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Impact of rainfall on travel time and fuel usage for Greater Mumbai city

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Abstract

Climate change can severely affect the rainfall pattern of a city and thus impact transport related activities. Travel time and mileage are an important transport parameter that may significantly be affected by rainfall. Objective of the study was to estimate the difference in travel time and fuel consumption for rainfall and non-rainfall days for Greater Mumbai. The study analyzed the impact of different intensities of rainfall on travel time and mileage for two roads of Greater Mumbai. A survey was carried out to collect data on the chosen transport parameter at different rainfall intensity. Rainfall intensity was categorized based on Indian meteorological department's standards. The results shows that travel time and fuel consumption are influenced by intensity of rainfall. Due to rainfall, there is an increase in travel time by 10-130% for both the roads studied. Also, travel time during evening peak hours is ~10% higher than morning peak hours.

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*Keywords:*Greater Mumbai; Rainfall; Travel time; Fuel consumption.

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1. Introduction

Climate change due to global warming is affecting various sectors including transportation sector. Travel time, speed, and fuel consumption are some parameters, in addition to transport infrastructure, which may get affected due to climate change induced extreme rainfall. The impact may seriously affect the performance of the transport network system. Especially extreme rainfall may have a serious impacts on transport parameters (Koetse and Rietveld, 2009). Considering the given impacts of weather and climate change, it is thus necessary to incorporate climate data into transportation studies.

Although literatures related to rainfall have reported a decreasing annual trend over India but there still exists a debate about the trend in extreme rainfall events amongst scientists. Different studies for the country have demonstrated decrease in total number of rainfall days but an increase in heavy rainfall days as well as an increase in frequency of such heavy rainfall days (Patankar et al., 2010). Apart from this, the post-monsoon, pre-monsoon and winter monsoon patterns have increased (Kumar et al., 2010). Extreme weather events have increased in India from 80 in 1978 to 460 in 2006. On a linear scale there is an increase of 10 events per year of which share of flooding is 38% (Singh, 2012). For India, the global warming caused by greenhouse gas is likely to intensify the rainfall over South Asia as suggested by future climate models (Lal et al., 2000; May, 2002, 2004, 2011; Meehl and Arblaster, 2003; Rupakumar et al., 2006).

Mumbai, the economic capital of India receives an average 2500 mm/year of rainfall. Of the total annual rainfall received, 36% is in July, 23% in June, 23% in August and 13% in September (Rana et al., 2012). Rainfall season runs for four months in a year with many events of extreme rainfall (100mm/day). Though as reported, the annual rainfall trend for the city is decreasing but the seasonal rainfall trend shows a significant increasing trend (Rana et al., 2012). The city has also witnessed many such cases of extreme rainfall event in past 2006 and 2015 resulting in economic losses (Ranger et al., 2011). Rainfall results in flooding of low lying areas in Greater Mumbai every year. There are 213 low lying areas in Greater Mumbai which are vulnerable to flooding every year.

Every year the flooding in an area impacts the travel time and speed of vehicle and thus results in congestion like situation. Thus this impact of rainfall on transport parameters can be quantified in terms of travel time (delay in minutes), speed (km/hr) and fuel consumption (l). Travel time is the time taken to travel on a route from one point to other. It is the simplest indices understood by planners, engineers and consumers (Traffic measurement, 2016). Many studies have been published on the changes in travel time and speed due to the growth of vehicles, the type of road or peak and non-peak hours etc. but very few literatures are available on the impact from rainfall and rainfall extremes on travel time especially for India. For almost all transport related studies clear conditions of weather is assumed (Agarwal et al., 2005).

Globally also few literature exists on impact of rainfall on travel time. For example in highway capacity manuals (HCM) of U.S, it is reported that free flow speed is reduced by 9.7 km/hr due to light rainfall and by 19.3 km/hr due to heavy rain (TRB, 2000). Tsapakis et al., (2013) tried to estimate for Greater London the impact of different intensity of snow, rainfall, and temperature on travel time with the help of automated number plate recognition (ANPR) data.

