Characterizing Traffic Behavior on Flooded Roads of Metro Manila

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Abstract: Metro Manila faces recurrent flood-related issues, leading to significant disruptions in transportation infrastructure even with minimal rainfall. Existing models rely on assumptions and theoretical values for key parameters. There is still a gap in understanding the effects of flooding based on real-world traffic conditions. This study aimed to investigate the impact of flooding on road demand and vehicle mix in Metro Manila. Fifteen (15) 30-minute video clips of flooded roads from MMDA's CCTV archive were analyzed. The results show that increased flood depth correlates strongly with reduced vehicle volume demand. Additionally, lane closures exacerbate the reduction in traffic volume, with more closures leading to greater disparities in vehicle flow. Lastly, as flood depths increase, there is an observed shift in vehicle composition, with a greater presence of larger vehicles and a decrease in lower ground clearance vehicles. These findings can be used as reference for future flood-based traffic models.

Keywords: Metro Manila, Flooding, Road Demand, Vehicle Mix, Modelling, Empirical Observations

1. INTRODUCTION

1.1 Background of the Study

Due to their frequent and instantaneous nature, flooding is considered the most costly natural hazard in terms of loss of human life and damage to personal property (Shah *et al.*, 2019). It poses a significant threat to transportation infrastructure due to its extensive nature, presenting substantial risks to both moving and parked vehicles. In urban areas, flooding is significantly more common after intense precipitation due to the loss of natural vegetation cover and the prevalence of numerous impervious surfaces, which lead to reduced rainfall infiltration and increased surface runoff (*Pour et al.*, 2020). Urban flooding can result in roughly 40% of a city's road network being partially submerged or completely impassable, leading to reduced accessibility. This causes significant disruptions characterized by vehicle speed reductions, longer travel times, and increased distances traveled within and around the affected area (Diakakis *et al.*, 2020).

The Philippines, with its tropical and maritime climate, experiences frequent heavy rainfall and flooding (PAGASA, 2023). Since the 19th century, flooding has been a longstanding issue in Manila, which has only intensified over the years with increasing annual rainfall and the occurrence of super typhoons (Afuang, 2001; Endo *et al.*, 2009). According to data from the Metro Manila Development Authority (MMDA), urban flooding frequently impacts key roads situated in major economic hubs across the Metro (Lagmay *et al.*, 2017).

Due to this, the combined fuel wastage and economic losses resulting from flooding-related traffic congestion can amount to 2.4 billion pesos per day in economic losses. Similarly, Roquel *et al.* (2019) have demonstrated that operational disruptions due to flooding in the cargo movement sector can have far-reaching economic consequences, resulting in an estimated loss of 297 billion pesos for the entire economy.

Because of the significant impact of urban flooding on the transportation systems in cities, numerous studies and models have been done (Kasmalkar *et al.*, 2020; Shahdani *et al.*, 2022). However, the Philippines still currently lacks a flood-based traffic disruption model for its major cities. An initial study by Bacero & Fillone (2023) examined the impact of flooding on truck movement in Metro Manila; however, numerous assumptions were made regarding the model. Thus, this study will focus on the impact of flooding on vehicle movement in Metro Manila.

1.2 Statement of the Problem

Metro Manila faces persistent flood risks due to several factors such as climate change, rapid urbanization, and poor urban flooding (Bankoff, 2003). Because of this, Metro Manila, even amidst light to moderate rainfall, experiences frequent urban flooding that heavily impacts the transportation infrastructure. Despite this, the city currently lacks an accurate flood-based traffic disruption model. There is still a gap in understanding the effects of flooding based on real-world traffic conditions. Current research has relied on assumptions for the input values (e.g., proportion of vehicles, road capacity, etc.) of their transportation models. Abad & Fillone's (2017) study had provided each road type's reduced capacity based on flood heights; however, these are all based on the authors' estimate on which vehicles could and could not traverse the flood levels. Similarly, the study of Bacero & Fillone (2023) only assumed the vehicle mix and road capacity relative to the degree of typhoon.

1.3 Objectives

As flooding incidents continue to disrupt transportation systems, a critical gap exists in the understanding of the relationship between capacity of flooded streets and vehicle demand characteristics (e.g. vehicle mix, travel speed, etc.) and their ability to navigate flooded streets under reduced road capacity. This paper seeks to address this gap by quantifying the effects of flooding in vehicle movement. Specifically, the study aims:

- To investigate the change in vehicle volume on road segments during flooding events.
- To determine the vehicle mix (e.g., cars, motorcycles, trucks, etc.) under varying flood depths in Metro Manila.

1.4 Significance of the Study

The flooding caused by excessive rainfall in Metro Manila necessitates comprehensive urban planning, disaster management, and transportation infrastructure development. This study provides valuable insights into the impact of flooding on vehicle movement and its overall effect on Metro Manila's urban transportation system. By examining the specific effects on traffic conditions, the research offers a more accurate and updated perspective on urban resilience and disaster management. While platforms like Waze offer real-time traffic data, they do not distinguish between how different types of vehicles respond to challenges like flooding. Discussions from previous literature shows that vehicle size plays a critical role in how drivers navigate flooded roads, with larger vehicles more confident in traversing these areas, while smaller vehicles are more hesitant (Hilly et al., 2018; Pregnolato et al., 2017). This highlights the importance of a flood-based traffic disruption model, which quantifies the behavior of different vehicle types during flood events. Such a model enables transportation planners to design resilient infrastructure and effective traffic management strategies by understanding the proportion of vehicles willing to traverse flooded roads at varying water levels. The findings of this study also raise awareness among Metro Manila residents about transportation vulnerabilities, helping them make informed decisions during flood events. Additionally, the insights can guide government authorities in developing disaster response plans, allocating resources efficiently, and implementing tailored flood mitigation strategies. Finally, the methodologies used in this research provide a valuable framework for future studies, enabling continuous innovation in addressing flooding and disaster preparedness in urban areas.

