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Impact of past rainfall events on the urban transport of the Mumbai Metropolitan Region: current and future projections

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Abstract

This paper analyses the impact of rainfall events on the urban transport of the Mumbai Metropolitan Region (MMR), Maharashtra, India. We utilised a high flood level map for rainfall events of 2005 and 2007 to prepare a flooded transport network for MMR from 2005 to 2050. This flooded network was modelled in previously formulated travel demand model for MMR restricting the speed and public transport access links based on the flood depth. The results show that maximum cancelled vehicle trips would be from private mode (~60%) in 2050. The cancelled passenger trips from metro and suburban rail would be ~52% due to both rainfall events in 2050. This decrease in the trips contributed to the reduction in passenger and vehicle activity by an average of ~ 45% and 75% in 2050. The analysis of this study will be beneficial for policy makers to implement various policies and remedial measure towards reducing the effect of such rainfall events in future.

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Keywords: : Travel demand modeling; VKT; passenger km; floods; cancelled trips

1. Introduction

Cities are social centers and living in cities depends upon several facilities and functions such as housing, water and energy, transport infrastructure, education and employment. Urban cities include rapid urbanization and growth which results in numerous problems for policy makers and administrators. Urban floods, one of these problems, are becoming a pressing challenge. The main causes of floods include improper planning, climate change, heavy rainfall coupled with inadequate or poor drainage facilities, obstruction of drains etc. (NIUA, 2016; Singh et al., 2018). Urban floods result in significant tangible impacts, including monetary losses, and intangible impacts ,including non-monetary losses. (Hammond et al., 2015).

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Transport infrastructure is the immediate affected area of flooding as storm water easily finds its way into it. (Singh et al., 2018). There is abundant literature and studies are available for the climate change’s impact on transportation

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sector through vehicle emissions, but limited studies are available on impact of urban flooding on the transportation infrastructure. This gap can be filled by studying the impact of past flooding events on existing and future transport infrastructure to ensure their resiliency.

In India, many cities have experienced urban flooding in the past (NIUA, 2016; Rafiq, Ahmed, Ahmad, & Khan, 2016). Mumbai has experienced past three rainfall events, i.e. 26th July 2005, 30th June 2007 and 19th June 2015. 2005 event is classified as ‘very heavy’ by Indian Meteorological Department (IMD) criteria (> 200mm/day) as it recorded 944.42 mm of rainfall in 24 hours with a >200 years return period (TERI, 2016). Remaining two events, 2007 and 2015, recorded 314.5 mm and 300 mm of rainfall in 18.5 and 24 hours respectively with a same return period of 10 years (NIUA, 2016; TERI, 2016). These events disrupted the transportation services in Mumbai and brought city to halt.

There are many studies carried out in the past on 2005 rainfall event (Bhagat, Guha, & Chattopadhyay, 2006; Gupta, 2007; Ranger et al., 2011). Gupta (2007) and Bhagat et al. (2006) studied the causes and concerns involved in these floods whereas Ranger et al.(2011) studied the vulnerability of Mumbai to heavy rainfall and pressing need for the effective climate change adaptation. However, limited literature is available on impact of the past rainfall events on the transport infrastructure of the Mumbai Metropolitan Region (MMR). Therefore, the main objective of this paper is to study the impact of past rainfall events on the urban transport sector of MMR.

2. Methodology

Methodology for determination of impact of rainfall events such as of 2005 and 2007 in 2005 (base year), 2021, 2031 and 2050 shall consist of two stages namely, (1) extraction of the flooded transport network from the flooded map of MMR and (2) formulation of the travel demand model incorporated with the flooded transport network and speed restrictions (Fig. 1.). Lastly, a comparison of cancelled trips, passenger kilometres travelled and vehicle kilometres travelled was made to estimate the impact of the rainfall events on the urban transport sector of MMR.

2.1 Study area

Mumbai Metropolitan Region (MMR), a metropolitan area of Maharashtra, India - includes Mumbai - the state capital with its satellite towns and was selected for this study. With the development over a span of few decades, it has grown into 9 municipal corporations, 15 smaller municipal councils and 1000 villages which attribute to it being India’s largest urban agglomeration and one of the largest in the world. Mumbai Metropolitan Region Development Authority (MMRDA) is an organization of Maharashtra state government, responsible for the development, town planning, housing and transportation in the region. MMR spread over 4,355 km^2 of the area houses over 20.7 million population as of 2011. Mumbai, also known as the commercial capital of India, is responsible for 17% share in the country’s gross domestic product (GDP) (MCGM, 2016). It is one of the largest agglomerations of the world with 31,700 people living per km^2 (United Nations, 2018).

