shapefile	Kumamoto Prefectural Police	Correlation analysis

2.3 Modifying the Walk Score Methodology

This study modified the Walk Score methodology from the following two aspects: (1) focusing on the diversity of facilities and (2) the distance decay function.

Based on the Walk Score methodology (Walk Score, 2011) and considering the 2012 Kumamoto Person Trip survey result, the post office was added to the bank category, and coffee shops were merged into a restaurant category as one category. In addition, public transit facilities and medical institutions were added to the list because these two types of facilities are often used by residents, especially the elderly, in daily life, according to the survey. Then corresponding weights were assigned to different types of facilities considered to be of high importance to walkability, medium importance, or low importance. The categories and weights of these facilities are listed in *Table 2*. Based on the simplified and topologically processed road network, the network dataset was constructed, and urban network analysis in GIS was used to extract all facilities within a 15-minute walking time. Studies have shown that the degree of facility diversity has a higher impact on urban vitality than facility density (Long and Zhou, 2016). In this study, without considering the density of the same facility, we selected the point closest to the residential address of each type's facility as the score of this type of facility and multiplied the weight by the decay rate corresponding to the walking time to get the score of each type of facility.

Table 2. Category and corresponding weight of facilities

Category	Weight	Category	Weight
Catering (Restaurant, Bar, Coffee shop)	3	Public Transit (Bus stop, Tram station)	2
Shopping (Convenience store, Supermarket)	3	Medical Institution	1
Sports Facility (Park, Sports yard)	2	Financial Facility (Bank, Post office)	1
Education (Kindergarten, School, University)	2	Book (Book store, Library, Community centre)	1

The distance decay function is based on the law of universal gravity. The interaction between geographic elements is inversely proportional to the square of the distance. Because the decay of the distance is continuous, we used a Gaussian decay function instead of a piecewise decay function. The distance decay function determines the percentage of a facility's total score based on the distance between the address being examined, which we refer to as the origin, and the facility's location. Given that 15 minutes of walking is the maximum that most people are willing to walk (Andres and Robert, 2021), we considered the facilities within a 15-minute walking time. The horizontal axis represents the walking time from the residential address to the facility, and the vertical axis represents the percentage of the total score that the facility will receive. When there was no distance, the percentage was 1; when the walking time reached 15 min, the percentage became 0. We performed fitting in the Python platform, and the distance decay curve was obtained in *Figure 2*, and the distance decay function was obtained as follows:

$$f(x) = exp^{-\frac{(x-0.34117)^2}{2\times 6.5655^2}} \qquad (1)$$

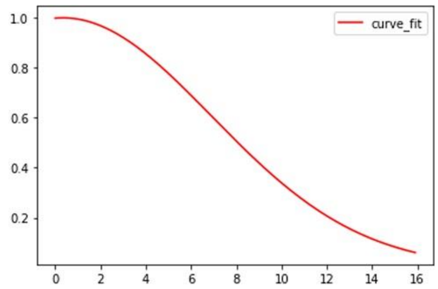

Figure 2. Distance decay function

2.4 Calculating the Walk Score of each residence

Previous studies typically calculated the Walk Score of hundreds of sample addresses. Even if the data were directly obtained from the Walk Score website, only a few thousand sample addresses were analyzed. Sampling analysis is affected by the size of the sample, the distribution of the sample, etc., resulting in deviations between the calculated results and the actual situation. In this study, we calculated the Walk Score for all 215,309 residential addresses in Kumamoto City. By calculating large-scale big data, we can accurately grasp the distribution pattern and Walk Score level of Kumamoto City and thus can objectively and accurately obtain the correlation coefficient between Walk Score and safety factors. The number of residential addresses in each district was distributed as follows: Central District (n=36364), East District (n=48494), West District (n=32283), North District (n=43706), and South District (n=54192).

2.5 Pairwise Pearson Correlation Analysis

After the Walk Score of each residential address was calculated, official data from the Kumamoto Prefectural Police Department were used to explore the correlation between safety factors of the neighborhood environment and the Walk Score. *Figure 3* shows the distribution patterns and kernel density results for pedestrian traffic accidents and city crime data. Pairwise Pearson correlation was used to analyze the correlation between variables at the city-wide and individual district levels. SPSS Statistics version 19 was used for analysis.