1.5 Limitations

The 30-minute observation period was determined by the limitations of the available footage provided by the Metropolitan Manila Development Authority (MMDA). Due to data access constraints, extending the observation beyond this timeframe was not feasible. Despite this limitation, the 30-minute footage offered valuable insights into the immediate impacts of flooding on traffic conditions. This duration was sufficient to capture significant variations in traffic flow and flooding patterns, which were crucial for understanding the immediate effects of flooding on traffic.

2. REVIEW OF RELATED LITERATURE

2.1 History of Rainfall & Flooding in the Philippines

The Philippines, characterized by its tropical and maritime climates, experiences high temperatures during the dry season (December to May) and significant rainfall during the rainy season (June to November). Historical rainfall data from 1991-2020 indicates an average annual precipitation of 2,348 millimeters, with considerable geographic variability: from 960 millimeters in southeastern Mindanao to over 4,050 millimeters in central Luzon (World Bank Group, 2021). Metro Manila's rainfall data, analyzed across several periods from 1901 to 2018, reveals an average annual precipitation of 2,450 millimeters (Bagtasa, 2019). A focused study on Metro Manila's rainfall patterns during 2013-2014 identified peak hourly rainfall in the early afternoon during the southwest monsoon season (Bañares *et al.*, 2021).

The Philippines is regularly impacted by tropical storms and typhoons, with about 20 typhoons entering its area annually, leading to severe rainfall and flooding (Yumul *et al.*, 2010). Notable typhoons like Xangsane, Ketsana, and Noru caused extensive damage, displacing millions and highlighting the region's vulnerability (Abon *et al.*, 2011; Mukhtar, 2022; Philippine Star, 2014). Flooding in Manila has been documented since the 19th century, with significant events like the 1942 flood and the 'Great Flood' of 1972, which resulted from consecutive typhoons (Bankoff, 2003). Increasing annual rainfall and more frequent heavy rain events have been observed since the 1950s, exacerbating flood risks (Afuang, 2001; Endo *et al.*, 2009).

2.2 Degradation of the Transportation System during Flooding

In the Philippines, intense thunderstorms can cause knee-deep or waist-deep flooding on major roads, paralyzing traffic (Lagmay *et al.*, 2017). Flood simulations estimate that traffic jams from such events cost the economy around 2.4 billion pesos ($48 million) per day due to wasted gasoline and lost productivity. Moreover, economic losses from disruptions in road freight operations due to flooding can reach 297 billion pesos for a 5-year flood event, with an annual probability of occurrence of 20% (Roquel *et al.*, 2019).

Public transit is also heavily affected by flooding, with long waits and stranded commuters leading to delays and uncertainties (Abad *et al.*, 2020). Commuters in Metro Manila often adapt by departing earlier, but spatial differences in behavior changes are notable. Employment constraints influence commuters' ability to adjust, and the availability of alternative routes does not significantly alter commuting patterns, indicating a reliance on familiar routes even during adverse weather. These findings underscore the severe impact of flooding on transportation systems, necessitating robust flood management and infrastructure resilience strategies.

2.3 Vehicle Mobility during Flooding Conditions

Pregnolato *et al.* (2017) developed a depth-disruption function that correlates flood depth with vehicle speed, considering vehicle design and stability issues. This empirical relationship improves the assessment of flooding impacts on road transport but still requires more robust data. Similarly, Hilly *et al.* (2018) found that vehicle speeds decreased significantly as floodwater depth increased, especially beyond 30 cm, leading to traffic delays. Their study quantified delay costs at different flood depths, highlighting that outside peak hours, even 10 cm of floodwater caused noticeable speed reductions.

Suwanno *et al.* (2021) used the macroscopic fundamental diagram (MFD) to analyze traffic flow and density relationships in Bangkok during flooding. They observed that higher flood levels led to more scattered and discrete MFDs, indicating reduced traffic continuity. Vu *et al.* (2024) studied traffic volume changes in Ho Chi Minh City during urban flooding, noting a significant decrease in motorcycle volume and an increase in passenger car volume when water levels reached at least 20 cm.

2.4 Flood-Based Traffic Impact Models

Despite the Philippines' extensive history of urban flooding, the country currently lacks a comprehensive flood disruption model for its major cities. Abad & Fillone (2017) conducted a study assessing the impact of three flood heights—low (10 cm to 50 cm), medium (50 cm to 150 cm), and high (exceeding 150 cm)—on traffic flow, travel time, and speeds. Their model indicated adverse effects on these parameters, but it relied on assumptions about road data based on flood height, highlighting the need for more empirical data.

A more recent study by Bacero & Fillone (2023) focused on the impact of flooding on truck movements. They found that flooding did not necessarily increase Vehicle Delay Time (VDT) and Vehicle Hours Traveled (VHT) across study areas because smaller vehicles might avoid flooded routes, reducing overall traffic volume. However, roads directly affected by flooding saw increased VDT and VHT as trucks were forced to take longer alternative routes, resulting in more time and distance traveled. These roads also experienced decreased average speeds and a reduced Vehicle Capacity Ratio (VCR) due to fewer vehicles. While the study provided new insights into vehicle movement during floods numerous assumptions were made on the design of the model. This underscores the need for further research to verify these assumptions and validate the model's results.

3. METHODOLOGY

3.1 Videos for Analysis

The study utilized 30-minute video clips extracted from the MMDA's CCTV archive, capturing various intersections and roads from elevated viewpoints. The footage included both flooded and non-flooded scenarios, obtained from the same days of the week and time frames for comparative analysis. A total of 15 roads were observed, differing in road type (i.e., primary or secondary) and road characteristic (i.e., free-flowing or intersection). Table 1 presents the roads studied.