2.2 Data source

The methodology and results of Travel demand modelling (TDM) for business as usual (BAU) scenario of the urban transport sector of MMR were obtained from our previous study (Sharma et al., 2018). GIS shape files for two past rainfall events, 26 July 2005 and 30 June 2007, were obtained from TERI (2016). The reduction in travel speed with respect to flood depth was taken from Pregnolato et al. (2017)

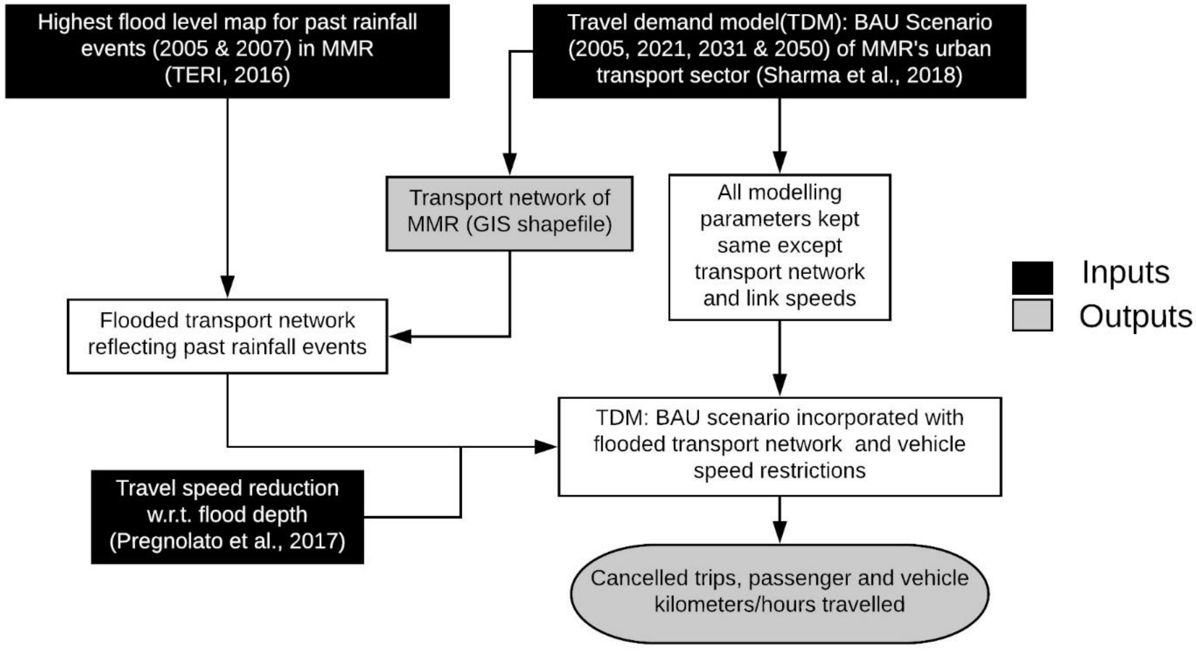

Fig. 1. Methodology

2.3 Flooded urban transport network

High flood level (HFL) raster maps for past rainfall events obtained from TERI (2016) was used to extract the flooded urban transport network. This was done by superimposing and clipping the transport network of MMR, which is a part of our previous study (Sharma et al., 2018), over the HFL maps of past rainfall events. The transport network was extracted for the years 2005, 2021, 2031 and 2050.

2.4 Travel demand model formulation

Validated travel demand model formulated in our previous study Sharma et al. (2018) was used to estimate the impact of rainfall events on the urban transport sector of MMR. This was done by replacing the existing transport network in BAU scenario with the flooded transport network obtained in the previous step. A relationship between vehicle travel speed and flood depth was obtained from Pregnolato et al. (2017) which is enumerated in Table 1. This relationship was used to restrict traffic on transport links or roads depending upon the flood depth. The model was formulated in Cube Base and Voyager: transportation planning software by Citilabs (Citilabs, 2018).

