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Investigation of weather impacts on pedestrian volumes

Khaled Shaaban [a,*], Deepti Muley [a]

[a]*Qatar University, PO Box 2713, Doha, Qatar*

Abstract

This study investigates the impacts of temporal and weather characteristics on pedestrian volumes in a hot climate condition. A major neighborhood located in an urban area in Doha, Qatar was chosen as a case study site. The pedestrian volume data was gathered for three seasons, two days in each season, and three time periods for each day using observations from video recordings for the entire neighborhood. Overall, low pedestrian activity was noticed for all seasons. Pedestrians walked more during the weekday in the winter season, and during the weekend in the summer and spring seasons. Generally, the pedestrian volume was higher during the evening time. The results of a multiple linear regression analysis showed that the pedestrian volume had a log-linear relationship with the weather characteristics. The temperature was the only significant parameters affecting the pedestrian volume. This research is one of the first to study the effect of weather conditions on the pedestrian volumes in a hot weather climate environment.

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1. Introduction

Walking is an important physical activity suitable for all age groups irrespective of their physical conditions. Some studies indicated that the weather has a significant impact on pedestrian walking behavior (Westphal, 2012;

* Corresponding author. Tel.: +974-4403-4185; fax: +974-4403-4172.
E-mail address: kshaaban@qu.edu.qa

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Chan and Ryan, 2009). However, little is known about the effect of weather conditions on the walking behavior and specifically about the pedestrian volumes. Pedestrian volumes are not studied widely due to the difficulty involved in collecting reliable data. In addition, no study has assessed the weather impact on pedestrian volumes for extreme hot climate conditions. The main objective of this paper is to study the variation in pedestrian volumes for different times of the day, type of day, and seasons for a hot climate region for an entire neighborhood and further explore the relationship between pedestrian volume and weather characteristics. For the purpose of this study, pedestrian volume denotes the number of people seen on the streets walking or performing any outdoor physical activity.

2. Background

Due to lack of studies on the pedestrian volumes and weather conditions; studies related to transit ridership and bicycle counts also mentioned as they involve some walking and outdoor physical activity. Recently, two studies analyzed the variation in transit ridership with weather to find that the number of trips was reduced due to rain and wind, and increased with the rise in temperature in Spain (Arana et al., 2014) and non-commuter trips with time flexibility were highly affected by weather activity than fixed time commuter trips (Singhal et al., 2014). Also, bicycle counts studied by Nosal and Miranda-Moreno (2013) for urban cycle facilities in various cities, indicated that non-linear relationship existed between temperature and relative humidity with positive and negative trends respectively for hourly and daily bicycle counts. Rain also showed significant negative impact which increased with increase in the rain intensity.

Suminski et al. (2008) investigated the association between physical activity and meteorological conditions by studying activities on sidewalks, streets, and outdoor oval tracks. The counts of people performing various activities were made through observations. A group of twelve census blocks was selected from an urban area in Columbus, Ohio. Hourly meteorological data were obtained from the local airport. Descriptive statistics, student t-tests, Pearson Product Moment Correlation coefficients were determined, and multiple linear regression models were developed. The temperature was found to have a positive relation with the number of users using the track, but no relation was found with the number of users on sidewalk and streets. More users were seen on the sidewalks, streets, and tracks on the weekdays compared to the weekends. Further, the meteorological conditions were found to be related with physical activities undertaken on the weekdays but were not related to activities performed on the weekends. Overall, in an open air setting, a significant relationship existed between the physical activity and environmental factors.

Aultman-Hall et al. (2009) merged the automated pedestrian counts and weather reports for a single location at the Montpelier Vermont downtown for an entire year to study the effect of weather variability on pedestrian volumes using linear regression method. Four weather parameters, temperature, depth of precipitation, relative humidity, and wind were considered for analysis. The results showed that weather and season affected the pedestrian volumes. The precipitation reduced the average hourly volume of pedestrians by about 13% while winter months reduced the volumes by 16%. The weather was found to have a maximum variation of 30% in hourly pedestrian volumes.

Attaset et al. (2010) evaluated the effect of weather (temperature, precipitation, wind, and cloud cover) on the pedestrian volumes using linear regression analysis. The hourly pedestrian data was collected from thirteen sidewalk locations in Alameda County, California for a year with the help of automatic counters, and weather data was obtained from nearby weather stations. The results showed that precipitation had the largest effect on the pedestrian volume with 35% to 56% reduction in pedestrian volume; the effect was more on weekends. The cloud cover, higher winds, hot and cold temperatures reduced the pedestrian volumes. Relative humidity and dew point did not have a significant impact on the pedestrian volumes.