Table 1. Observed roads

Road Name	Road Type	Road Characteristic
EDSA - Balintawak Market	Primary Roads	Free-Flow
EDSA - Camp Aguinaldo	Primary Roads	Free-Flow
EDSA – White Plains	Primary Roads	Free-Flow
EDSA - Dario Bridge	Primary Roads	Free-Flow
EDSA - Oliveros NB	Primary Roads	Free-Flow
MIA Domestic Terminal 2 (SB)	Primary Roads	Free-Flow
MIA Domestic Terminal 2 (NB)	Primary Roads	Free-Flow
Roxas - EDSA Flyover	Primary Roads	Free-Flow
Andrews - Tramo	Primary Roads	Intersection
EDSA - Kamuning (NB)	Primary Roads	Intersection
Kamias (WB)	Secondary Roads	Intersection
Kamias (EB)	Secondary Roads	Intersection
E. Rodriguez corner Araneta (WB)	Secondary Roads	Intersection
E. Rodriguez corner Araneta (EB)	Secondary Roads	Intersection
Roxas - Kalaw	Secondary Roads	Intersection

3.2 Number of Lanes

The study used Google Maps' Street View to examine the number of lanes per road segment. In counting lanes, exclusive vehicle lanes, such as bus lanes on EDSA, were excluded. According to Arasan & Vedigiri (2009), dedicated lanes are designed for single vehicle types and operate under different dynamics, allowing them to avoid congestion and operate more swiftly. These exclusive lanes do not align with the traffic scenarios of adjacent lanes, leading to their exclusion from the general lane count. The study focused only on general-purpose lanes, which are accessible to all vehicles. Exclusive lanes were defined as those with distinct separation from other lanes through physical barriers or regulatory measures. Lanes without physical barriers, such as bike lanes shared with other vehicles, were considered general-purpose lanes because they are still influenced by external traffic. Table 2 presents the number of lanes and the presence or absence of exclusive lanes for each road studied.

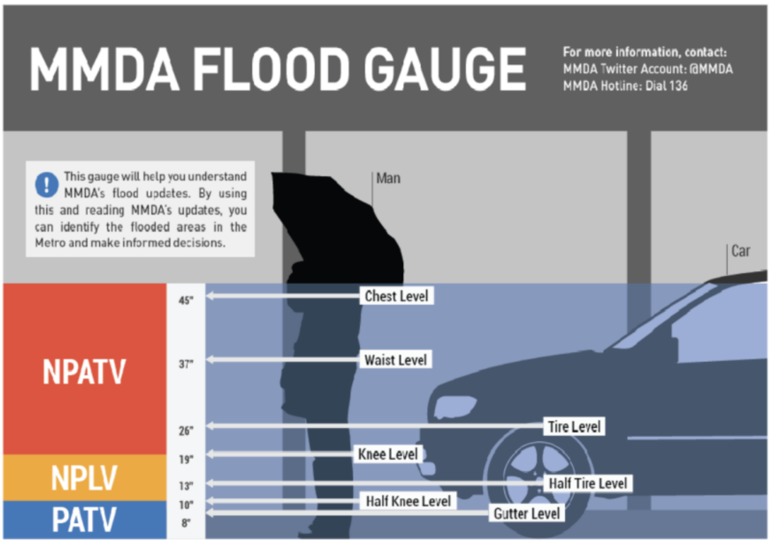
Table 2. Summary of lanes

Road Name	Number of Lanes (per Direction)	Bus lane	Bike lane
EDSA - Balintawak Market	5	✓	x
EDSA - Camp Aguinaldo	5	✓	✓
EDSA - Dario Bridge	5	✓	x
EDSA - Oliveros NB	5	✓	x

EDSA - White Plains	4	✓	✓
MIA Domestic Terminal 2 (NB)	3	x	x
MIA Domestic Terminal 2 (SB)	3	x	x
Roxas - EDSA Flyover	5	✓	✓
Andrews - Tramo	4	x	x
EDSA - Kamuning (NB)	3	x	x
E. Rodriguez (EB)	4	x	x
E. Rodriguez (WB)	4	x	x
Kamias (EB)	2	x	x
Kamias (WB)	2	x	x
Roxas - Kalaw	5	x	x

3.3 Flood Depth

In order to determine the effects of varying flood depths on the road traffic characteristics, the maximum flood depth and sampling flood depth were both measured. For the maximum flood depth, the values were estimated according to the MMDA Flood Gauge as shown in Figure 1 (Abana *et al.*, 2019). Using this metric, the maximum water level (converted from in to cm) within the road was approximated by gauging the height of the water in relation to the classifications outlined by the MMDA. The flood depth at the most submerged section of the road was assessed at five-minute intervals, with the highest recorded flood depth being identified as the maximum depth for that road segment.



This gauge will help you understand MMDA's flood updates. By using this and reading MMDA's updates, you can identify the flooded areas in the Metro and make informed decisions.

Figure 1. MMDA flood gauge

3.4 Analysis

3.4.1 Road demand

Road demand pertains to the extent of traffic on a particular road network, reflecting the level of usage. To assess this, the volume of vehicles was observed through a manual count of vehicles passing through the road in both flooded and non-flooded conditions. For the manual count, all vehicles that utilized the road being observed were counted, regardless of the direction they traveled (i.e., left, right, and through). From this, the peak 15-minute volume was obtained, and multiplied by four to obtain the peak hourly volume of the road (see Eq.1).

$$\text{Road Demand} = 4 \times V_{15} \qquad \text{(Eq. 1)}$$

3.4.2 Vehicle mix

The vehicle aims to represent the percentage of vehicles that traverse a flooded road, and assess whether the presence of flood has a significant impact on the type of vehicles traversing a flooded road. In order to determine this, a manual count of vehicles passing through the area in both flooded and non-flooded conditions were conducted (see Figure 2). These vehicles were categorized as either private or public transit, and further classified according to their respective type. Table 2 presents the vehicle types studied.