For roads, travel speed was restricted for flood depth <0.5 m and were assumed to be closed for flood depths ≥ 0.5 m. The affected vehicles include cars, two wheelers, three wheelers and buses. For public transport, no access and transfer links were generated for the flood depths greater than 0.5 m which will make the public transport services inaccessible for the passengers. The affected services include intermediate public transport (IPT): three wheelers and taxis, suburban rail, bus, metro and mono rail. No speed restrictions for flood depth less than 0.5 m were applied for transit services (suburban rail, metro and mono rail).

Since these rainfall events are unprecedented and uncertain, the mode share of urban transport has been assumed same as BAU scenario. This modelling exercise was followed for both the rainfall events (2005 & 2007) for 2005, 2021, 2031 and 2050. The cancelled trips, passenger kilometres, passenger hours travelled and vehicle kilometres travelled were obtained as the final output from the model.

Table 1. Travel speed reduction with respect to flood depth (Pregnolato et al., 2017)

Flood depths (m)	Travel speed reduction
0 - 0.1	no change
0.1 - 0.2	0 - 25%
0.2 - 0.3	25% - 50%
0.3 - 0.4	50% - 75%
0.4 - 0.5	75% - 99%
above 0.5	road closed

3. Results and discussion

After modelling both rainfall events i.e. 2005 and 2007, the cancelled vehicle and passenger trips, passenger and vehicle kilometers travelled were obtained as the output from the model. These are presented and discussed in the following sections:

3.1 Cancelled trips

Fig. 2 depicts the cancelled private vehicle trips in 2005 and 2007 flood events. Car and two-wheeler follow almost similar trend in the cancellation in both events. Cancelled trips are more for rainfall event 2005 than 2007 in all the years. The maximum cancellation will be in year 2031 in rainfall event 2005 and a minimum cancellation of 56% due to 2007 rainfall event in 2050. This is due to the increase in the existing mode share of metro from 2031 to 2050 and the greater intensity of 2005 floods than 2007 floods.