Kim and Yamashita (2011) investigated the relationship between built environment characteristics, such as landscaping, cleanliness, amenities such as curb ramps and seating, shade, street furniture condition, paving materials quality, sidewalk continuity, and environmental quality, such as odors and noise, and other elements such as presence of hawkers, solicitors, and vendors for a tourist destination Waikiki in Honolulu, Hawaii. The data was collected for 87 sidewalk segments using hand counting devices for two years. Descriptive statistics, correlation coefficients and General Linear Modeling (GLM) technique was used to assess the relationship between pedestrian volume and various variables. The volume of pedestrians was varying greatly with seasonal, temporal, and weather factors and circumstances. The GLM analysis showed that a complex and multi-dimensional relationship existed between pedestrian volume and different parameters.

Miranda-Moreno and Lathi (2013) assessed the weather impact on pedestrian hourly volumes, weekday, and weekend volumes for the temperate and cold season in Montreal, Canada. The pedestrian counts were obtained on an hourly basis at five locations using Eco-counter Pyro electric double short-range sensors for one year. The data was analyzed using log-linear time-series regression models and regression models using weather parameters (temperature, wind speed, relative humidity, and precipitation). Overall, the hourly volumes in cold months were lower than temperate months but with similar trends. Also, weekend flows were less than weekday flows. Further, the built environment was found to have an effect on the volume as well as the hourly patterns of the pedestrian distribution. The weather showed more impact on the weekends compared to the weekdays. The temperature and pedestrian volumes were having a non-linear relationship in temperate months and linear relationship in winter months. Lastly, the rain and wind speed also had an impact on the pedestrian volume with greater effect in winter months.

3. Side description

Qatar is a small sized hot and dry climate country, with an area of 11,610 km^2 (World Bank, 2015) and a population of 2,216,180 people (QSA, 2015), located in the Arabian Peninsula, Middle East. People in Qatar are extremely dependent on cars for transportation (Shaaban and Hassan, 2014). More people are willing to pay for parking versus free parking in order to walk less to their final destination (Shaaban and Pande, 2015). This country mainly witnesses three seasons; extremely hot weather during the summer season, pleasant weather during the winter season, and moderate weather during the spring season. The average daily temperature ranges from 14 °C to 41 °C over the year. The length of the day varies from 10.5 hours to 13.5 hours over a year with a wide variation in relative humidity from 18% to 94%. The wind speed varies from 1 m/s to 8 m/s with some rare occurrences of gust. The cloud cover varies from clear to partly cloudy, and the precipitation, mostly in the form of moderate rain, occurs on 19% of the days (Weatherspark, 2015).

Fig. 1. Aerial view of Al Sadd, Doha, Qatar (source: Timezones, 2015)

For the purpose of this study, Al Sadd neighborhood, situated in an urban setting, with mixed land use was selected. This neighborhood provides a vibrant community with multi-family residential land use, mosques, large shopping centers, public institutions, schools, light industries with commercial frontage. Al Sadd neighborhood is located on the west side of the Doha city at about 5 km distance from the city center. The size of the neighborhood considered for this study was 124.1 hectares with a population of 14,113 people (QSA, 2015). The entire neighborhood has fully planned sidewalks for pedestrian use. It is considered as one of the oldest neighborhoods in Doha that has been receiving infrastructure improvements during the past ten years. Generally, residents of diverse nationalities live in Al Sadd neighborhood. This neighborhood provides ample opportunities for walking or performing outdoor activities.

4. Methodology

Two datasets were obtained for this study. First, the pedestrian volume data was collected for the three seasons over a year. Data was collected during one weekday (a Wednesday) and one weekend (a Saturday) for the three seasons. Three time periods were chosen for volume counts, morning, afternoon, and evening. The pedestrian volumes were counted through observational surveys conducted using video recording with the help of a dashboard camera equipped with a Global Positioning System (GPS). The car followed a predefined route to cover the entire neighborhood and the pedestrian volume for the entire neighborhood was obtained for each time period. The recording time varied between a minimum of 66 minutes and a maximum of 132 minutes. The wide variation in total recording time was observed due to varying traffic conditions existing on the streets during different times of the day. The second data set related to weather conditions was obtained from the nearest weather station (Weatherspark, 2015). Data regarding the average temperature, relative humidity, wind speed, cloud cover, and precipitation was obtained. The weather characteristics were observed at 7:00 am, 12:00 pm and 6:00 pm for the morning, afternoon, and evening for all observation periods as this was the starting time of the video recording. The two datasets were combined to find the Spearman's correlation coefficients in order to determine the association between pedestrian volume, weather characteristics, and time-dependent parameters. Further, multiple regression models were developed to quantify the effect of weather characteristics on the pedestrian volume for different times of the day and the type of day. A season model was not developed due to the limited number of observations. Table 1 shows the details of the different variables used in the study.