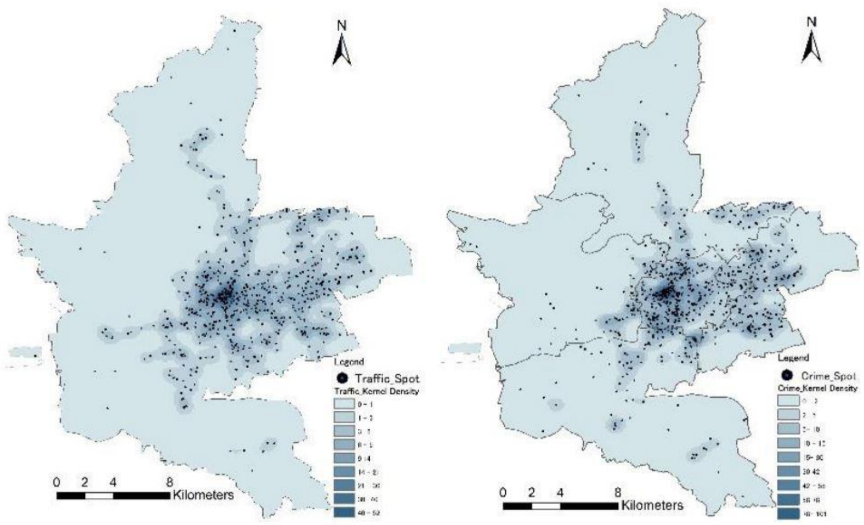

Figure 3. Distribution map of Safety factors: Distribution map of pedestrian traffic accidents (left), distribution map of city crime (right)

3. RESULTS

3.1 Spatial Distribution of Walk Score in Kumamoto

Figure 4 shows the Walk Score of 215309 residential addresses in Kumamoto City. Based on the Walk Score methodology, the Walk Score was divided into five levels: dark green represents the highest level, and red represents the lowest level, which is totally car-dependent. As shown, Kumamoto has reached a certain level of walkability, with the majority addressing being somewhat walkable or better than that. The most distributed results were light green, which was the level of very walkable; the least distributed results were dark green and red, which were the level of the walker’s paradise and totally car-dependent. However, significant spatial differences were observed. Almost all residential addresses have reached a very walkable level in the Central District, except the upper right corner adjacent to the North District was slightly lower. More than half of the residential addresses have reached a very walkable level in the East District, and the areas adjacent to the Central District are all very walkable. The areas with the best Walk Scores were concentrated in the Kengun area because of the existence of the Kengun Commercial Street. As for North District, West District, and South District, the spatial distribution of Walk Score in these districts was quite similar because mountains and farmland are located in the peripheral suburban areas of these districts. Except for areas around some hubs with high Walk Scores, most areas with high Walk Scores were distributed in the area close to the Central District, and the overall trend showed that the Walk Score gradually decreased as it moved far away from the Central District.