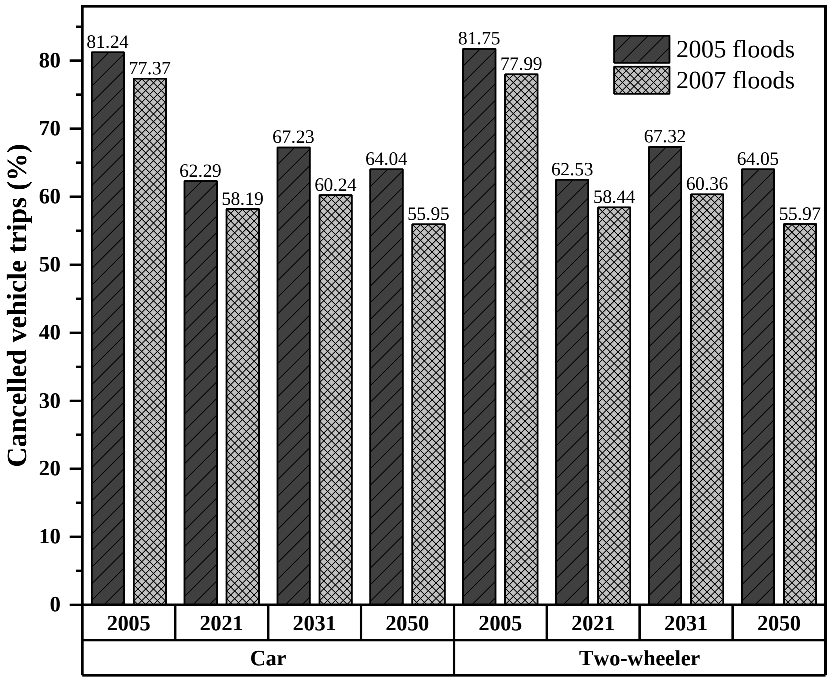

Fig. 2. Cancelled vehicle trips (%) due to 2005 and 2007 floods

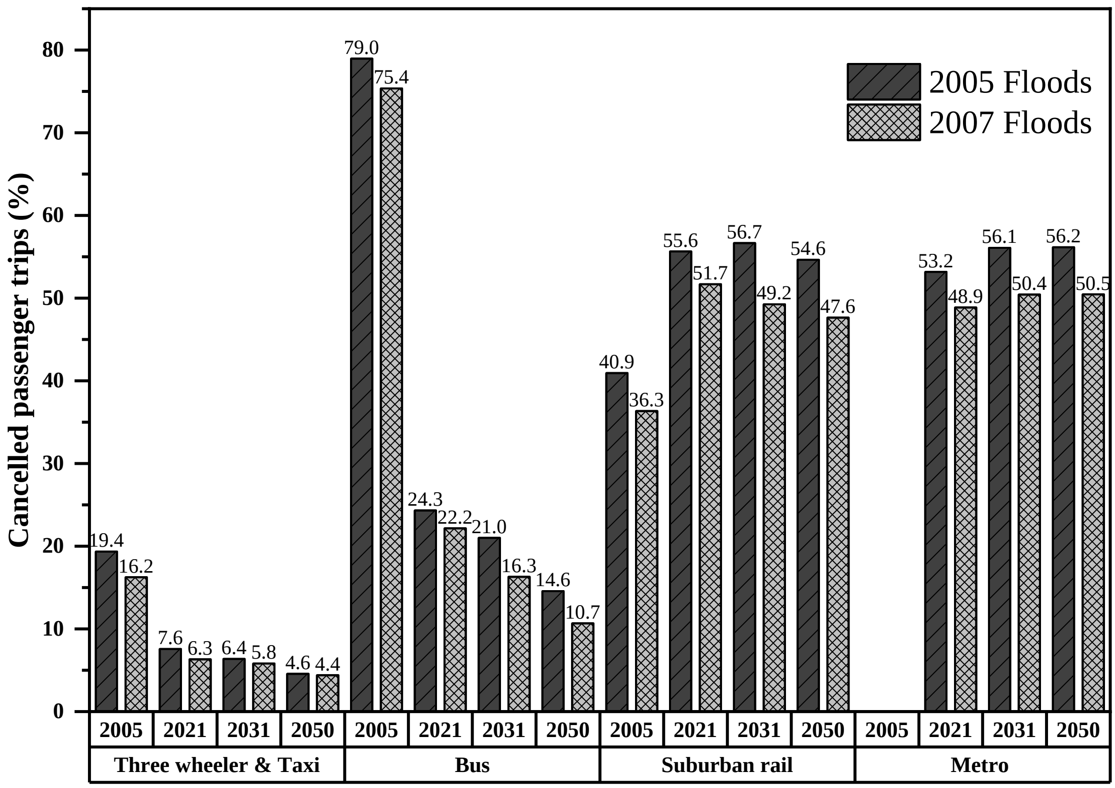

Fig. 3. Cancelled passenger trips (%) due to 2005 and 2007 floods

Fig. 3 shows that maximum cancellation of passenger trips was from bus trips in 2005 which decreased further to 10.7% from 79%. The cancelled passenger trips follow the similar trend as of the cancelled vehicle trips as the cancelled trips in 2005 floods are more than that of 2007 floods. The increase in the cancelled trips from suburban rail and metro rail in future years is because of the increase in the number of passengers in these years. Similarly, the decrease in the cancelled trips from bus and IPT in future years can be attributed to their declining share in these years. Passenger trips in mono rail were unaffected in both rainfall events because of the small route (~20km) it covers. Therefore, mono rail has been excluded from the analysis.

3.2 Passengers and vehicle kilometres travelled

Passenger kilometers would be reduced by 41% and 34% due to 2005 and 2007 floods in 2005 as compared to BAU scenario (Fig. 4). This reduction is set to increase to 48% and 42% in 2050. If 2005 floods occur again then they will be responsible for ~50% reduction in passenger km in the future due to inundation of highways and access lanes of public transport. Similarly, vehicle kilometers travelled illustrated in Fig. 5 reveal 79% and 78% reduction in 2005 and 2007 floods respectively as compared to BAU scenario in 2005. This reduction is set to reach 77% and 75% in 2050. Therefore, vehicle activity would be reduced to only 25% because of the extreme flooding in the future .