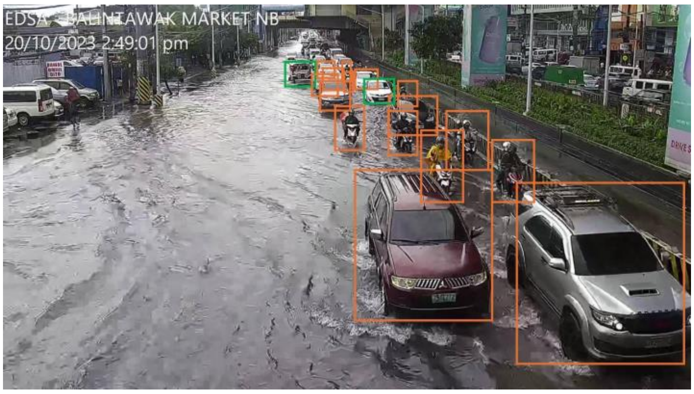


Figure 2. Counting vehicle mix (orange = private and green = public)

Table 2. Vehicle classification

Category	Type
Private	Sedans Crossover SUV Vans Motorcycles Light Cargo Rigid Truck (2 axle) Rigid Truck (3+ axle) Trailer Truck Non-Motorized Bike Others
Public	Tricycles PUJ E-jeep Taxi UV Express

	Bus

The “Others” vehicle category includes various unique and specialized vehicles that differ from conventional types due to their distinct physical attributes or behaviors. These vehicles play specialized roles and have a limited presence on the roads, making it unnecessary to create separate categories for each. This category included armored cars, ambulances, fire trucks, pedicabs, police cars, minibuses and owner-type jeeps.

4. RESULTS AND DISCUSSION

4.1 Road Demand

To assess the change in road demand due to flooding, the percentage difference between the total volume of the flooded and non-flooded conditions were calculated. Figure 3. presents the change in volume per road relative to the maximum flood depth observed within that road segment.

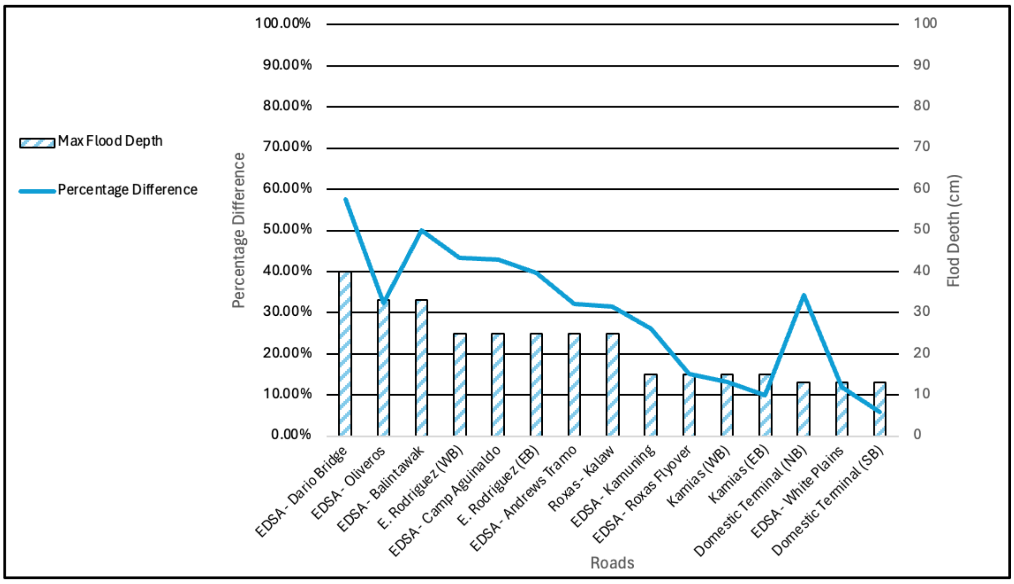


Figure 3. Change in vehicle volume relative to flood depth

The relationship between flood depth and traffic volume is evident, with higher flood depths corresponding to a more significant decrease in vehicle traffic. For example, locations with deeper floods, such as EDSA - Dario Bridge (40 cm) and EDSA - Oliveros (33 cm), experienced a substantial drop in vehicle volume, with percentage differences of 57.56% and 52.91%, respectively. In contrast, areas with shallower floods, like Domestic Terminal (SB) and Kamias (EB), had smaller percentage differences of 5.96% and 9.93%, indicating a lesser impact on traffic volume. This pattern can be attributed to the increased challenges posed by higher flood depths, leading drivers to reroute or avoid affected areas, resulting in a significant decrease in vehicle traffic. The findings align with model-based results of Bacero & Fillone (2023), which suggest that during flood events, a substantial portion of vehicles are unable to use the roads, with the percentage decreasing relative to the severity of the flood events.

However, while the general trend indicates higher flood depths leading to higher volume changes and vice versa, there are some outliers. There are other factors, such as the road segment’s location, that may contribute to the observed differences. For instance, Domestic Terminal (NB) serves as the primary route to Ninoy Aquino International Airport

(NAIA) Terminal. Due to this, adverse weather conditions leading to flight delays or cancellations can impact the volume of vehicles enroute to the airport, influencing the observed change in volume.

Ferguson *et al.* (2023) found that lane closures, a common consequence of flooding, can significantly affect traffic volume. To assess the impacts, Figure 4 illustrates the impact of lane closures on the percentage change of traffic volume between flood and non-flood conditions. Roads without lane closures experienced a 17.94% change in traffic volume, while roads with one, two, and three lane closures had 34.47%, 41.75%, and 57.56% changes, respectively. This indicates that increased lane closures lead to greater disparities in traffic volume, highlighting the impact of reduced road capacity during flooding.