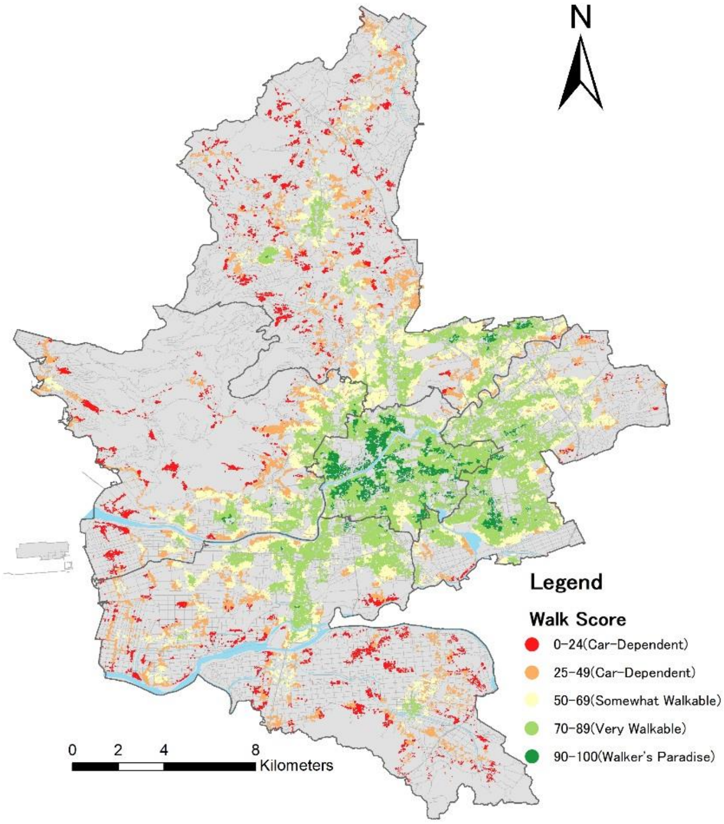

Figure 4. Spatial pattern of the Walk Score in Kumamoto city

The entire city of Kumamoto reached an average Walk Score of 63.16, with a standard deviation of 23.44. There was an extensive range of Walk Scores, of which the maximum was 98.54 and the minimum was only 0. The corresponding frequency and proportion of each level's Walk Score were calculated. As shown in *Table 3*, the proportion of walkable addresses (Walk Score no less than 50) was up to 76%. Meanwhile, almost half of the residential addresses have reached the level of very walkable, and 6% residential addresses have attained the level of Walker's paradise (Walk Score is more than 90). This indicates that half of the residents could meet their daily trip needs by walking. However, up to 10% of residential addresses achieved a Walk Score of no more than 25, indicating an urgent need to add facilities among these residences.

Table 3. Corresponding frequency and proportion of each level's Walk Score

Walk Score	Description	Frequency	Proportion
90–100	Walker's paradise	12625	0.06
70–89	Very walkable	93359	0.43
50–69	Somewhat walkable	57170	0.27
25–49	Somewhat car-dependent	30902	0.14
0–24	Car-dependent	21253	0.10

Table 4 shows the average, standard deviation, and range of the Walk Score for each district. It can be seen from the table that Central District has reached the best level, followed by East District, while West District, North District, and South District were all lower than those in Central District and East District, and all three were very close in terms of both average score and standard deviation. The average Walk Score of the Central District and East District has reached more than 70, and the standard deviation of both districts

is relatively low, which indicates that the Central District and East District have reached a very walkable level, and the spatial variation inside these two districts was small. The average scores of the West District, North District, and South District were lower than the average score of the whole city, but all had reached more than 50, which indicates that these three districts have reached a certain level of walkability. However, the standard deviations of these three districts were also relatively large, which indicates that there was apparent spatial variation in these districts. As for the distribution range of Walk Score in each district, the score span was huge, except for the Central District, which had a minimum value of 23.37, while the other four districts were all only 0, which also indicated that there were residential addresses in each district that needed urgent improvement.

Table 4. Descriptive statistics of Walk Scores, including whole city and each district

	M	**SD**	**Range**
Whole City (n=215309)	63.16	23.44	0-98.54
Central District (n=36364)	83.73	9.12	23.37-98.54
East District (n=48494)	72.38	14.12	0-96.2
West District (n=32283)	54.61	23.57	0-94.76
North District (n=54192)	54.36	23.08	0-98.26
South District (n=43706)	53.17	25.36	0-96.01

Abbreviations: SD, Standard Deviation; M, Mean

3.2 Association between Walk Score and Safety Factors

Overlapping pedestrian traffic accidents and city crimes with Walk Scores calculated in each residential address, we obtained two maps, shown in *Figure 5*. The common place was that the most concentrated areas of both pedestrian traffic accidents and city crime were in the central commercial area of the Central District, where only a few residential buildings were located. In addition, other relatively concentrated areas were almost distributed in the same area with high Walk Score residential addresses. The difference is that, in the suburban periphery of the city, crime is more dispersed and distributed in different places than pedestrian traffic accidents, especially in the southern area of the city. Comparatively, pedestrian traffic accidents are more aggregated in the southern hub and alongside the main road of the north area.