The result illustrated the with change in rainfall/snow intensity the travel time was affected. Temperature had no impact on travel time. The reduction in travel time ranges from 0.1% to 6.0% depending on the intensity of rain and snow.

In Ontario, a decrease in speed was observed by 5-10 km/hr for light rain (Ibrahim and Hall, 1994). In Canada also for light rain the speed was found to reduce by 10%. On an average, a decrease of 2 to 10% in travel speed have been reported due to light rainfall (Smith et al., 2004; Wang et al., 2006). Heavy rainfall whereas recorded a greater reduction in travel time by around 4-20% (Tsapakis et al., 2013). Speed was also observed to reduce by 6.03 km/h due to heavy rainfall in Nagoya city of Japan (Wang et al., 2006). For Washington the impact of heavy rainfall ranged from 17% - 20% (Stern et al., 2003). However, most of the studies reviewed have failed to define or quantify the intensity of rainfall and have just reported rainfall as light or heavy. Likewise only one study was found for India related to impacts of rainfall on transport parameter. The study carried out for Delhi determined the impact on speed and the findings indicated a drop in speed by 10% due to rainfall and also an increase in idling time during to rainy and cloudy weather (Chakrabarty et al., 2014).

Many of the studies which have been carried out have fail to define the intensity of rainfall or have failed to describe the impact under different intensities of rainfall. This study also quantify travel time, speed and fuel consumption. The results will highlight the impact for different time of day, different type of road and mileage. Most importantly Mumbai faces rainfall for four months in a year. Hence, the main objective of the work was to highlight the impact of different rainfall intensities on travel time, speed and fuel consumption for two major routes in Greater Mumbai area in India. In achieving the objective of this study, experimental study was carried out for travel time and fuel consumption data.

2. Methodology

2.1. Study area

The study area was the city of Greater Mumbai, economic capital of India and located on the south west part of country. Two major routes are selected which provide east–west and north-south connectivity. The city received large rainfall amounts owing to the orographic effect from strong western and south-western monsoon (Rana et al., 2012). During rainfall season the duration of a rainfall event usually ranges from 30-120 min, however, in some cases they can be as long as 3–4 h (Rana et al., 2012). During rainfall seasons daily rainfall amounts of up to 250 mm are common (Rana et al., 2012). Like any other metropolitan city, it faces congestion issues despite having the highest share of public transportation as the mode choice.

2.2. Data Source

2.2.1. Meteorological data

Daily precipitation data, was collected for study period (June to September, 2016) from disaster management department of Municipal Corporation of Greater Mumbai (M.C.G.M.) which has rain gauge meters installed at various locations in Mumbai after 2006 extreme rainfall event (900mm/day). The data from rain gauge meter was obtained for each road under study. The Indian meteorological department’s (IMD) classification system was used in the study as given in Table 1. The rainfall data for four months in 2015 where classified based on Indian Meteorological Department classification for study.

Table 1. Classification of rainfall based on intensity for Indian rainfall by IMD (IMD, 2018)

Sl. No.	Classification	Rainfall (mm/day)
1.	No rain	0.00
2.	Very light rain	0.1 to 2.4
3.	Light rain	2.5 to 7.5
4.	Moderate rain	7.6 to 35.5
5.	Rather heavy rain	35.6 to 64.4
6.	Heavy rain	64.5 to 124.4
7.	Very heavy rain	124.5 to 244.4

2.2. Traffic survey on three major roads in Mumbai

Travel time and mileage survey was carried out for two major routes of Mumbai: Jogeshwari –Vikhroli link road (J.V.L.R.) and Lal bahadur Shashtri Marg (L.B.S.) (Figure 1 and 2). The stretch of the road under study was 9.3 km. The survey was carried out for morning peak (8:00 am to 11:00 am), afternoon (1:00 p.m to 3:00 p.m) and evening peak (5:00 p.m to 8:00 p.m). The details about the location of the site is displayed in the following maps with the travel routes.