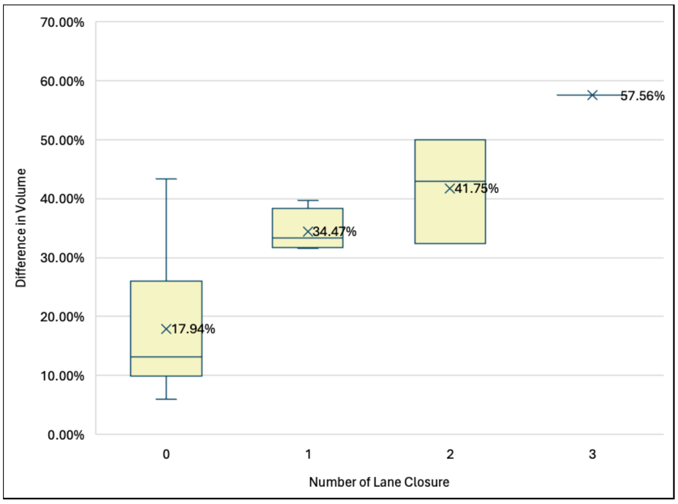


Figure 4. Change in volume due to number of lane closures

4.2 Vehicle Mix

Table 3 illustrates the effects of flooding on the volume of vehicles for different modes. The results were calculated as the percentage of each category relative to the total vehicles per condition. This provides insights on the change in vehicle mix caused by the presence of floodwaters within the road.

Table 3. Change in volume of vehicles

Vehicle Type	Flooded	Non-flooded	Difference
Passenger Car	46.88%	45.65%	1.23%
Motorcycle	36.99%	38.20%	-1.21%
Truck	7.79%	7.40%	0.39%
Public Transit	7.69%	7.97%	-0.28%
Non-Motorized Bike	0.64%	0.78%	-0.14%

The data shows a clear correlation between vehicle type and the ability to traverse flooded roads. Passenger cars exhibit a higher percentage in the flooded scenario (46.88%) compared to the non-flooded scenario (45.65%), with a 1.23% difference. This suggests that passenger cars are more capable of navigating flooded roads than other vehicles. In contrast, motorcycles have a lower percentage in the flooded scenario (36.99%) compared to the non-flooded scenario (38.20%), a -1.20% difference. This indicates that motorcycles are less prevalent during flooded conditions, possibly due to the challenges of navigating through water on two wheels. These findings align with prior research by Vu (2023), which observed a decrease in motorcycle volume and an increase in passenger car volume during flooded conditions, particularly when water levels reach a minimum of 20 cm.

Trucks also show a slight increase from 7.40% to 7.79%, a 0.39% difference, implying that trucks may be better suited for flooded conditions compared to other vehicle types. This aligns with findings of Bacero & Fillone (2023) that larger vehicles, such as trucks, tend to have higher ground clearance and better traction, making them more capable of traversing flooded areas.

For public transportation, the data shows a decrease from 7.97% in the non-flooded scenario to 7.69% during flooding, a -0.28% difference. This suggests that public transportation becomes less viable or accessible during flood events, which may make it more difficult for commuters and students to reach their destination.

4.2.1 Private vehicles

Models in previous literature assume that higher flood depths lead to an uptick in the volume of larger vehicles (e.g., trucks) and a decline in the volume of smaller vehicles (e.g., passenger cars, motorcycles). However, observations from flooding events in Metro Manila indicate that specific vehicle types within these broader categories are influenced differently by flood depth.

To evaluate the effects of flood depth on a more extensive vehicle mix, a study examined the relationship between maximum flood depth and the change in vehicle mix for private vehicles. The results, illustrated in Figure 5, were calculated as the percentage difference in vehicle volumes between flooded and non-flooded conditions. Negative values indicate a decrease in traffic volume for flooded conditions, while positive values represent an increase.