Table 1. List of variables used for analysis.

Category	Name	Type	Description
Pedestrian volume	Volume	Continuous	Number of pedestrians at a time period
Time-dependent characteristics	Season	Categorical	Season of observation
	Type of day	Categorical	Type of day of observation
	Time of day	Categorical	Time of day of observation
Weather characteristics	Temperature	Continuous	Average temperature (°C) at the time of study
	Relative Humidity	Continuous	Relative humidity (%) at the time of study
	Wind speed	Continuous	Average wind speed (m/s) at the time of study
	Cloud cover	Continuous	Cloud cover at the time of study (%)

5. Results and discussion

5.1. Preliminary results

Table 2 shows the number of pedestrians observed for different times, days, and seasons along with the average weather conditions at the time of recording. No precipitation was observed on all observation days. The winter season can be taken as the best season for walking as the temperature is within a comfortable range for human beings, followed by spring, and summer temperatures. The pedestrian volume count at the end recorded that total

3044 pedestrians were spotted outdoors in Al Sadd neighborhood. Specifically, 1454 pedestrians were observed during winter, 630 pedestrians were seen during summer, and 960 pedestrians were seen during the spring season.

From the pedestrian count, it is evident that as the weather conditions become unfavorable, the walking activity reduces drastically similar to Miranda-Moreno and Lathi (2013). In the winter season, the maximum number of pedestrians walked, this amount reduced by about 34% in spring and 57% in summer. The comparison of pedestrian volumes between a weekday and a weekend for a season showed that the winter and spring seasons observed around 45% more pedestrians on a weekday and on a weekend respectively, similar to findings by Suminski et al. (2008). On the contrary, in the summer season, a marginal difference was observed between the pedestrian volumes on a weekday and a weekend. Miranda-Moreno and Lahti (2013) noted that in both seasons pedestrian flows were lesser on weekends and were following similar patterns, but here the weekend pedestrian volumes in summer and spring seasons were more than on a weekday, also the trends are different.

The time of day variation shows more trips in the evening on all observational days except for a weekday afternoon in summer and a weekday morning in the spring season. The evening peak occurs after 6:00 pm while for Miranda-Moreno and Lahti (2013) the evening peak occurred mostly between 4 pm to 6 pm. This shows that people preferred to walk in the late evening when the weather cools down significantly. Further, specifically in winter, fewer pedestrians walked in the afternoon perhaps due to the availability of more suitable weather conditions in the morning and evening. In summer, more walking in the afternoon was seen; this may be due to work related purposes.

Table 2. Pedestrian volumes and weather data for the three seasons.

Season	Type	Day, Date	Time	Temperature °C	Relative Humidity %	Wind speed m/s	Cloud cover	Pedestrian volume	Daily total	Season total
Winter	Weekday	Wednesday, 5/3/2014	Morning	20	60	0.5	20%	320	861	1454
			Afternoon	28	30	2.6	50%	200		
			Evening	23	46	2.6	25%	341		
	Weekend	Saturday, 8/3/2014	Morning	22	89	1.0	Clear	173	593	
			Afternoon	28	60	2.1	10%	100		
			Evening	25	63	2.1	10%	320		
Summer	Weekday	Wednesday, 16/7/2014	Morning	35	42	2.1	Clear	104	306	630
			Afternoon	43	12	5.7	Clear	114		
			Evening	42	9	4.6	Clear	88		
	Weekend	Saturday, 19/7/2014	Morning	35	57	2.6	10%	92	324	
			Afternoon	41	35	3.6	Clear	114		
			Evening	35	66	3.6	Clear	118		
Spring	Weekday	Wednesday, 8/10/2014	Morning	32	46	3.1	CAVOK	141	391	960
			Afternoon	38	23	7.7	Clear	122		
			Evening	34	24	6.7	Clear	128		
	Weekend	Saturday, 11/10/2014	Morning	30	84	1.5	25%	153	569	
			Afternoon	36	47	3.6	10%	153		
			Evening	33	54	3.6	10%	263		