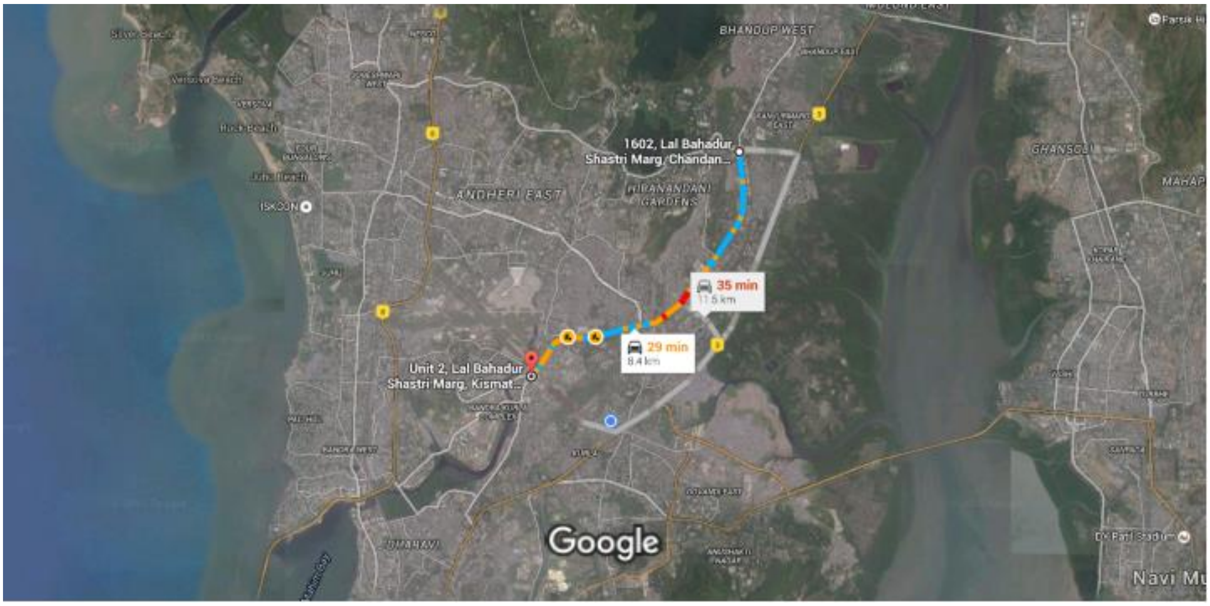


Fig.1. The survey was carried out from Kurla to Gandhinagar on the stretch of Lal bahadur Shashtri Marg (Google maps)