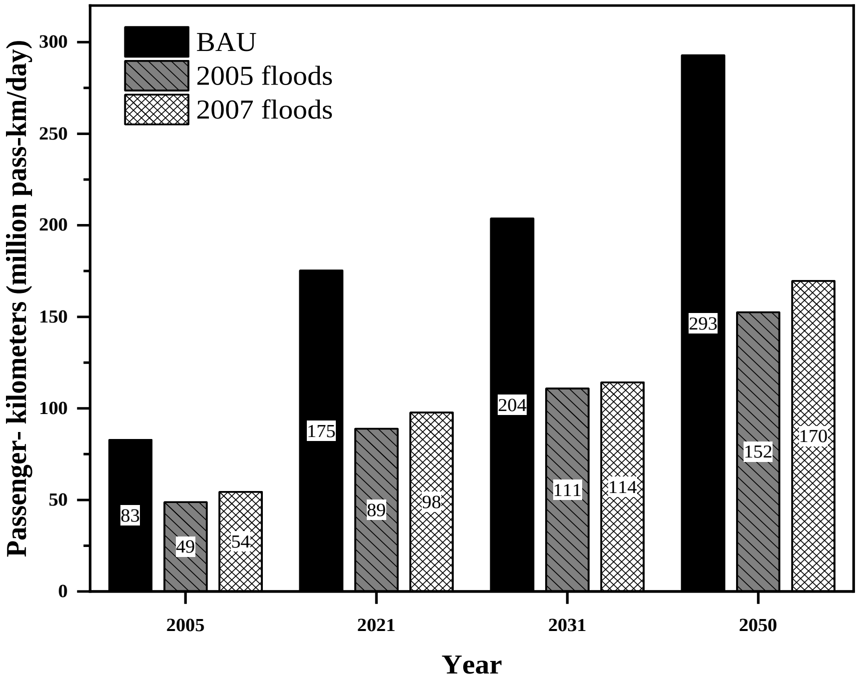

Fig. 4. Passenger-kilometres (million pass-km/day) in BAU scenario, 2005 and 2007 floods

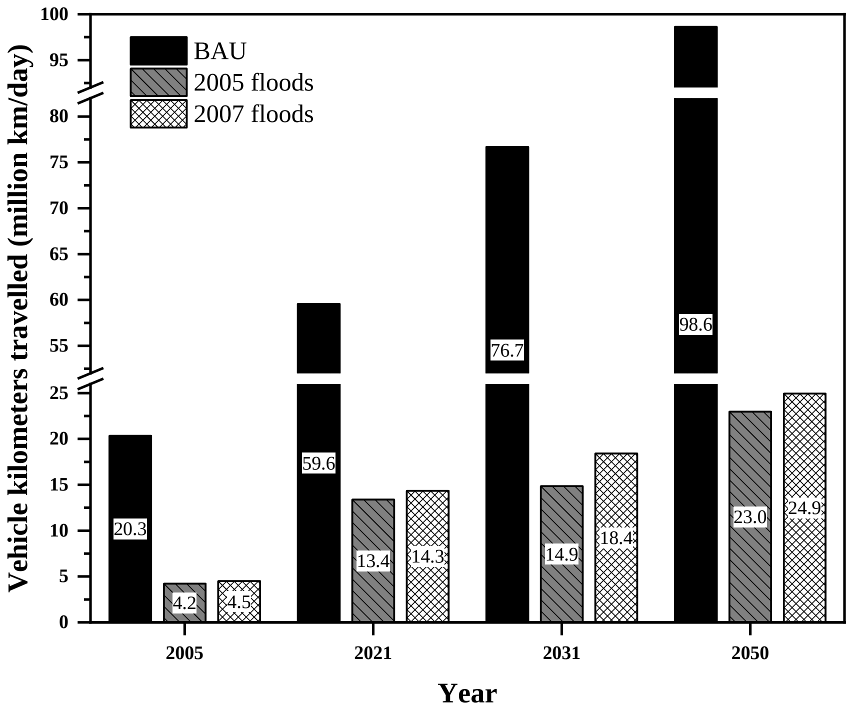

Fig. 5. Vehicle kilometres travelled (VKT) (million km/day) in BAU scenario, 2005 and 2007 floods

4. Conclusions

The study focused on the impact of extreme rainfall events on urban transport sector of Mumbai Metropolitan Region. The results show that if similar extreme rainfall events such as of 2005 and 2007 occur again in 2050 than there will be ~64% and 56% cancelled private vehicle trips due to 2005 and 2007 floods respectively. Similarly, suburban rail and metro passenger trips will decrease by average ~53% due to 2005 and 2007 floods respectively in 2050. The passenger and vehicle activity will reduce by an average of ~45% and 75% respectively due to both rainfall events in 2050. Therefore, suitable remedial and adaptation measures are required to decrease the susceptibility of urban transport towards heavy rainfall. These remedial measures may include the inclusion of pervious roads, upgradation of drainage facilities and special transport infrastructure for emergency evacuation.

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