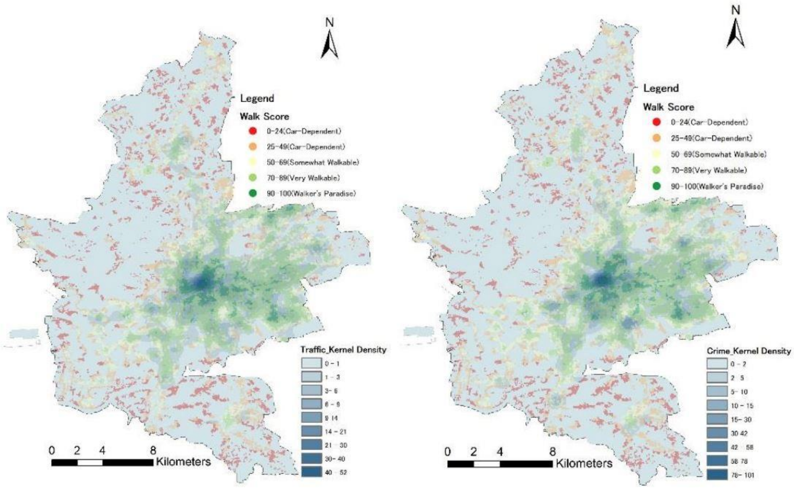

Figure 5. Overlay map of Walk Score and pedestrian traffic accidents kernel density (left), overlay map of Walk Score and city crime kernel density (right)

Pairwise Pearson correlations between Walk Score and the number of pedestrian traffic accidents and city crimes in the 800m buffer of each residential address were carried out to determine the association between Walk Score and safety factors of the neighborhood environment, including correlation coefficients of the whole city and each district. As shown in *Table 5*, in the whole city aspect, the correlation coefficients of Walk Score and pedestrian traffic accidents, as well as Walk Score and city crime, reached 0.613 and 0.588, respectively. The results were statistically significant ($p < .001$). This indicated that the Walk Score was associated with safety factors of the neighborhood environment, and a high Walk Score may indicate a greater possibility of pedestrian traffic accidents and city crimes. Regarding each district, both correlation coefficients in the Central District were the lowest, at only 0.468 and 0.381, followed by the East District, with correlation coefficients of 0.55 and 0.569, respectively. North and South districts had relatively higher correlation coefficients than other districts. This may be due to the high Walk Score and small spatial difference in the Central and Eastern districts; thus, the correlations between Walk Score and safety factors of the neighborhood environment were also lower.

Conversely, Walk Scores of North and South districts were lower, and the spatial difference was significant; thus, the correlations between Walk Score and safety factors of the neighborhood environment were also higher. However, it is worth discussing that the correlation between Walk Score and city crime in West District was lower than that of North District and South District, which were at the same level as Walk Score, and even lower than that of East District. Of these two factors, the correlation coefficient between Walk Score and pedestrian traffic accidents was higher than that between Walk Score and city crime in the whole city aspect and all districts except the East District. This may be because some of the crimes occurred in remote suburbs and sparsely populated areas, while pedestrian traffic accidents were almost always in downtown areas with high populations or alongside main roads.

Table 5. Correlation analysis of Walk Score and safety factors

	Whole City	**Central District**	**East District**	**West District**	**North District**	**South District**
	PTA	PTA	PTA	PTA	PTA	PTA
Walk Score	0.613	0.468	0.55	0.617	0.654	0.688
	Crime	Crime	Crime	Crime	Crime	Crime
Walk Score	0.588	0.381	0.568	0.523	0.652	0.607

All Sig. =.000, Correlation is significant at the 0.01 level.

Abbreviations: PTA, Pedestrian Traffic Accident.

4. DISCUSSION

To the best of our knowledge, this study is the first to estimate the Walk Score of Japanese cities based on the Walk Score methodology. While a recent study shows that Walk Score appears to be a valid measure of neighborhood walkability in Japan (significant positive correlations were observed between Walk Score and environmental attributes relevant to walking) (Koohsari, Sugiyama et al., 2018), we noted that the Walk Score used in this study was obtained from the Walk Score website and only 1,072 residential addresses were analyzed. Another study on South Korea, an Asian city, also modified the Walk Score methodology to estimate Walk Score rather than directly obtaining it from the website. However, the study area was divided into 100 m × 100 m grid points, and a Walk Score was assigned to each grid (Kim, Won et al., 2019) This method may reflect the actual walkability level to some extent, but it would cause certain inaccuracies. In this study, we assigned the Walk Score to the residential addresses of all residential buildings except those that were disintegrated, so each point was the result of the actual existing point, which objectively reflects the walkability level of the city. Compared to previous studies, this study has made a significant breakthrough in the number of research objects. The data were obtained or crawled from the official website, and the calculation process was performed using ArcGIS and Python platforms; thus, the results were reliable and accurate. In addition, this study also evaluated the correlation between the Walk Score and pedestrian traffic accidents, and no previous studies have analyzed the relationship between these two factors. Although situations may vary in different cities, according to the analysis results of this study, the Walk Score has its limitations and ensuring safety while improving destination accessibility is a major issue.