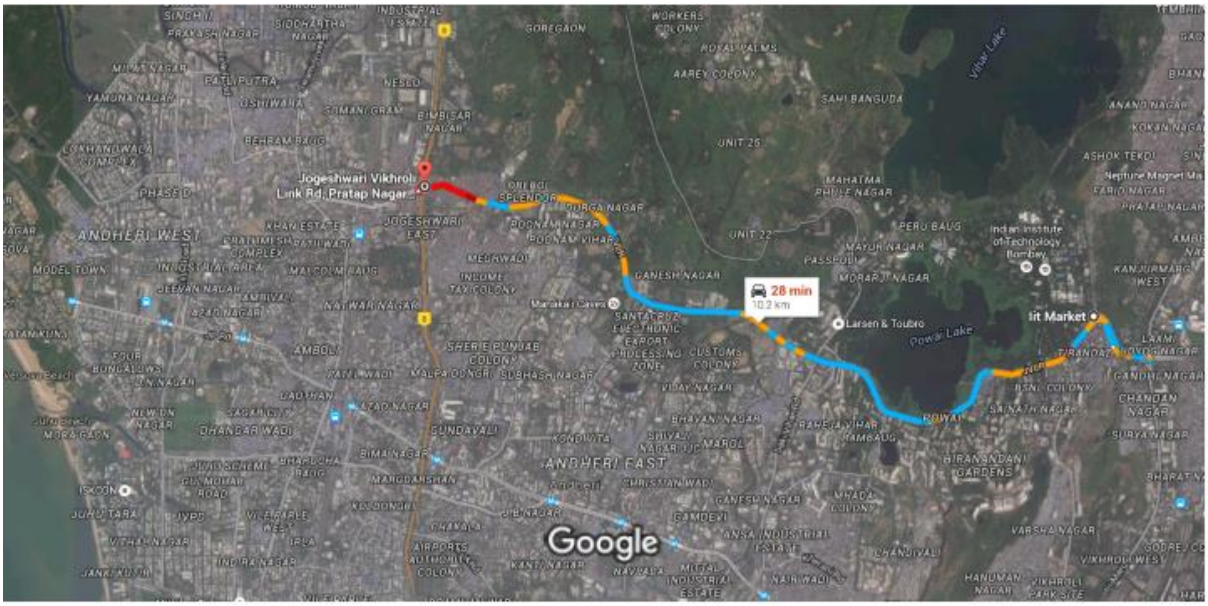


Fig. 2. The survey was carried out from origin to end of Jogeshwari Vikhroli link road (Google maps)

These roads carry huge traffic load through Greater Mumbai and hence experience frequent congestion and jams. Owing to availability and affordability the mode of transport chosen were auto-rickshaw and taxi. A preliminary survey was first carried on the road, to be surveyed, to identify the section of the road, length of the road and points of origin and destination. Various factors such as traffic volume, availability of taxi and auto-rickshaw, uniformity of road (i.e. to check for any construction or repair activity that might hamper or change the natural flow of traffic), presence of bus stops to serve as origin, location from the nearest rain gauge station and destination points were taken into account before the road section was selected. The first trip on each road was done in auto-rickshaw to identify the direction of major flow of traffic. For this, journey in both the directions was undertaken successively so as to ascertain the direction of peak flow in that duration. The survey was initially carried out during summer season to get the value of travel time index in dry condition which will serve the base of calculation to determine difference in travel time during rainfall season. Three such trips in a week for a month (March) were done during summer season (dry road condition) on different days (usually successive) and daily trips were taken during rainfall season which starts from June and remains up to September for Greater Mumbai. Around 12 samples were collected for dry conditions and 15 to 20 samples for rainfall conditions (for each category of rainfall). Thus the direction of major traffic flow on a road at the given time interval was identified. Origin and destination points were kept as bus stops to allow for exact time and distance measurement even when travelling by bus. Auto-rickshaw's electronic meter was used to measure the distance between the origin and destination points which was further verified using google maps. The time of survey for the roads was chosen so as to coincide with their peak and off-peak time flow which was identified based on the traffic count data from the TRANSFORM (2008). The peak hour data was collected on working days while off-peak data (free-flow speed) were collected on weekends (Sunday mornings).

2.3Measuring the mileage of the survey trips

For fuel consumption data, the survey was carried out during morning (peak), afternoon (off-peak) and evening (peak) hours with the use of a hired diesel car (1400 cc). The test vehicle was run at different time of the day to capture the speed and travel time of the traffic at the two routes. To understand the impact of speed on fuel consumption the vehicle was allowed to run on the selected route and was stopped after an interval of 2-3 km to note the time taken to travel and the mileage. Time taken to travel was noted down manually as well as on the Global Positioning System (GPS) instrument whereas the mileage was noted down from the car readings. Thus the survey helped in determining the time of travel, speed and fuel consumption data on the selected routes at different time in a day.