5.2. Correlation coefficients

The Spearman's correlation coefficients were calculated to test the degree of association between variables used in this study; the results are presented in Table 3. The value of correlation coefficient ranges from -1 to +1. A value of zero indicates no defined relationship and a value of -1/+1 indicate perfect negative/positive correlation between the two variables. In this case, mainly the relationship between the pedestrian volume and weather and time--dependent parameters is of interest. The temperature and season showed a strong negative correlation, and wind speed and cloud cover have a moderate negative and positive relationship with pedestrian volume respectively. The time of day and relative humidity showed a weak negative and positive relationship respectively with the pedestrian volume. The type of day showed no relationship with the pedestrian volumes. In this case, temperature and season showed the strongest correlation with the pedestrian volume, while Aultman-Hall et al. (2009) found that all correlations were weak (below 0.2) except between wind speed and relative humidity (-0.4).

Table 3. Spearman's correlation coefficients.

	Pedestrian volume	Temperature	Relative Humidity	Wind speed	Cloud Cover	Season	Type of day	Time of day
Pedestrian volume	1	-0.726	0.293	-0.406	0.485	-0.686	-0.049	-0.379
Temperature		1	-0.663	0.702	-0.503	0.870	-0.084	0.225
Relative Humidity			1	-0.746	0.150	-0.398	0.674	-0.173
Wind speed				1	-0.412	0.418	-0.359	0.078
Cloud Cover					1	-0.549	-0.085	0.131
Season						1	0.000	0.000
Type of day							1	0.000
Time of day								1

5.3. Regression analysis

This section relates the pedestrian volumes and weather characteristics to determine factors affecting pedestrian volume using the Multiple Linear Regression (MLR) technique. An MLR model was developed, assuming a linear relationship between the dependent and independent variables, to determine the pedestrian volume for a particular time period using weather and time-dependent parameters. Since the dependent variable was not normally distributed, a log transformation was used for developing the MLR model. Kolmogorov-Smirnov test for testing normality assumption accepted null hypothesis with a p-value of 0.200. A stepwise regression analysis was performed by including the season, type of day, and time of day as categorical independent variables in addition to the temperature, relative humidity, wind speed, and cloud cover as continuous independent variables. The cloud cover for CAVOK and Clear condition was taken as 0%. The results showed that only temperature was found to be statistically significant while all other parameters were statistically not significant in determining the pedestrian volume.

Two tests for significance were performed; the F-test to test the null hypothesis that there is no relation between the input variables and the output variable, and the t-test to check null hypothesis that the coefficient for the variable in consideration is zero. The combined regression analysis rejected the null hypothesis of F-test showing the model significance of total regression as 0.000 (<0.05) indicating that at least one independent variable significantly contributed to understanding the variation in the number of pedestrians. The null hypotheses for t-tests were also rejected as all the coefficients have a value significantly different from zero. The R^2 for the model was at 54.4% which was adjusted to 51.6% showing acceptable results. The temperature showed a negative effect on the dependent variable i.e. pedestrian volume. Table 4 shows the detailed results of MLR.

$$PedestrianVolume = e^{6.570-(0.048\times Temperature)} \quad (1)$$

Table 4. Details of the regression model.

Variables	Estimates			
	Coefficient	Std. Error	t-statistic	Significance
Temperature	-0.048	0.011	-4.372	0.000
Intercept	6.570	0.359	18.291	0.000
No of samples	18			
F-statistic	19.118			
R^2 (Adj)	51.6%			

6. Conclusions

The results showed that the weather has a significant impact on the pedestrian volumes in hot weather environment. This statement should be further verified using additional sites. In addition, the results can be extended by studying the impact of weather on the different pedestrian characteristics including gender, age, and ethnic background. The temperature, wind speed, season, and time of day were negatively correlated, and relative humidity and cloud cover were positively correlated with the pedestrian volume. Amongst all the studied weather characteristics, the temperature was the only statistically significant variable affecting the pedestrian volume, and all other variables were not statistically significant. This was expected because Qatar is a hot climate country where the average daily temperature in summer can go above 50 °C. This finding indicates a strong argument in favor of modification in walking infrastructure to suit local climate conditions and promote more walking in all seasons and throughout the day.

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