However, this study had some limitations. Although the Walk Score estimation was assigned to each residential address, the floor areas and accommodation population of each residential building were not considered. Residential addresses were only the starting point or end of travel, and the main body of each travel was ultimately people rather than buildings. Thus, it is necessary to add a demographic factor that more accurately reflects the neighborhood's walkability. On the other hand, this study only evaluated the correlation between walkability and safety factors of the neighborhood environment, and the correlation between Walk Score and pedestrian traffic accidents was greater than that with city crime. However, this study did not propose a method to judge walkability in combination with destination accessibility or the safety of the neighborhood environment.

We also know that the factors affecting walkability are by no means only these two aspects, pleasant streetscape, interesting interface, parking, and density, all of which impact the result. Cervero pinpointed “3D” diversity, density, and design as the key elements of the built environment that, in specific spatial patterns, enable alternative transportation in 1997 (Cervero and Kockelman, 1997). After a decade of successive research on the topic, “3D” was transferred into “5D” and “aP” with two factors added, destination accessibility and distance to transit to the list by Ewing and Cervero (2010). He also found that the neighborhood with the most “Ds” has the lowest VMT (vehicle miles traveled) after analyzing travel data on hundreds of mixed land developments (Ewing, Greenwald et al., 2013). Some scholars have pointed out that walkability is a highly complicated issue, and it cannot be evaluated simply by a comprehensive combination of several indicators. Forsyth mentioned that walkability is judged according to walking purposes (e.g., walking to get somewhere, engaging in exercise, socializing, enjoying the outdoors, or walking as part of some other activities such as looking after children or engaging in paid work); different purposes may need different kinds of places to achieve (Forsyth, 2015). Kim argued that walkability is a complex and somewhat nebulous set of capacities embodied in any urban morphology and that it should not be conflated with or derived from actual levels of walking (Dovey and Pafka, 2020). The Walk Score is an effective method to estimate the walkability of a city quickly, but its single measure of facility convenience also indicates the limitations of the method. In future research, we suggest that more aspects of urban design be included. Of course, this does not mean using a series of formulas to calculate the numerical level but to extract some regulations from the complex and huge system of urban form.

5. CONCLUSION

In conclusion, this study measured the Walk Score of 215309 residential addresses in Kumamoto City based on the Walk Score methodology. For the whole city, the proportion of walkable addresses was up to 76%; meanwhile, nearly half of the residential addresses reached the level of very walkable, and 6% of the residential addresses attained the level of Walker's paradise, which meant that overall Kumamoto had reached a certain level of walkability. For the score features of different districts, the average Walk Scores of the Central and East districts exceeded 70, and the standard deviation of both districts was relatively low. The average scores of West District, North District, and South District were lower than the average score of the whole city, but all had reached more than 50 points, which indicates that these three districts have reached a certain level of walkability. However, the relatively large standard deviation of these three districts indicates evident spatial variation in these districts.

Moreover, pairwise Pearson correlations between the Walk Score calculated above and the safety factors of the neighborhood environment were carried out on the scale of the whole city and five separate districts. At the city level, the correlation coefficient between Walk Score and pedestrian traffic accidents reached 0.613, and the correlation coefficient with crime accidents reached 0.588. Meanwhile, in each district (except the Central District), the correlation coefficients were all above 0.5. However, in the Central District, the coefficients were only 0.468 and 0.381, respectively. This indicated that Walk Score was associated with safety factors of neighborhood environment, and the correlation was more evident in districts where the overall level of Walk Score was lower and spatial difference was relatively larger. Of these two safety factors, pedestrian traffic accidents have a stronger correlation with Walk Score than city crime both at the city level and in all districts, except that it was almost the same in the East District.

The present study fills the research gap in exploring the relationship between Walk Score and pedestrian traffic accidents by considering safety as an important factor in convincing people to walk. The results show that, based on the accessibility of facilities, ensuring pedestrian traffic safety and reducing city crime are important aspects of enhancing public safety and achieving healthy urban development. In addition, the methodology used here can be easily extended to other related studies and can guide other researchers.

AUTHOR CONTRIBUTIONS

QZ conceived the study, performed the statistical analysis, and drafted the manuscript. RH contributed to the supervision of the study, interpretation of results and revision of the manuscript. All the authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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