3. Results

3.1 Impact on travel time

3.1.1 Lal bahadur Shashtri Marg (L.B.S.)

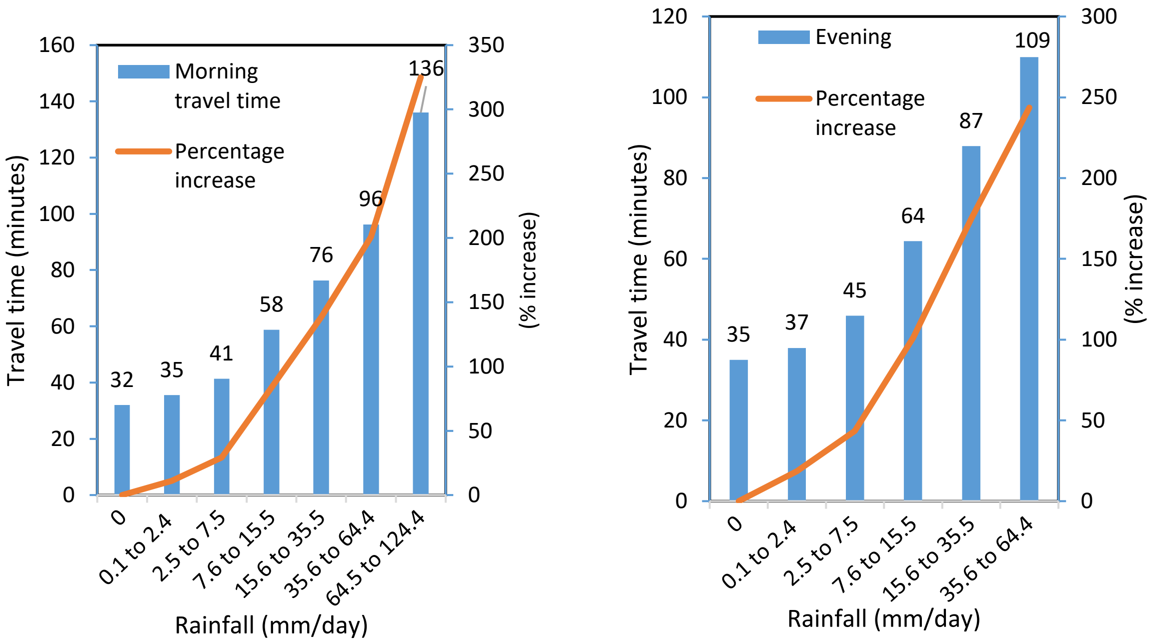
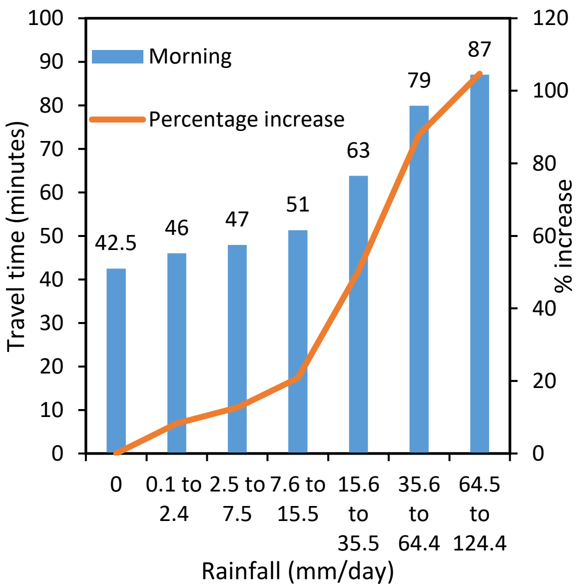


Fig. 3. Travel time for LBS (a) Morning peak our; b) Evening peak hour

Figure 3 presents the difference in travel time for rainy and dry conditions (morning and evening) as well as the percentage increase in travel time during rainfall. Light rainfall has the smallest impact on travel time. As the rainfall increases the travel time increases. The impact of rain is more during evening conditions as seen in the results especially for very heavy rainfall categories (64.4 to 124.4 mm/day). No data could be obtained for 64.4 to 124.4 mm/day rainfall in evening due to flooding situations observed at L.B.S Marg. Mumbai received around 283 mm/day of rainfall in June month due to which L.B.S Marg which comes under low lying area was completely flooded and thus resulted in unavailability of vehicle to carry out the survey. The sample size was also affected due to unavailability of vehicle for carrying out the survey. Smallest percentage difference in travel time occurs at low intensity of rainfall which is around 10.9% and the highest for heavy rainfall around 138%. The evening time showed slight difference in travel time on a higher side by 4 to 40%. The higher congestion levels at L.B.S Marg may be because it is only a four lane road and is surrounded by residential, commercials and shopping areas. The road was also found to get inundated after every downpour of more than 65 mm/day which resulted in no vehicle availability. Though being a major arterial road, many places had illegal parking and also illegal double parking which created more burden on the network especially during festivals. At few spots, damaged paver blocks was also observed near starting point (Kurla) and at end junction (towards Powai).