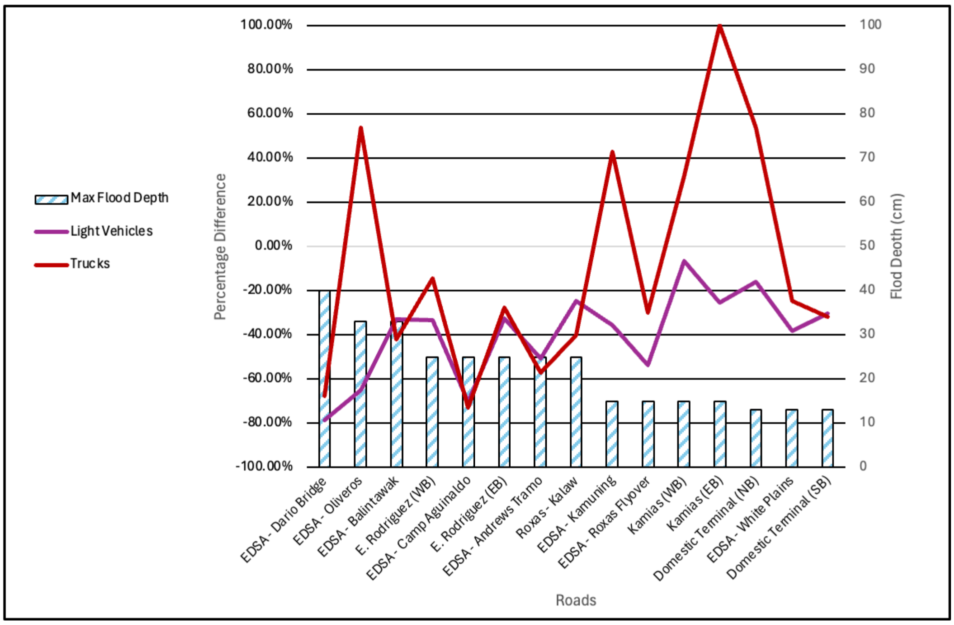


Figure 5. Change in volume for private vehicles relative to flood depth

Based on the figure, the largest decrease in vehicle mix for private vehicles was observed in EDSA - Dario Bridge, EDSA - Oliveros, and EDSA - Camp Aguinaldo, with reductions ranging from around 60% to over 80% for light vehicles (i.e., sedans, crossovers, SUVs, vans, motorcycles). This data highlights that the change in vehicle mix is directly linked to the maximum flood depth, with higher flood depths restricting the movement of light vehicles. In contrast, trucks tend to see smaller percentage differences or even increases during flooded conditions, indicating that their increased height makes them less affected by floods. Interestingly, there is no consistent relationship between maximum flood depth and the change in truck volume, with some roads experiencing an increase in truck numbers during floods while others see a decrease. This contradicts the assumption that higher flood depths would lead to trucks being the only vehicles using flooded roads, as suggested by Bacero & Fillone (2023).

The behavior of motorists in response to increased flood depths plays a crucial role in this phenomenon. Higher flood depths can lead to congestion due to lane closures, as observed in areas like EDSA – Camp Aguinaldo (see Figure 6), where traffic is funneled into fewer lanes, creating bottlenecks. Smaller vehicles, more vulnerable to flood damage, avoid flooded lanes by merging into others, exacerbating congestion. On the other hand, larger vehicles, although more capable of navigating floods, are impeded by the congestion caused by smaller vehicles. Therefore, higher flood depths exhibit an inverse relationship with the ability of trucks to navigate flooded roads, as increased flood depths are more likely to cause lane closures, hindering the passage of smaller vehicles and creating blockages for larger vehicles that could otherwise navigate the flooded area.

Figure 6. Bottleneck scenario in EDSA - Camp Aguinaldo

However, it should be noted that the floods analyzed in this study are caused by a typical rainfall event in Metro Manila, compared to a full on typhoon assumed by Bacero & Fillone (2023). In the Philippines, typhoon preparation involves advanced warnings, and school and work suspensions during the event, leading to fewer vehicles on the road. This aligns with the findings of Vu & Nguyen (2019), indicating that motorists are more likely to cancel or delay trips when informed of heavy rain before departure compared to encountering it during the journey. Therefore, the motorists in this study likely continued their journey despite encountering floods during the trip, as opposed to being deterred by advanced warnings and preparations associated with typhoons.

4.2.1.1 Light vehicles

A closer look at the volume of light vehicles show that sedans and motorcycles, which typically have lower ground clearance and water wading depths, experience the highest decrease in volume during flooding (refer to Figure 7). In contrast, SUVs and vans have the lowest decrease, with some roads even witnessing increased volumes of these larger vehicles.

Ground clearance is the distance between the lowest point of the vehicle and the ground, while water wading depth is the maximum depth of water a vehicle can safely drive through without risking damage. When roads flood, vehicles with low ground clearance and wading depth risk having their undercarriage submerged, which can cause damage to vital components.

Larger vehicles often have higher wading depths, allowing them to traverse deeper water without mechanical issues or damage. This difference in physical characteristics may alter motorists' perceptions of driving through flooded waters. Vehicle ground clearance and water wading depth directly influence the volume of light vehicles within flooded road segments, with vehicles possessing higher ground clearance and wading depth exhibiting a higher tendency to traverse flooded roads.

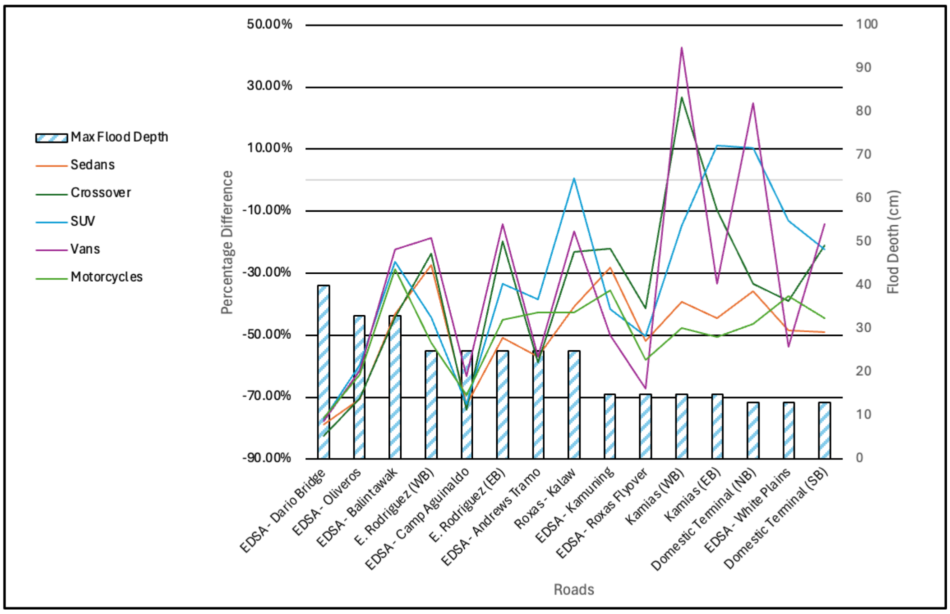


Figure 7. Change in volume for light vehicles relative to flood depth

4.2.1.2 Trucks

Although Bacero & Fillone (2023) provided an in-depth analysis on the impact of flooding on truck movement, their study generalized trucks into one subset of vehicles. However, in reality, there is a wide variety of truck classifications (e.g., utility and goods truck, heavy trucks, trailer trucks) that vary vastly in their physical characteristics (e.g., sizes, vehicle ground clearance), which may have an effect on truck driver's behavior to brave flooded roads. To assess this, Figure 8 depicts the change in volume of varying truck types relative to the maximum flood depth for a road segment.