3.1.2 Jogeshwari Vikhroli Link Road (JVLR)



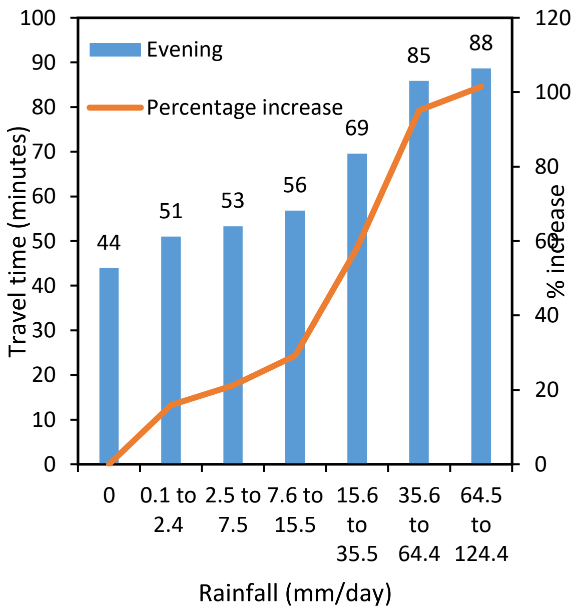


Fig. 4. Travel time for JVLR (a) Morning peak our; b) Evening peak hour

Figure 4 shows the travel time and percentage increase in travel time for rainfall and dry day for J.V.L.R. road. The travel time readings for rainfall above 124.4 mm/day could not be obtained due to unavailability of vehicle and flooding conditions on road. Whereas J.V.L.R. experienced flooding only a few spots instead of completely flooded roads and hence readings could be obtained for morning conditions. Nevertheless, the travel time showed an increasing trend with the increase in the intensity of rainfall. The difference in travel time for dry and rainfall conditions are slight less as compared to that recorded at L.B.S site. Smallest percentage difference in travel time occurs at low intensity of rainfall which is around 8% and the highest for heavy rainfall around 95%. The travel time difference obtained for J.V.L.R road is similar to L.B.S road as it is also surrounded by residential, commercial and shopping areas which results in congestions. However, may be due to the number of lanes (6-lanes) at J.V.L.R the results are better in comparison to L.B.S Marg. There were many other issues as well causing congestion like, parking of illegal private buses was observed leading to reduction in road lanes, during continuous downpour the signals became un-functional which also created confusion among the riders leading to reduction in speed. Traffic slowdown was observed due to absence of proper direction board and a few potholes were observed.

3.1.3 Relationship between speed and mileage

From the records of survey, it was observed that for JVLR speed during the off-peak hours is lowest as compared to peak hours (both morning and evening). For the same distance average speed observed during morning, afternoon and evening is 19.98 km/hr, 27.7 km/hr and 15.1 km/hr respectively. It was also observed that both during morning and evening the most congested site were between main gates IIT to Larsen & Tuobro building. In case of mileage, it was observed that the mileage of the vehicle obtained was highest in the afternoon as compare to other hours. During morning, afternoon and evening the average mileage observed was 15km/l, 18 km/l and 11 km/l respectively. From the records it was observed that speed for LBS during the off-peak hours is lowest as compared to peak hours (both morning and evening). For the same distance average speed observed during morning, afternoon and evening is 19 km/hr, 21 km/hr and 19 km/hr, respectively. Both during morning and evening, the most congested site were between Godrej petrol pump in Vikhroli to Phoenix mall, Kurla. In case of mileage, it was observed that again the mileage of the vehicle obtained was highest in the afternoon as compare to other hours. During morning, afternoon and evening the average mileage observed was 14km/l, 16 km/l and 13 km/l, respectively. A relationship was developed between speed and mileage for both the roads to determine the amount of fuel consumed (Figure 5). The results that a linear relationship between speed and mileage with R^2 value of 0.92.