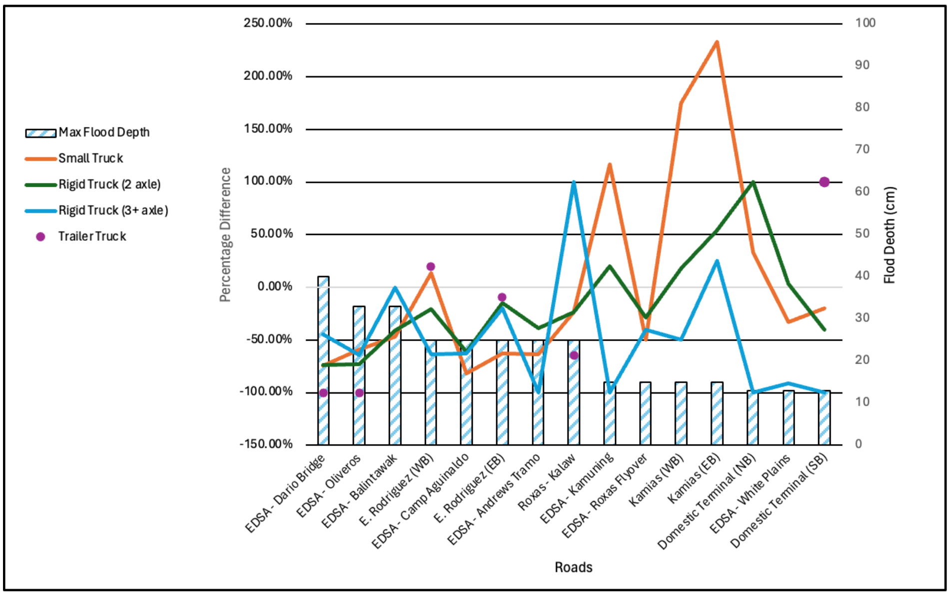


Figure 8. Change in volume for trucks relative to flood depth

Based on the figure, roads with higher maximum flood depths experience a more significant decrease in traffic volume for larger trucks, such as rigid trucks with 3+ axles and trailer trucks, compared to smaller vehicles like small trucks and rigid trucks with 2 axles. This suggests that larger trucks tend to avoid flooded roads more than smaller vehicles. Interviews conducted by Kelley & Prabowo (2019) during an extreme flood event in Lawonua revealed that heavy rain and flooding deter drivers of large trucks from passing through due to slippery roads, high accident risks, and lack of compensation in case of accidents. This reluctance to operate in such conditions may also apply to Filipino drivers of large trucks. The limited maneuverability of large trucks becomes challenging during flooded conditions, where lane closures and congestion are common. Unlike smaller trucks that can switch lanes more easily, large trucks are more likely to remain in their original lane to avoid accidents, resulting in no significant increase in their volume during flooded conditions.

Conversely, roads with lower flood depths typically witness significant increases in truck volume as lane closures are less frequent, allowing for smoother traffic flow. In such scenarios, trucks show the highest percentage increase compared to other vehicle types, indicating their capability to navigate flooded roads when unobstructed. This highlights an indirect impact of higher flood depths on truck movement, with larger trucks being most affected by vehicle blockage.

However, it is crucial to acknowledge the limited sample size for larger truck sizes in certain locations, where either no data or minimal observations (1 to 2 vehicles on average) were recorded. This limitation makes it challenging to draw definitive conclusions regarding the vehicle mix of large trucks during flooded conditions.

4.2.2 Public vehicles

According to Abad & Fillone (2019), patrons of public transportation within Metro Manila typically perceive public transit as low risk during flooding. This means that most individuals perceive the effects of flooding as having little to no effect on their preferred mode of transportation and traffic conditions as a whole. To assess this, Figure 9 depicts the change in volume of various road-based public transportation relative to the maximum flood depth for a road segment. It should be noted that not all public vehicles were present in the roads studied.

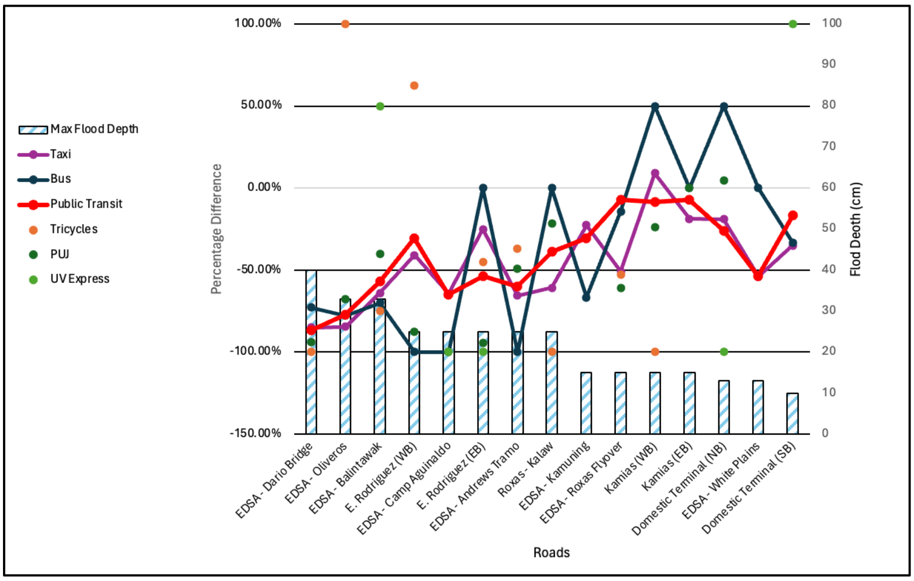


Figure 9. Change in volume for trucks relative to flood depth

The data indicates that there is no clear relationship between the ground clearance of public vehicles and the maximum flood depth. Despite being larger, buses, UVs, and PUJs tend to experience a decrease in volume at higher flood depths. Instead, the overall volume of public transit decreases as flood depth increases, contradicting the prevailing notion among travelers regarding the effects of flooding on public transport (Abad & Fillone, 2019). Studies have shown that Filipinos are dissatisfied with the current public transportation infrastructure and system as a whole (Nogueira *et al.*, 2023; Bombais *et al.*, 2016). This suggests that public transit is already subpar under normal conditions, leading individuals to perceive no significant difference between normal and flooded conditions. Additionally, Filipino travelers are unlikely to adapt their commuting behavior in response to increasing flood depths (Abad *et al.*, 2020). Consequently, as the volume of public transit decreases with increased flood depths, this leads to prolonged waiting times and overcrowded vehicles.

Table 4 illustrates the total change in vehicle mix across various public transportation modes. The data show that PUJs and buses, which operate on fixed routes, experienced minimal changes in their modal shares during flood events. This stability is likely due to their designated routes, which rarely change significantly. While their fixed routes limit flexibility in responding to floods, they remain a consistent and reliable option for commuters. In contrast, taxis and UVs, which provide point-to-point services, saw decreases in their modal shares, with taxis experiencing the largest drop. This decline is likely because their service model allows them to choose alternate routes, enabling them to avoid flooded areas.

Table 4. Change in volume of public transit

Vehicle Type	Flooded	Non-flooded	Difference
PUJ	22.83%	22.48%	0.35%
Tricycle	7.03%	5.49%	1.53%
Taxi	64.17%	65.91%	-1.74%
UV Express	0.59%	0.85%	-0.26%
Bus	5.39%	5.27%	0.12%

Although the EDSA Bus Carousel is a crucial road-based mode of transport along the EDSA transport corridor, it was excluded from the study due to the buses having their own exclusive lane. As aforementioned, exclusive lanes cater to single vehicles, operating under distinct rules to promote swift movement and avoid congestion (Arasan & Vedigiri, 2009). Initial observations indicate that this holds true even in flooded conditions, with the buses experiencing zero congestion despite the height of the floods continually increasing. Future studies could carry out a more detailed analysis on the effects of flooding on the speed and headway of public vehicles within exclusive lanes.

5. CONCLUSION

Metro Manila's persistent urban flooding, caused by its tropical climate, heavy rainfall, and super typhoons, leads to significant economic losses and transportation disruptions (Abon *et al.*, 2011; Bankoff, 2003; Bañares *et al.*, 2021; Bagtasa, 2019; Mukhtar, 2022; Philippine Star, 2014). Flooding on key roads in major economic hubs results in fuel wastage and daily economic losses of 2.4 billion pesos due to traffic congestion, with cargo movement disruptions adding an estimated 297 billion pesos in losses for the entire economy (Lagmay *et al.*, 2017; Roquel *et al.*, 2019). Previous models on flood-induced traffic disruptions have relied on assumptions without robust empirical data (Abad & Fillone, 2017; Bacero & Fillone, 2023). This study aimed to address these gaps by directly observing and analyzing real-world vehicle movement during flooding, focusing on changes in vehicle volume and mix under varying flood depths, to provide a more accurate dataset on the effects of flooding in Metro Manila.

This study analyzed 15 30-minute video clips of both flooded and non-flooded conditions obtained from the MMDA's CCTV archive. The findings from these videos revealed a clear correlation between vehicle volume and the presence of flooding, with higher flood depths exhibiting a more significant percentage difference in vehicle volumes between flooded and non-flooded conditions. Roads with higher flood depths experienced substantial decreases in vehicle traffic. In contrast, locations with lower flood depths had relatively smaller impacts on vehicle volumes. Additionally, increased lane closures due to flooding were found to significantly impact traffic volume changes. Roads without lane closures saw the smallest change in traffic volume. As the number of lane closures increased (i.e., one, two, and three) the changes in traffic volume became progressively larger.

The study explored changes in vehicle mix during flooding, revealing notable shifts in vehicle types' presence on flooded roads. Passenger cars showed a higher percentage in flooded scenarios, suggesting their adaptability to traverse flooded roads, while motorcycles exhibited a lower percentage, indicating their vulnerability. Light vehicles like sedans and motorcycles experienced the most significant volume decrease due to their lower ground clearance, whereas SUVs and vans saw minimal decrease or even increased volumes due to higher ground clearance. Trucks showed varied responses based on flood depth and lane closures, with larger trucks less frequent in heavily flooded areas due to maneuverability issues but showing increased volume at lower flood depths. Public transportation volume decreased overall with increasing flood depth, contrary to common perception. PUJs and buses, as route-based services, maintained stable modal shares, while taxis and UVs experienced decreases, particularly taxis.

These findings can be used as reference for future researchers. By incorporating this empirical data, future flood-based traffic models can become more sophisticated and accurate in their representations of traffic conditions during flood events. This improved model accuracy will enable more reliable predictions of traffic flow, congestion patterns, and travel times, which are crucial for effective emergency response planning, infrastructure resilience assessments, and the development of adaptive traffic management strategies tailored to flood-prone urban areas.

Despite the findings, there remain areas for improvement in future studies. Firstly, expanding the geographic scope and data collection efforts to cover the entire Mega Manila area, enabling a more comprehensive analysis of flooding's effects across different cities and provinces. Secondly, future research could delve deeper into the factors influencing Filipino drivers' perceptions and behavior regarding flooding. Conducting surveys and analyzing how motorists are likely to react if the road is flooded can shed light on the decision-making processes employed by individuals during such events. Lastly, future studies could benefit from extended observation periods to capture more comprehensive data on how traffic conditions evolve over time. As the study focused on the immediate impact of flooding, as observed within the 30-minute window. The dynamics of how rapidly roads flood or drain, and the temporal effects on traffic as water levels subside, were not addressed. Observing these processes would provide additional insights into how the duration of flooding affects traffic flow.

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