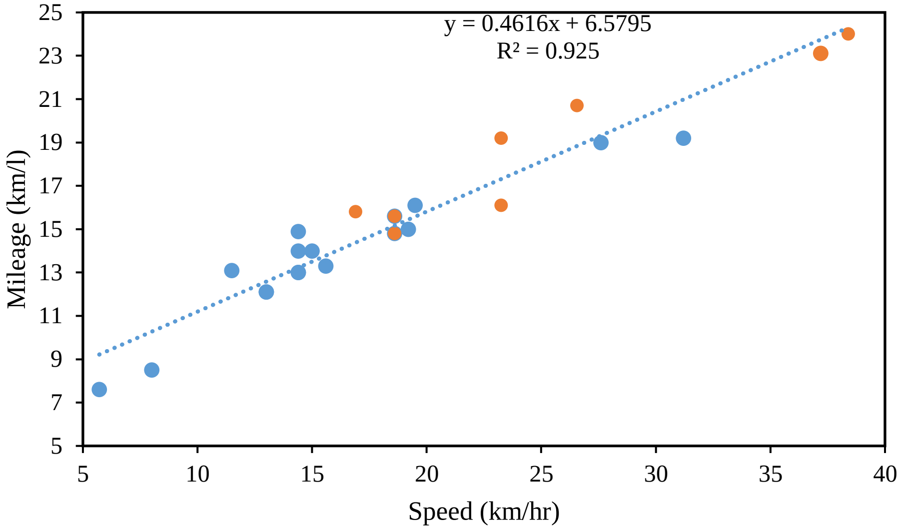


Fig. 5. Relationship between speed and mileage for both the roads

3.1.4 Fuel consumption

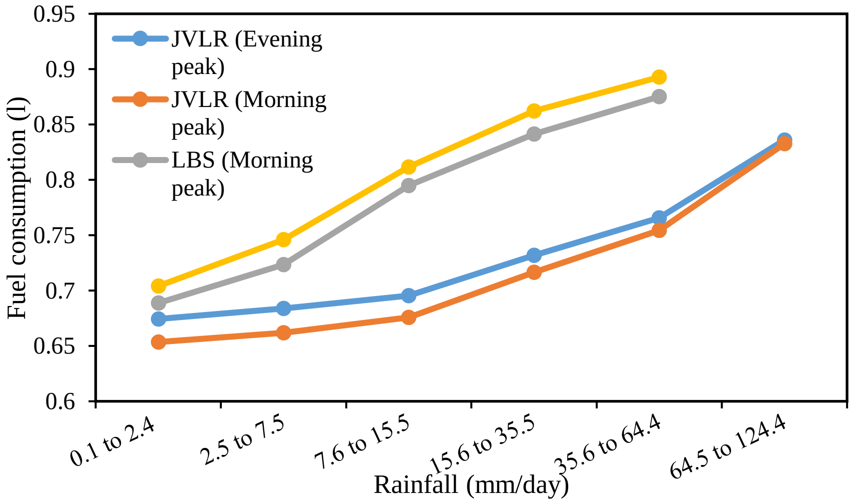


Fig. 6. Fuel consumption for both roads at different time of day

Fuel consumption for LBS is higher than JVLR for the same distance 9.3 km, around 5 to 16% for both morning and evening conditions (Figure 6). This may be due to the road condition, number of lanes, illegal parking etc. as similar to travel time survey observations. Similar to travel time, fuel consumption for evening peak hours for both roads are higher than morning peaks by 1-4%. As seen similar to travel time, fuel consumption also changes with the intensity of rainfall.

4. Conclusion

In this study, the impact of different rainfall intensities on travel time and mileage (fuel consumption) was determined for selected (arterial roads) roads in Greater Mumbai. Travel measurements indicated that for both the roads, rainfall intensity affected the transport parameter selected. Amongst both the roads, L.B.S Marg was the most affected from rainfall. Travel time increased from 10% to 130% for LBS Marg and for JVLR it increased from 10% to 90%. Thus, the speed and fuel consumption was also on higher side for LBS Marg compared to JVLR by 5% to 6%. The travel time during evening hours for both the roads was ~10% higher than morning hours, hence, the fuel consumption was also higher by 4%. In case of mileage, during morning, afternoon and evening the average mileage observed for both roads was 14km/l, 16 km/l and 13 km/l, respectively. The findings of the study can thus help transport planners and engineers take future decisions considering climate change in mind.

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